



JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTES OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
ENVIRONMENTAL ENGINEERING CHAIR

Evaluation of Groundwater Quality and Potential Pollution Risk Analysis: The Case of Botor Tolay District, Jimma Zone, Oromiya National Regional State, Ethiopia

By: Fitsum Gidey Hailu

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Environmental Engineering

November, 2021

Jimma, Ethiopia

JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTES OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
ENVIRONMENTAL ENGINEERING CHAIR

Evaluation of Groundwater Quality and Potential Pollution Risk Analysis: The Case of Botor Tolay District, Jimma Zone, Oromiya National Regional State, of Ethiopia

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Environmental Engineering

By: Fitsum Gidey Hailu

Advisor: Dr.Ing. Fekadu Fufa (Asso. Prof.)

Co-advisor: Mr. Adisu Befekadu (MSc.)

November, 2021

Jimma, Ethiopia

DECLARATION

This final Thesis is my original work and has not been presented for a degree of masters in any of the Ethiopian Universities.

I have recognized all material in this Thesis, which are not my own work, through appropriate referencing and acknowledgement.

Fitsum Gidey Hailu	/11/2021
Candidate	Signature	Date

This final thesis will be submitted for examination with my approval as a university supervisor.

Dr. Ing. Fekadu Fufa (Asso. Prof.)	/11/2021
Advisor	Signature	Date

Mr. Adisu Befekadu (MSc.)	/11/2021
Co-advisor	Signature	Date

ACKNOWLEDGMENTS

First of all, I would like to thank Almighty GOD who made it possible, this Thesis. My gratitude and appreciation also goes to my advisors, Dr. Ing. Fekadu Fufa and Mr. Adisu Befekadu for giving relevant materials, constructive comments and suggestion in preparing this Thesis. Secondly, I want to thank Environmental Laboratory technician Mr. Firomsa Bidira for his great support on laboratory works. Finally, I would like to thank Jimma University Institute of Technology especially Environmental Engineering chair, for coordinating and giving all necessary support.

ABSTRACT

Water quality is determined by physical, chemical and microbiological properties of water. The quality of water degrades through pollution from point and non-point sources. Water quality degradation is one of the major environmental problems of these days. The study was conducted to evaluate the physico-chemical parameters of groundwater quality for drinking and irrigation suitability and to assess the potential pollution risk of groundwater in Botor Tolay district, Jimma Zone, Oromiya National Regional State, Ethiopia. A total of 16 samples were collected from borehole, shallow well, hand dug well and protected springs by representative sampling technique and analyzed for physical and chemical parameters. Electric conductivity, sodium absorption ratio, magnesium hazard, residual sodium carbonate and Kelly ratio were evaluated for irrigation suitability assessment. Potential pollution risk of groundwater samples were assessed using D8 flow direction algorithm. The analyzed data was presented by using table, graphs, piper diagram and figures and were compared with WHO guideline value for drinking suitability. The result showed that for all the groundwater samples the concentration of pH, TH, CO_3^{2-} , Cl^- , NO_3^- and SO_4^{2-} were below the recommended WHO value which were suitable for drinking in terms of these parameters. For most of the groundwater samples the concentration of EC, TDS, TA, Mg^{+2} , Na^{+2} , K^{+2} , Ca^{+2} , F^- and Fe^{+2} were found below the WHO standards thus, suitable for drinking purpose whereas the obtained value of Mn^{+2} , turbidity and temperature of all the groundwater samples were exceeds the limit of WHO standards which were not suitable for drinking purpose. Interpretation of all physico-chemical parameters were carried out using AquaChem software (Version 2014.2), Microsoft excel (Version 2013) and SPSS (Version 20). All groundwater samples were found suitable for irrigation water according to EC and SAR whereas only 50% water sample were suitable based on MH and KR. According to RSC all groundwater samples were suitable for irrigation water except sample S4, S7, S9 and S12. The potential pollution risk assessment of groundwater samples were classified as no, low, medium and high with sample number of 8, 3, 4, and 1, respectively.

Keywords: Groundwater, Physico-chemical, pollution, Risk, Suitability, Water quality

TABLE OF CONTENTS

DECLARATION I

ACKNOWLEDGMENTS II

ABSTRACT..... III

LIST OF TABLES VIII

LIST OF FIGURES X

LIST OF ACRONYMS XII

1 INTRODUCTION..... 1

 1.1 Background 1

 1.2 Statement of the Problem 3

 1.3 Objectives..... 5

 1.3.1 General Objective 5

 1.3.2 Specific Objectives 5

 1.4 Research Questions 5

 1.5 Significance of the Study 5

 1.6 Scope of the Study..... 6

 1.7 Limitation of the Study 6

2 LITERATURE REVIEW 7

 2.1 Groundwater Overview 7

 2.2 Groundwater Occurrence 8

 2.3 Groundwater Utilization..... 8

 2.4 Groundwater Pollution 9

 2.5 Pollution Risk Assessment of Groundwater Well..... 10

 2.5.1 Hydrological Modeling..... 10

 2.5.2 Overview of Methods for Flow Direction Determination 11

2.5.3	Defining a Flow Direction Algorithm.....	12
2.6	Groundwater Quality.....	12
2.7	Water Quality Parameters	13
2.7.1	Physical Water Quality Parameters	13
2.7.2	Chemical Water Quality Parameters.....	17
2.7.3	Bacteriological Water Quality Parameters.....	23
2.8	The Use of Groundwater for Irrigation Purpose	24
2.8.1	Electrical Conductivity(EC).....	26
2.8.2	Sodium Adsorption Ratio (SAR).....	26
2.8.3	Magnesium Hazard (MH).....	27
2.8.4	Residual Sodium Carbonate (RSC)	28
2.8.5	Kelley’s Ratio (KR).....	29
2.9	Aquachem Water Quality Database	29
2.10	Hydro-geochemical Facies.....	29
2.11	Principal Component Analysis.....	29
3	MATERIALS AND METHODS	31
3.1	Description of the Study Area.....	31
3.2	Research Design and Period.....	32
3.3	Types of Data	32
3.3.1	Primary Data	32
3.3.2	Secondary Data	32
3.4	Sampling.....	32
3.5	Sample Preservation.....	34
3.6	Study Variables	35
3.7	Materials.....	36

3.8	Chemicals and Reagents.....	37
3.9	Analysis of Water Sample.....	37
3.10	Pollution Risk Assessment.....	38
3.10.1	Model Validation	38
3.11	Data Quality Assurance and Quality Control.....	38
3.12	Ethical Consideration	38
3.13	Plan for Dissemination.....	39
4	RESULTS AND DISCUSSIONS	40
4.1	Physical Parameters.....	40
4.1.1	Temperature	40
4.1.2	pH.....	42
4.1.3	Electric Conductivity	43
4.1.4	Total Dissolved Solid.....	45
4.1.5	Turbidity	47
4.2	Chemical Parameters.....	49
4.2.1	Total Hardness	49
4.2.2	Total Alkalinity.....	51
4.2.3	Calcium.....	53
4.2.4	Magnesium.....	55
4.2.5	Chloride.....	57
4.2.6	Sulphate.....	59
4.2.7	Carbonate	61
4.2.8	Bicarbonate	62
4.2.9	Fluoride	63
4.2.10	Sodium	66

4.2.11	Potassium	68
4.2.12	Nitrate	70
4.2.13	Manganese	72
4.2.14	Iron	74
4.3	Hydro-geochemical Facies	77
4.4	Principal Component of the Groundwater Samples	79
4.5	Groundwater Suitability for Irrigation Purpose	80
4.5.1	Electrical Conductivity	80
4.5.2	Sodium Adsorption Ratio	82
4.5.3	Magnesium Hazard	83
4.5.4	Residual Sodium Carbonate.....	85
4.5.5	Kelley’s Ratio	86
4.6	Potential Pollution Risk Assessment.....	88
4.6.1	No Potential for Pollution	88
4.6.2	Low Potential for Pollution.....	89
4.6.3	Medium Potential for Pollution	89
4.6.4	High Potential for Pollution	90
4.7	Model Validation.....	91
4.8	Well Depth and Nitrate Concentration of the Water Samples	93
5	CONCLUSIONS AND RECOMMENDATIONS	95
5.1	Conclusions	95
5.2	Recommendations	96
	REFERENCES	97
	ANNEXES	108

LIST OF TABLES

Table 2.1 Qualitative observation of its physical properties of water.	14
Table 2.2 Common water pH level.	16
Table 2.3 Classification of hardness.	18
Table 2.4 Classification of irrigation water based on electrical conductivity.....	26
Table 2.5 Irrigation water classification based on SAR.	27
Table 2.6 Suitability of groundwater for irrigation according to RSC.	28
Table 3.1 GPS reading of the selected sites in the study area.....	33
Table 3.2 Materials.	36
Table 3.3 Chemicals and reagents.	37
Table 4.1 Area coverage of interpolated temperature.....	41
Table 4.2 Area coverage of interpolated pH concentration.	42
Table 4.3 Area coverage of interpolated EC concentration.	44
Table 4.4 Area coverage of interpolated TDS concentration.	46
Table 4.5 Area coverage of interpolated turbidity.	48
Table 4.6 Classification of hardness and area coverage of interpolated TH	50
Table 4.7 Area coverage of interpolated TA concentration.....	52
Table 4.8 Area coverage of interpolated Ca^{2+} concentration.....	54
Table 4.9 Area coverage of interpolated Mg^{2+} concentration.....	56
Table 4.10 Area coverage of interpolated Cl^- concentration.	58
Table 4.11 Area coverage of interpolated SO_4^{2-} concentration.	60
Table 4.12 Area coverage of interpolated HCO_3^- concentration.	62
Table 4.13 Area coverage of interpolated F^- concentration.....	65
Table 4.14 Area coverage of interpolated Na^+ concentration.....	67
Table 4.15 Area coverage of interpolated K^+ concentration.....	69
Table 4.16 Area coverage of interpolated Mn^{2+} concentration.....	73
Table 4.17 Area coverage of interpolated Fe^{2+} concentration.	75
Table 4.18 Minimum, maximum and mean physico-chemical parameters.	77
Table 4.19 Groundwater type of the water sample in the study area.....	79
Table 4.20 PC loadings and explained variance for the first five pcs of the data set.	80
Table 4.21 Classification of irrigation water based on EC.	81

Table 4.22 Classification of irrigation water based on SAR.	82
Table 4.23 Classification of irrigation water based on MH.....	84
Table 4.24 Suitability of groundwater for irrigation according to RSC	85
Table 4.25 Classification of irrigation water quality based on KR.....	86

LIST OF FIGURES

Figure 3.1 Location map of Botor Tolay district.	31
Figure 3.2 Map of sampling points.	34
Figure 4.1 Comparison of temperature value of the sample with WHO (2004) standard	40
Figure 4.2 Spatial map of the temperatures of the groundwater samples.	41
Figure 4.3 Comparison of groundwater samples pH values with WHO (2004) standard.	42
Figure 4.4 Interpolated map pH of the groundwater samples.	43
Figure 4.5 Comparison of groundwater samples EC values with WHO (2004) standard.	44
Figure 4.6 Interpolated map of EC of the groundwater samples.	45
Figure 4.7 Comparison of groundwater samples TDS values with WHO (2004) standard. ..	46
Figure 4.8 Interpolated map of TDS of the groundwater samples.	47
Figure 4.9 Comparison of water samples turbidity values with WHO (2004) standard.	48
Figure 4.10 Interpolated map of turbidity of the groundwater samples.	49
Figure 4.11 Comparison of groundwater samples TH values with WHO (2004) standard.	50
Figure 4.12 Interpolated map of TH of the groundwater samples.	51
Figure 4.13 Comparison of groundwater samples TA values with WHO (2004) standard.	52
Figure 4.14 Interpolated Map of TA of the Groundwater Samples.	53
Figure 4.15 Comparison of groundwater samples Ca^{2+} values with WHO (2004) standard. ..	54
Figure 4.16 Interpolated map of Ca^{2+} of the groundwater samples.	55
Figure 4.17 Comparison of groundwater samples Mg^{2+} Values with WHO (2004) standard. ..	56
Figure 4.18 interpolated map of Mg^{2+} of the groundwater samples.	57
Figure 4.19 Comparison of groundwater samples Cl^- values with WHO (2004) standard.	58
Figure 4.20 Interpolated map of Cl^- of the groundwater samples.	59
Figure 4.21 Comparison of water samples SO_4^{2-} values with WHO (2004) standard.	60
Figure 4.22 Interpolated map of SO_4^{2-} of the groundwater samples.	61
Figure 4.23 Comparison of water samples HCO_3^- values with WHO (2004) standard.	62
Figure 4.24 Interpolated map of HCO_3^- of the groundwater samples.	63
Figure 4.25 Comparison of water samples F^- values with WHO (2004) standard.	64
Figure 4.26 Interpolated map of F^- of the groundwater samples.	66
Figure 4.27 Comparison of water samples Na^+ values with WHO (2004) standard.	67
Figure 4.28 Interpolated map of Na^+ of the groundwater samples.	68

Figure 4.29 Comparison of groundwater samples K^+ values with WHO (2004) standard.....	69
Figure 4.30 Interpolated map of K^+ of the groundwater samples.	70
Figure 4.33 Comparison of water samples Mn^{2+} values with WHO (2004) standard.	73
Figure 4.34 Interpolated map of Mn^{2+} of the groundwater samples.	74
Figure 4.35 Comparison of groundwater samples Fe^{2+} values with WHO (2004) standard. .	75
Figure 4.36 Interpolated map of Fe^{2+} of the groundwater samples.	76
Figure 4.37 Piper diagram of groundwater samples in the study area.	78
Figure 4.38 Interpolated map of EC of the groundwater samples.	81
Figure 4.39 Interpolated map of SAR of the groundwater samples.	83
Figure 4.40 Interpolated map of MH of the groundwater samples.	84
Figure 4.41 Interpolated map of RSC of the groundwater samples.	86
Figure 4.42 Interpolated map of KR of the groundwater samples.	87
Figure 4.43 Flow pathway of grid cell, containing well points.	89
Figure 4.44 Cell receiving only a single inward flows.	89
Figure 4.45 Cell receiving a single inward flow with accumulated flows.	90
Figure 4.46 Cell receiving flow from three neighboring cell with accumulated flows.	91
Figure 4.47 Aspect, showing slope direction earth surface of the study area.	92
Figure 4.48 Sample clipped from aspect showing cell flow direction.	93
Figure 4.49 Well depth vurses nitrate concentration of groundwater samples.	94

LIST OF ACRONYMS

CFU	Colony Forming Unit
DNA	Deoxyribonucleic Acid
EDTA	Ethylenediamine Tetra Acetic Acid
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GPS	Geographical Positioning System
IAEA	International Atomic Energy Agency
IGRAC	International Groundwater Resources Association Center
MPN	Most Probable Number
PH	Potential Hydrogen
QA/QC	Quality Assurance/Quality Control
SSA	Sub Saharan Africa
TA	Total Alkalinity
TDS	Total Dissolved Solid
TH	Total Hardness
UN	United Nation
UNICEF	United Nations International Children's Emergency Fund
UNWA	United Nation Water Africa
USGS	United State Geological Survey
WHO	World Health Organization

1 INTRODUCTION

1.1 Background

Water is a chief natural resource which is essential for the existence of life and is a basic human entity. Water resources are used for various purposes like drinking, agricultural, industrial, household, recreational, and environmental activities (Bear, 1979).

According to Brhane (2018), in any sectorial operation the use of water for drinking, agriculture, industry and domestic are very vital. The principal sources of water supply for various operations are surface and sub-surface water.

Groundwater refers to all the water occupying the voids, pores, and fissures within geological formations, which originated from atmospheric precipitation either directly by rainfall infiltration or indirectly from rivers, lakes or canals. Sands, gravels, sandstones, and limestone formations were the usual sources of groundwater supply though some might be drawn from impervious rocks such as granite when they had an over the burden of sand or gravel (Olumuyi wa *et al.*, 2012).

Groundwater is a widely dispersed resource and an important source of global water supply. The worldwide distribution of fresh water supplies is unequal and its supply is becoming scarce day by day due to population growth and various human activities. On earth 97.2% of water is salty and 2.8% is fresh water from which about 20% constitutes groundwater (Kolekar, 2017).

Water quality is as relevant as the quantity available. It interacts with soil, rock, and organic debris once precipitation reaches the ground, dissolving still more chemicals naturally, apart from any contamination produced by human activities. Since it fell as rain, the form and concentration of salts in water depend on the processes that have influenced the water. Groundwater is not pure water since it generally contains dissolved mineral ions that for different purposes deteriorate the water quality status and impair its usefulness. The standard for groundwater quality required for different objectives are therefore variable. Therefore, the quality of water determines if the groundwater is suitable for the purpose for which it is abstracted. Drinking water standards in particular are sever, because people's health is at stake. Water quality thus must be a consideration when evaluating water supplies (Brhane, 2018)

According to Richard *et al.* (2017), globally abstractions of groundwater, for rural and urban domestic use, for livestock, for crop irrigation and for industry, and the return flows resulting from these uses, create links between land, its uses, and its underlying aquifers to the quantity and quality of groundwater in those aquifers, and how they change over time. According to Chapman (1996), it is impossible to underestimate the value of groundwater in the water supply. In arid or semi-arid areas, it is common to think of groundwater as more important and surface water as more important in humid areas. The global value of groundwater, however, is shown by inventories of groundwater and surface water use. The reasons for this include its convenient availability close to where water is required, its excellent natural quality (which is usually sufficient for low or no treatment potable supplies) and its relatively low production cost.

Groundwater constitutes a natural source of fresh water, mainly used for consumption and communal purposes. Groundwater pollution risk is mainly related to hydrogeological factors, that is, vulnerability of groundwater to pollution and anthropogenic factors related to the land use forms (Zwahlen, 2003). Risk can be defined as the probability of an unwanted event that results in negative consequences (Ostrom and Wilhelmsen, 2012).

Recently groundwater has become a major source of water for many industries and municipalities and also for agriculture activities (Kumar *et al.*, 2014). Most of the groundwater is clean, but groundwater can become polluted or contaminated if no further protection is being considered (El-Naqa *et al.*, 2006). The movement of contaminants that infiltrate into soil and groundwater occurs through wastes disposals, discharge of effluent from industries or release of chemicals through agriculture activities (Neshat *et al.*, 2014). Agricultural activities have been identified as one of the non-point sources of pollutants to groundwater and soil. They affect groundwater quality in many ways. For example, it can become polluted when people use too much fertilizer or pesticides on their crops area. Agricultural pollutants such as nitrate and heavy metals from fertilizer will dissolve in the surface water such as river or irrigation water and then infiltrate through the soil and groundwater zone (Ahmed, 2009).

Some groundwater pollution risk assessments focus on the risk stemming from only one specific source of pollution, for example nitrates derived from agricultural fertilization

(Saidi *et al.*, 2011; Kozłowski and Sojka, 2019), waste disposal sites (D abrowska *et al.*, 2018; Soltysiak *et al.*, 2018), or even biofuel-related land use (Li and Merchant, 2013). According to Chapman (1996), untreated groundwater supplies from protected wells with hand pumps are likely to be their best solution for many years to come, for many millions more, especially in sub-Saharan Africa, who do not yet have any sort of improved supply. In arid and semi-arid regions of Ethiopia, groundwater is the only realistic means of meeting rural communities, noting that groundwater also supplies many urban centers, including the capital city of Addis Ababa. In this regard, the future development of Ethiopian settlements and urban centers depends heavily on the ability of nearby aquifers to meet ever-increasing demand from population growth and industries (Kebede, 2013). IAEA (2013), claims that over 70% of the water supply in Ethiopia comes from groundwater and only 34% of the population has access to an improved supply of water. In order to ensure sustainable and judicious use of water resources, groundwater investigation is therefore indispensable.

Like other parts Ethiopia the main sources of water supply in Jimma zone are groundwater in the forms of spring, hand dug well, shallow well and deep wells which are used for drinking, agriculture, industry and other domestic purposes. However the groundwater quality are of major concern affecting health of population in different ways because of using those sources without having detail information's that shows the suitability of groundwater sources for the required purposes.

The water supply source in Botor Tolay district and its surrounding peasant association for cooking, drinking, and other domestic purposes is often directly sourced from groundwater without any treatment and the level of pollution has become a cause for major concern. There is no any documented work that reveals the chemical composition of drinking water around Botor Tolay area. This will have a negative implication on the health condition of the society living around that area. Therefore, the aim of this research is to investigate physico-chemical parameter of the groundwater to evaluate the suitability of the groundwater for drinking and irrigation purpose and to assess risk of pollution.

1.2 Statement of the Problem

According to District *et al.* (2019), groundwater is the world's largest source of high quality water for human use. However, more risks to its quality rather than degradation have been

created by widespread pollution of groundwater. In most situations, such as rapid and unplanned urbanization, intensive agricultural and industrial activities, pose a significant threat to the quality of groundwater.

The World Health Organization (WHO) report states that, as significant as four-fifths of diseases are due to poor quality of drinking water in the world, as cited in (Wegahita *et al.*, 2020). Hence, the purpose of groundwater quality assessment is not only to rate groundwater quality, but it is also closely related to human health and to save a lot of people suffering from various diseases. Therefore, it is necessary to evaluate groundwater quality correctly. Bantin *et al.* (2020) clarifies that in other parts of the world, and especially in the sub-Saharan context, where water supplies are scarce and remain fragile and endangered, the degradation of water quality in aquatic ecosystems is an increasingly important problem.

Fluoride and arsenic are the two the most widely reported SSA geogenic water quality problems that occur naturally. Dental and skeletal fluorosis can result from high fluoride levels in water, whereas long term exposure to arsenic can lead to a range of adverse health effects, including hyperkeratosis, circulatory disorders, diabetes and cancers (Richard *et al.*, 2017).

In most sectors of many nations, groundwater has become the primary source of water supply. The most common source of drinking water in many areas of Ethiopia, primarily in small towns and rural areas, is groundwater from boreholes (deep wells), shallow wells, hand dug wells and springs. Nevertheless, no research on groundwater quality for various uses has been carried out (Berhanu *et al.*, 2020).

Like other part of Jimma zone district, Botor Tolay district uses groundwater source for domestic and other purposes. However, there are many source which are not used for drinking purpose because of their quality problem. Some of the district's groundwater sources are hot in nature, some forms layer after being placed in clean plastic container and most sources seems thicker than ordinary natural water when they are used for drinking. In addition there are impacts seen because of drinking of those source without having any document which reveals the quality of the groundwater of the area. The impact seen particularly in keta town is mottling of teeth among the users of those groundwater sources. Due to such unknown quality problems people are also suffering from travelling long

distance to fetch water in preferring one source from the others. No study has been conducted to address this issue. Therefore this study was required to evaluate the physico-chemical status of the groundwater sources to evaluate their suitability and assess risk of pollution.

1.3 Objectives

1.3.1 General Objective

The general objective of this study was to evaluate the physico-chemical parameters of groundwater for drinking, irrigation and the potential pollution risk in Botor Tolay district, Jimma Zone, Oromiya National Regional State, Ethiopia.

1.3.2 Specific Objectives

- ❖ To determine the physico-chemical properties of the groundwater;
- ❖ To evaluate the suitability of the groundwater for drinking and irrigation purpose; and
- ❖ To assess the potential pollution risk of the groundwater.

1.4 Research Questions

- ❖ What are the physico-chemical composition of the groundwater?
- ❖ Does the groundwater of the district are suitable for drinking and irrigation purpose?
- ❖ Does the groundwater of the study area are vulnerable to pollution?

1.5 Significance of the Study

The physico chemical studies of the groundwater will contribute the understanding of the factors that affect groundwater quality for drinking and irrigation uses. The study will have various advantages to the community served from the groundwater sources of the study area. This will make settle those rumors related to water quality of the area by revealing the output of the study to the wider community and concerned body of the area. The study will save peoples of the area who are suffering from drinking the groundwater with unknown contaminant and concentrations which can lead to different water related diseases.

The result of this study also will be significant to minimize groundwater pollution risks by applying protection measures on the identified vulnerable areas and aquifers for risk based water quality management.

Generally the study results will be important to mainstream groundwater protection mechanisms by considering different management scenario for groundwater resources

management; resource allocation and prioritization of groundwater related activities and integration with different land uses; for sector integration so as to define role and responsibilities, bases for further research and inputs for quality and risk based management of groundwater resources.

1.6 Scope of the Study

The study was carried out in Botor Tolay district, Jimma zone, Oromiya National Region, Ethiopia. Groundwater sample from borehole, shallow well hand dug well and protected spring were used for the quality analysis and D8 flow modeling was used for pollution risk assessment of the groundwater wells of the study area. Due to insufficient resources and time available only small number of groundwater well samples were used in order to complete the study.

1.7 Limitation of the Study

The number of groundwater sample and point location of groundwater that was taken for the physicochemical and potential pollution risk analysis were small in number compared to the rest of the groundwater sources found in the area of study and only selected parameters were analyzed due to resource limitation. There were also groundwater sources without access road to take sample and difficulty in obtaining groundwater sample this limit the required study to be done. However, maximum effort was done to fill gap and accomplish the study.

2 LITERATURE REVIEW

2.1 Groundwater Overview

Groundwater provides almost half of all drinking water worldwide, about 40% of water for irrigated agriculture and about 1/3 of water supply required for industry. It sustains ecosystem, maintains base flow of river and prevent land subsidence and seawater intrusion. Groundwater is an important part of climate change adaptation and is often a solution for people without access to safe water. Despite these impressive figures, invisible groundwater is out of sight and out of mind for most people. Human activities (including population and wealth growth) and climate variability are increasing pressure on groundwater resources; consequently, pollution and over-extraction problems are regularly reported in many parts of the world (Water, 2015).

As the world's largest distributed store of fresh water, groundwater plays a central part in sustaining ecosystems and enabling human adaptation to climate variability and change. Aquifers have a buffering capacity and they are naturally more resistant to external impact than surface waters. Since variability of surface water availability is increasing due to climate change, strategic importance of aquifers for water and food security is clearly growing (Amanambau *et al.*, 2020).

According to Villholth *et al.* (2010), after devastating events, such as tsunamis, aquifers will replace affected drinking water sources in time. In settling displaced people, relief agencies need to know about the availability of groundwater for water supply (after natural disasters or conflicts). Finally, for those without access to clean drinking water, groundwater is also a potential alternative. IGRAC (2018) finds that water related diseases are now one of the world's main health issues. The key strategy for eliminating water related diseases is to improve groundwater quality management in combination with advancements in sanitation and personal hygiene. Groundwater can be contaminated by agriculture, sewage, manufacturing and mining, landfills and waste management, traffic and transport, as well as by chemical processes in the geological climate. Some of the necessary steps to maintain and enhance the quality of groundwater and our health are routine groundwater monitoring, risk assessment, protection from point source and diffuse contamination, and pollutant removal.

2.2 Groundwater Occurrence

In several distinct geological formations, groundwater exists. Almost all rocks in the upper part of the Earth's crust have openings called pores or voids, whatever their form, origin or age (Chapman, 1996). Groundwater can be found in layered sedimentary aquifers, in hard rock aquifers with complex inter-connections, and in karst aquifers with large inter-connected solution cavities (Lall *et al.*, 2020). Studies *et al.* (2018) assert that groundwater is water that occurs under the surface of the earth in the pore spaces and fractures of geologic materials. It originates as rainfall or snow and then travels through the groundwater system via the soil and rock, where it ultimately returns to surface streams, lakes, or oceans.

Alemayehu (2006) suggests that the occurrence of groundwater is always primarily influenced by the area's geophysical and climatic conditions. A peculiar feature of Ethiopia, which is characterized by the broad heterogeneity of geology, topography, and environmental conditions, is the difficulty of obtaining productive aquifers as cited by (Melesse *et al.*, 2013). The author also pointed out that groundwater is an important source for domestic and industrial water use in many parts of the country, particularly in rural areas and towns. The occurrence of groundwater, however, is not uniform because it depends on different environmental and geological variables Alemayehu (2006) as cited by (Melesse *et al.*, 2013).

2.3 Groundwater Utilization

According to Adimalla *et al.* (2018), because of its widespread availability and good quality, groundwater is an important source for humanity. Globally, groundwater is a significant source in semi-arid provinces for irrigation, domestic and industrial supply. Previous studies have shown that 65 percent of the global domestic water supply comes from groundwater, 20 percent from irrigation and about 15 percent for industrial purposes as cited in (Kaur *et al.*, 2019). Margat and Gun (2013) believes that with withdrawal rates currently in the approximate range of 982 km³/year, groundwater is the most mined raw material in the world. According to Jaroslav and Gun (2004), approximately 60% of the world's groundwater is used for agriculture; the remainder is almost evenly split between the domestic and industrial sectors. Siebert *et al.* (2010) suggested that globally about 38% of irrigated lands are equipped for irrigation with groundwater as cited by (Global and

Usage, 2016). Groundwater is extremely important in Africa. It is estimated that more than 75 percent of the African population uses groundwater as its main source of drinking water (UNWA, 2003). Pavelic (2012), observes that groundwater has been the preferred means of water supply in recent times to meet the increasing demand of rural, scattered communities and small urban towns across the SSA area. Pavelic (2012), also reports that the primary source of domestic water supply in Ethiopia is groundwater (85 percent). Groundwater supplies have natural pollution protection and, for the most part, do not need any treatment before being given to consumers. These allow systems to be less costly, more sustainable and are good alternatives to the supply of piped water (Pavelic, 2012).

Despite the high groundwater potential and opportunity to overcome dry spells and drought through supplementary irrigation leading to possibility to increased production and productivity in high potential areas, no significant attention has been given to using the groundwater resource for agriculture. A few places in Ethiopia though, have demonstrated the comparative advantages of groundwater irrigation over rain fed agriculture and surface water irrigation (Kassie, 2019).

2.4 Groundwater Pollution

According to Abdalla and Khalil (2018), groundwater pollution typically results from human activities in which contaminants that are prone to percolation are stored and distributed on or below the surface of the soil. Only after a drinking water source was impacted was almost every known distance of groundwater pollution found. The groundwater contamination by heavy metals [arsenic (As), lead (Pb), uranium (U), mercury (Hg), cadmium (Cd), nickel (Ni) and chromium (Cr).] and anions [sulfate (SO_4^{2-}), nitrate (NO_3^-), fluorides (F^-), etc.] is considered as a serious threat to humans due to their accumulation in human body, plants, crops, and animals (Jafari *et al.*, 2018; Rezaei *et al.*, 2019). Fakhri *et al.* (2018); Ali *et al.* (2019) suggest that the contamination may be from geogenic (weathering of rocks, minerals, and volcanic eruptions) and/or anthropogenic sources (domestic, industrial, and agricultural activities). The majority of the population in developing countries has to drink this contaminated water due to unavailability of alternate water resources and high cost of present water purification techniques (Rezaei *et al.*, 2019). Brack *et al.* (2016) believes that when we speak of groundwater contamination, we mean solutes dissolved in the water that can render it unfit for our use or unfit for an ecosystem

that the water enters. For a contaminant to be a true problem, it must be present at a concentration that poses some significant risk to human health or an ecosystem.

The principal natural chemicals found in groundwater are dissolved salts, iron and manganese, fluoride, arsenic, radionuclides, and trace metals. Both geologic and climatic conditions influence mineral composition. In arid regions with limited water recharge, slow percolation results in mineralized poor quality water high in sodium chloride. In humid climates, weathering of sedimentary rock leaches calcium and magnesium, creating excessive hardness and often dissolved iron and manganese. Fluoride is a constituent of mineral fluorite found in sedimentary, igneous, and metamorphic rocks. In some regions, high concentrations of fluoride in groundwater result in fluorosis (mottling of teeth) and, in extreme cases, bone damage (Abelson, 1984).

2.5 Pollution Risk Assessment of Groundwater Well

Natural characteristics of the aquifer and the presence of potentially polluting activities are quantifying the risk level which can be prioritized to control through implementation of groundwater protection measures. For this purpose, land use and land cover is an important parameter in assessing risks in combination with aquifer vulnerability assessment. Land use parameter is vital because it can reflect human activities like agriculture, urban planning industrial development and deforestation/afforestation which have greatest influence for natural feature changing (Boughriba *et al.*, 2010; Shrestha *et al.*, 2017; Lezzaik *et al.*, 2018).

2.5.1 Hydrological Modeling

In recent years, digital elevation models (DEMs) are widely used as input data for determining the flow directions in distributed hydrological models for discharge simulation due to their high effectiveness in representing the spatial variability of the earth's surface (Beven and Kirkby, 1979).

Numerous grid DEM based mostly algorithms used for deciding flow direction are developed and enforced in several GIS softwares for watershed and hydrological analysis (Costa-cabral and Burges, 1994; Tarboron, 1997).

2.5.2 Overview of Methods for Flow Direction Determination

2.5.2.1 Conventional Method

The most widely implemented and effective approach for flow direction determination and automated drainage recognition is probably the D8 (deterministic eight nodes) method (Martz, 1994). The D8 algorithm was first presented by O'Callaghan and Mark (1984). It assumes that a water particle in every DEM cell flows towards one and only one of its neighboring cells, that is the one within the direction of steepest descent. When single flow directions are determined, another vital characteristics, like the watershed boundary and watercourse network, will be derived directly. There is little doubt that the D8 algorithmic rule is extremely easy and convenient, and has wide pertinence in hydrological analysis (Jenson and Domingue, 1988). However, the D8 algorithm cannot provide an accurate match of the modeled to the real flow directions. The major limitations are, first, that only eight possible directions cannot represent the real flow directions, especially for groundwater, the paths of which are quite broad and diffuse (Quinn *et al.* 1991; Costa-cabral and Burges, 1994; Pan *et al.*, 2004), and second, that there is in continuity of drainage across flat areas or anywhere there is a pit in the DEM.

2.5.2.2 Other Algorithms

Single flow direction algorithms are criticized as a result of they cannot model flow dispersion (Quinn *et al.*, 1991; Costa-cabral and Burges, 1994). Researchers have tried to get rid of this limitation by using multi-flow direction algorithms where the outflow from one cell passes not only to its neighbor of steepest descent but also to other neighbors (Quinn *et al.*, 1991; Holmgren, 1994; Wolock and Jr, 1995; Tarboron, 1997; Aryal and Bates, 2008). The multi-flow direction algorithm (MD8) proposed by Quinn *et al.* (1991) allocates flow fractionally to all lower neighboring cells in proportion to their slopes. Although this method tends to provide more reasonable results than the D8 algorithm by avoiding concentration to distinct lines, the major disadvantage is that the flow from one cell is routed to all or any neighboring lower cells and thus dispersed to a significant degree, even for a convergent hill slope.

Tarboron (1997) addressed the Dinf (known as D_{∞}) approach to explain infinite potential single-direction flow pathways. However, just like the single flow direction algorithm, the Dinf algorithm has trouble in defining flow direction in flat areas. Seibert and McGlynn,

(2007) developed a new triangular multi-flow direction algorithm (MD_{∞}) for a range of flow routing and topographic index applications. Previous study has showed that the multi-flow direction algorithmic program could be additional acceptable for land flow analysis, whereas the one flow direction algorithmic program is superior in zones of convergent flow and huge drain areas with well-developed channels (Quinn *et al.*, 1991; Martz, 1994).

2.5.3 Defining a Flow Direction Algorithm

2.5.3.1 Assumptions

The first assumption was that from any point in the terrain, all water flows in the steepest direction, which should be a fairly agreeable hypothesis.

Secondly, it is assumed that all runoff that reaches a grid cell immediately becomes evenly distributed within the cell.

Thirdly, all eight flow directions was treated as equally prone to receive flows and

Finally, it was assumed that no flows can occur from a lower grid cell to a higher, although smaller portions of a lower grid cell may actually be at a higher altitude than their immediate neighborhood in a higher cell.

2.6 Groundwater Quality

According to Roy (2019), the chemical, physical and biological characteristics of water can be identified as water quality, typically with regard to its suitability for a specified use. Ground water's chemical, physical and biological quality varies by location and depth. Geogenic factors, such as adsorption/desorption kinetics associated with soil/rock minerals, or anthropogenic factors, such as farm agrochemicals or heavy metals from industrial operations, can regulate the presence of water pollutants (Lall *et al.*, 2020). Groundwater is a precious resource especially in arid and semi-arid regions of the globe due to limited occurrence of surface water resources. Stress on the available groundwater resource becomes acute owing to the demand by various sectors thus putting the quality at risk. Groundwater quality parameters exhibit considerable spatial variability and in many regions of the world. Groundwater quality is strongly influenced by anthropogenic activities and its pollution has become a severe problem for society at large (Tarawneh *et al.*, 2019). Selvakumar *et al.* (2017) observes that the quality of groundwater depends not only on natural factors such as aquifer lithology, velocity of groundwater, water quality

and contact with other water or aquifer types, but also on human activities and the atmosphere.

Both natural and various forms of human activities have led to low quality of groundwater (Van der Gun, 2021).

Groundwater in both urban and agricultural areas of the world is a critical source of freshwater (Kumar *et al.*, 2020). However, its unjust abstraction and rapidly growing pollution pose a significant threat to the worldwide sustainable supply of water.

According to Li *et al.* (2018), through leaching cationic and anionic compounds, such as fluorides, sulphates, heavy metals and metalloids, natural processes, such as weathering, combined with local geology, may also impact the quality of groundwater as cited by (Masindi and Foteinis, 2021). Kaur *et al.* (2019) affirms that in particular, groundwater fluoride is a global concern, with $\sim 200 \times 10^6$ individuals, among others, at risk of endemic fluorosis (skeletal and dental) and neurotoxicological effects in children.

The water content of groundwater varies greatly in Ethiopia. Geology, physico-chemical causes, biological factors, anthropogenic and effect such as manufacturing, urban and agricultural emission, geomorphological and geological ecosystem, as well as climatic conditions are mainly impacted (Pavelic, 2012).

2.7 Water Quality Parameters

Water quality is determined by physical, chemical and microbiological properties of water. These water quality characteristics throughout the world are characterized with wide variability. Therefore the quality of natural water sources used for different purposes should be established in terms of the specific water quality parameters that most affect the possible use of water (Shah, 2017).

2.7.1 Physical Water Quality Parameters

Physical characteristics of water (temperature, color, taste, odor etc.) are determined by senses of touch, sight, smell and taste. For example temperature by touch, color, floating debris, turbidity and suspended solids by sight, and taste and odor by smell (Shah, 2017).

Water for drinking should be free of objectionable taste, odor, color and suspended materials. These are often called aesthetic parameters. Aesthetic parameters are those detectable by the senses, namely turbidity, color, taste, and odor. They are important in monitoring community water supplies because they may cause the water supply to be

rejected and alternative (possibly poorer quality) sources to be adopted, and they are simple and inexpensive to monitor qualitatively in the field. The chemical quality influences also the physical quality. The appearance, taste, odor, and feel of water determine what people experience when they drink or use water and how they rate its quality; other physical characteristics can suggest whether corrosion and encrustation are likely to be significant problems in pipes or fittings (WHO, 2003).

The following are Table 1 where water contamination is indicated through visual observation, taste or smell. If contamination is suspected through observation, then testing is the next step to confirm the water quality.

Table 2.1 Qualitative observation of its physical properties of water (WHO, 2003).

Water Observations	Possible Contaminants
Foamy	Detergents
Black in colour	Manganese, bacteria growth
Brown, yellow or reddish in colour	Iron
Dark brown or yellow in colour	Tannins and pigment from leaves and bark
White deposits or scale	Hardness, dissolved metals
Earthy, fishy, muddy, peaty odour	Organic matter, algae, bacteria
Rotten egg odour	Hydrogen sulphide
Chlorine odour	Chlorine residual from water treatment process
Bitter or metallic taste	pH, zinc, copper

a. Temperature

In almost all USGS water research, water temperature plays a major role. Water temperature has a significant impact on biological activity and development, has an impact on water chemistry, may affect measurements of water amounts, and regulates the types of organisms living in water bodies. Due to its effect on water chemistry, temperature is also significant. At higher temperatures, the rate of chemical reactions usually increases. Water, particularly groundwater, will remove more minerals from the underlying rock at higher temperatures and would thus have greater electrical conductivity. The effect of temperature on biological activity and growth is important. The kinds of species that can live in rivers and lakes are regulated by temperature. They all have a preferred temperature range for

fish, zooplankton, phytoplankton, and other aquatic animals. As temperatures get too far above or below this preferred level, until there is eventually none, the number of individuals of the species decreases. In lakes and reservoirs, temperature is also important. It is due to the concentration of dissolved oxygen in water, which is very important for all aquatic life. When the seasons shift, many lakes undergo a 'turning' of their water layers. The top of the lake becomes colder in summer than the lower layers. The way that temperatures vary in lakes over seasons depends on where they are located. In warm climates the surface may never get so cold as to cause the lake "to turn." But, in climates that have a cold winter, temperature stratifications and turning do occur (Perlman and USGS, 2013)

b. pH

In a material, pH is a measurement of electrically charged particles. This shows how acidic or alkaline (basic) the compound is. The scale of the pH varies between 0 and 14. As it is considered an aesthetic quality of water, pH is not a quality that comes under the EPA regulation. However, the agency recommends that municipal drinking water suppliers keep their water supply at a pH of 6.5 to 8.5. Depending on weather conditions, human behavior, and natural processes, freshwater pH varies around the globe. Water with a very low or high pH level may be a sign of chemical or heavy metal contamination. Water that does not fall within the 6.5 to 8.5 "safe" pH range, particularly if it is alkaline, is not inherently unsafe. Very alkaline water can, however, have an unpleasant smell or taste, and pipes and water carrying equipment can also be affected. It is more likely that acidic water with a pH of less than 6.5 is polluted with toxins, rendering it dangerous to drink. It can corrode (dissolve) metal tubes as well (<https://www.healthline.com/health/ph-of-drinking-water> date accessed 05/02/2021).

Table 2.2 Common water pH level (<https://www.healthline>).

Type of water	pH level
Tap water	Varies; typically about 7.5
Distilled reverse osmosis water	5 to 7
Common bottled water	6.5 to 7.5
Bottled waters labeled as alkaline	8 to 9
Ocean water	About 8
Acid rain	5 to 5.5

c. Electric Conductivity

Electrical conductivity is the calculation of the electrical current conduction capability of a material or solution. It is a valuable method for determining water's purity. It is an excellent total dissolved solids (TDS) and salinity indicator that affects the taste of drinking water. Electrical conductivity variation is dependent on sedimentary structure and rock composition. Electricity does not conduct chemically pure water. Any increase in water's electrical conductivity suggests pollution. The calculation of contamination is a successful and rapid one. It is a good and fast measurement of pollution. Ground waters due to the presence of ions such as OH^- , CO_3^{-2} , Cl^- , Ca^{+2} etc., contamination also shows higher EC values. The overall allowable limits are $250\mu\text{S}/\text{cm}$ for drinking and $3000\mu\text{S}/\text{cm}$ for irrigation, respectively, as per the WHO and FAO standards (Ecjhao and Dandwate, 2012; Ezeribe *et al.*, 2012).

d. Total Dissolved Solids

Ecjhao and Dandwate (2012) believes that a calculation of the combined content of all inorganic and organic substances found in water is total dissolved solids. For groundwater classification, total dissolved solids may be regarded as a salinity measure. The presence of calcium, magnesium, sodium, potassium, bicarbonate, chloride and sulphate ions are the reason for TDS in groundwater. Agricultural runoff, waste pollution from factories and other human activities may be the key causes of higher TDS in the groundwater. The WHO's allowable cap for TDS is 500 mg/l.

e. 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. 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. 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).

2.7.2 Chemical Water Quality Parameters

Shah (2017) states that the chemical characteristics of natural water represent the soils and rocks that have been in contact with the water. Furthermore, water quality is impaired by agricultural and urban runoff and municipal and industrial treated waste water. The chemical characteristics of water also influence microbial and chemical transformations. The health issues associated with drinking water's chemical constituents vary from those associated with microbial pollution and derive mainly from the potential of chemical constituents to cause adverse health effects during extended exposure periods. There are few chemical water components that can lead to health issues due to a single exposure, except through significant accidental contamination of the source of drinking water (WHO, 2008).

a. Total Hardness (TH)

Water hardness is the standard indicator of water's ability to react with soap, with hard water requiring slightly more soap to create a lather. A visible deposit of precipitate (e.g. insoluble metals, soaps or salts) is also formed by hard water in containers, including the 'bathtub ring.' While other cations (e.g. aluminum, barium, iron, manganese, strontium and zinc) also contribute, it is not caused by a single substance but by a number of dissolved polyvalent metal ions, mainly calcium and magnesium cations. Most generally, hardness is expressed as milligrams of a litre of calcium carbonate equivalent. Although hardness is caused by cations, it may also be discussed in terms of carbonate (temporary) and non-carbonate (permanent) hardness (WHO, 2010).

Table 2.3 Classification of hardness (WHO, 2004).

TH Concentration (mg/l)	Classification
0-60	Soft
61-120	Moderately hard
121-180	Hard
>180	Very hard

b. Total Alkalinity (TA)

It is made up mostly of carbonate (CO_3^{2-}) and alkalinity of bicarbonate (HCO_3^-) serves as a pH stabilizer. The toxicity of many substances in the water is influenced by alkalinity, pH and hardness. Alkalinity including hydroxides, carbonates, and bicarbonates, is the presence of one or more ions in water. It can be described as acid neutralization capacity. In most drinking water sources, moderate alkalinity concentration is desirable to stabilize the acidity corrosive effects. Excessive amounts, however, can cause a variety of damage. The WHO standards express the alkalinity only in terms of total dissolved solids (TDS) of 500 mg/l (Mohsin *et al.*, 2013).

c. Calcium (Ca^{2+}) as CaCO_3

In bones and teeth, over 99 percent of total body calcium is contained, where it acts as a main structural factor. In metabolism, the remaining body calcium acts as a signal for essential physiological processes, including vascular contraction, blood clotting, contraction of muscles and transmission of nerves. Inadequate calcium intake was associated with increased risk of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, coronary artery disease, hypertension and stroke, insulin resistance and obesity (WHO, 2008).

UNICEF (2008) reports that mainly due to the presence of limestone, gypsum and dolomite minerals, calcium occurs in water. Industrial methods, as well as the treatment of sewage and wastewater, also introduce calcium to surface water and groundwater. The leaching of soil calcium can be increased by acidic rainwater. Calcium concentrations in natural waters are usually less than 15 mg/l, but concentrations can exceed concentrations in water associated with carbonate rich rocks 30 to a maximum of 100 mg/l. The concentration of salt water is several hundred milligrams per litre or more.

d. Magnesium (Mg^{+2})

Magnesium and other alkali earth metals are responsible for water hardness. Large number of minerals contains magnesium, for example dolomite (calcium magnesium carbonate); $CaMg(CO_3)_2$ and magnesite (magnesium carbonate). Magnesium is washed from rocks and subsequently ends up in water. Chemical softening reverse osmosis, electro dialysis, or ion exchange reduce the magnesium and the associated hardness to acceptable level. Magnesium sulphate is applied in beer breweries, and magnesium hydroxide is applied as a flocculent in wastewater treatment plants. However, due to the role magnesium plays in water hardness, WHO drinking water guideline has maximum contaminant level to be 150mg/l (WHO, 2006).

Magnesium is a key nutrient in the growth and function of the brain, muscle contraction and replication of DNA, and is an element in many enzymes. There are no confirmed cases of magnesium toxicity, but vomiting and diarrhea may be caused by large oral doses. Excess concentration of magnesium can contribute to mental state changes, lack of appetite, extremely low blood pressure and irregular heartbeat (Rasheed and Abdulgafar, 2014).

e. Chloride (Cl^-)

Shah (2017) believes that the concentration of chloride anions (Cl^-) influences the quality of water since the water quality deteriorates after the concentration of these anions increases, reducing the possibility of using natural water for various purposes (household, agriculture, industry and etc.). Magmatic rock formations that contain chlorine content minerals are the primary source of chloride anions (Cl^-) in natural water.

According to WHO (2006), chloride in drinking water originates from natural sources, sewage and industrial effluents, urban runoff containing de-icing salt and saline intrusion. The main source of human exposure to chloride is the addition of salt to food, and the intake from this source is usually greatly in excess of that from drinking water. Elevated concentration of chloride in increases the rates of metallic corrosion in water distribution system even though it depends on the alkalinity of the water. This can lead to increased concentrations of metals in the supply. No health based guideline value is proposed for chloride in drinking water. However, chloride concentrations in excess of about 250 mg/l can give rise to detectable taste in water.

f. Sulfate (SO_4^{2-})

Sulfate is a mixture of oxygen and sulphur. In many soil and rock formations, it occurs naturally. Most sulphates are formed in groundwater from the dissolution of minerals, such as gypsum and anhydrite. Sulphates in drinking water are also causes of saltwater infiltration and acid rock drainage. Man-made causes include industrial discharge and deposition from fossil fuel combustion (Sayato,1989a). The concentrations of sulphates in natural waters are normally between 2 and 80 mg/l. High concentrations above 400 mg/l can make drinking water unpleasant (UNICEF, 2008).

Shah (2017) concludes that sulfate anions (SO_4^{2-}) are commonly present in natural water as a result of chemical dissolution, dissolving minerals containing sulfur and oxidizing sulfates and sulfur. Sulfate anions (SO_4^{2-}) join natural water as a result of the oxidation of plant and animal substances. The increased concentration of sulfate anions (SO_4^{2-}) causes, on the one hand, certain physical characteristics of water (taste, smell, etc.) to alter for the worse and, on the other hand, has a destructive effect on human consumption. The concentration of sulfate anions (SO_4^{2-}) fluctuates from 5 mg/l to 60 mg/l in a wide range of surface water.

g. Carbonate (CO_3^{2-})

Carbonates are generated by the action of carbon dioxide in water on carbonate rocks such as limestone and dolomite. Carbonate produce an alkaline environment. Carbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbonic acid gas. In combination with calcium and magnesium cause carbonate hardness.

h. Bicarbonate (HCO_3^-)

The potential sources of bicarbonate include the presence of organic matter in the oxidized aquifer to produce carbon dioxide that supports mineral dissolution (Khashogji and El Maghraby, 2013).

Gastmans *et al.* (2010) believes that calcite and dolomite fossil carbon in the aquifer would supply half of all bicarbonate ions. This wetting makes calcium, magnesium and bicarbonate ions in the groundwater aquifers richer. The weathering of silicate minerals may result in bicarbonate ions.

i. Fluoride (F⁻)

Madhnure (2014) states that in many countries around the world, fluoride pollution of groundwater is a major concern as ingestion of excess fluoride, most specifically, causes fluorosis through consuming polluted groundwater. Geological and anthropogenic are the two factors primarily responsible for pollution of groundwater. Rock geochemistry has a significant effect on the contamination of geological fluorides. The responsible variables for fluoride leaching may be physiological conditions of rock, such as decomposition, dissociation and eventual dissolution along with long residence time.

Mukherjee and Singh (2018) believes that contamination of fluoride in groundwater is becoming a global concern because it is inevitable and uncontrollable. Geogenic sources are the primary cause of fluoride toxicity due to the ingestion of F⁻ polluted groundwater, based on available literature. The level of daily F⁻ exposure varies by region. The fish and tea consuming population is more prone to fluoride exposure as it contains high concentration of fluoride (Kanduti *et al.*, 2016). Fluoride is found naturally in groundwater and soil, but some anthropogenic activities increase the concentration of F⁻ with fluorinated industrial waste (iron, steel, glass, aluminum), or agricultural activities by using the phosphate fertilizers and certain pesticides (Gupta *et al.*, 2015; Srivastav *et al.*, 2018; Gupta *et al.*, 2019; Maurya *et al.*, 2019).

The presence of fluoride (F⁻) in drinking water has some health benefits for consumers such as, reducing dental cavities, but dental and skeletal fluorosis may result from excessive ingestion of this anion or its presence at high concentrations (> 1.5 mg/l) (Yadav *et al.*, 2015; Guissouma *et al.*, 2017; Raj and Shaji, 2017). Furthermore, excess F⁻ causes many other health issues, such as extreme gastroenteritis, salivation, anorexia, muscle fatigue, stiffness, restlessness, sweating, dyspnea, ventricular irregularities and tachycardia (Sahu *et al.*, 2017).

j. Sodium (Na⁺)

While sodium concentrations in drinking water are usually less than 20 mg/l, in some countries they can significantly exceed that. Sodium salt levels in the air are typically low compared to those in food or water. It should be noted that certain water softeners will significantly add to the drinking water sodium content. No concrete conclusions can be made about the potential connection between the occurrence of hypertension and sodium

in drinking water. No guideline meaning dependent on health is therefore suggested. However, concentrations greater than 200 mg/l can produce an unacceptable taste (WHO, 2006).

EURO Reports and Studies No. 2 (1970) states that the sodium ion is ubiquitous in water. Most water supplies contain less than 20 mg of sodium per litre, but in some countries levels can exceed 250 mg/l. Large amounts of sodium can all be added to water by saline intrusion, mineral deposits, seawater spray, sewage effluents, and salt used in road de-icing. Furthermore, chemicals for water treatment, such as sodium fluoride, sodium bicarbonate and sodium hypochlorite, can together contain levels of sodium as high as 30 mg/l as cited by (WHO, 1996).

k. Potassium (K^+)

Potassium is an important component in humans and exists widely, including all natural waters, in the world. Potassium occurs in ground waters as a result of mineral dissolution, from decomposing plant material, and from agricultural runoff. However, potassium contamination can occur due to the use of excess potassium permanganate as an oxidant in the treatment of water and due to the consumption of water obtained from water softeners using potassium chloride (WHO, 2009).

l. Nitrate (NO_3^-)

Relatively little amount of the nitrate found in natural waters is of mineral origin, most of it coming from organic and inorganic sources, the former includes waste discharges and the latter comprises chiefly artificial fertilizers. However, bacterial oxidation and fixing of nitrogen by plants can both produce nitrate.

Most importantly, high nitrate level in water to be used for drinking will render it hazardous to infants as it induce the "blue baby" syndrome (methaemoglobinaemia). The nitrate itself is not a direct toxicant but is a health hazard because of its conversion to nitrite [see also below] which reacts with blood hemoglobin to cause methaemoglobinaemia. As per the WHO guidelines the nitrate concentration of potable groundwater should not exceed 10 mg/l (Ezeribe *et al*, 2012; Devendra *et al*, 2014; Amr *et al*, 2013).

2.7.2.1 Heavy metals

a. Manganese (Mn^{2+})

Manganese can be characterized as one of the most abundant metals on earth. It is actually a part of more than 100 minerals, even though it is not present in its natural form. Manganese can exist in 11 oxidative states. Manganese occurs naturally in many surface water and groundwater sources and in soils that may erode into these waters. However, human activities are also responsible for much of the manganese contamination in water in some areas. Human activities are still, however, responsible for much of the pollution of manganese in water in some regions. Higher aerobic water levels are generally associated with industrial emissions (WHO, 2011). The concentration of manganese in drinking water above 0.5 mg/l is beyond our body's tolerable limit and results in esthetic effect generation (Alhibshi *et al.*, 2014; Shrivastava, 2014).

b. Iron (Fe)

Iron present in large quantities in soils and rocks, primarily in insoluble forms. However, several complex reactions that occur naturally in soil formations can give rise to more soluble forms of iron that will create more soluble forms of iron. Therefore, in water passing through such formations, be present. Therefore, significant quantities of iron can be found in the groundwater. The presence of iron in the supply of drinking water can cause serious problems. Although there is typically no adverse impact on individuals who drink water with a significant amount of iron, rather, the problems are primarily aesthetic, as the soluble (reduced) ferrous (Fe^{2+}) iron is oxidized in air to the insoluble ferric (Fe^{3+}) form, resulting in color or turbidity (or, in severe cases, precipitate formation) (Shrivastava, 2014).

2.7.3 Bacteriological Water Quality Parameters

Water is susceptible to contamination with microorganisms and organic matter among other pollutants regardless of the source (Gangil *et al.*, 2013; Oludairo *et al.*, 2015). The soil and rocks through which groundwater flows screen out most of the bacteria (Mwabi *et al.*, 2013).

Burns (2016) concludes that some microorganisms are used in water as an indicator of pollution possible, as well as an indication of water quality. The presence of human and animal waste and thus possible contaminants in drinking water is demonstrated through the

collection of indicator species. Indicator species are typically of human and animal intestinal origin (Burns, 2016). Therefore, the presence of indicator organisms in water indicates contamination of water by faecal matter, which could probably contain pathogens such as *Salmonella* and *Shigella* (Osaro and Oyaribhor, 2011). The most communicable wide spread health risk associated with drinking water is microbial contamination (Sayato, 1989b). Millions of people die yearly from diarrheal disease and a larger proportion are children aged below 5 years (Mohsin *et al.*, 2013).

The requirements set for the identification of indicator species for the study of water quality are: organisms must be predominantly of faecal origin and regularly present in fresh faecal waste; they must occur in higher numbers than the associated pathogens; they must be more resistant to environmental stresses and survive longer than the pathogen; they must not proliferate more than the associated pathogens (Burns, 2016).

The biological properties of natural water have been determined by the use of coliform organisms. Aerobic and/or optional gram-negative, nonspore forming, rod-shaped bacteria that ferment lactose into gas are the coliform group of bacteria. *Escherichia coli* is commonly used as an indicator organism. This organism is present in the intestine of warm blooded animals, including humans. Therefore the presence of *Escherichia coli* in water samples indicates the presence of fecal matter and then the possible presence of pathogenic organisms of human origin. The concentration of indicator organisms is reported in MPN/100 ml or in CFU/100 ml (Shah, 2017).

2.8 The Use of Groundwater for Irrigation Purpose

Throughout the world, irrigation (water for agriculture, or growing crops) is probably the most important use of water. Irrigation water is essential for keeping fruits, vegetables, and grains growing to feed the world's population, and this has been a constant for thousands of years. Estimates vary, but about 70 percent of all the world's freshwater withdrawals go towards irrigation uses (USGS).

Nishanthiny *et al.*, (2010); N (2011) suggest that due to the ever growing demand for the use of water in contemporary societies, water required for irrigation of cropped land is being degraded in terms of quantity and quality. In addition, crop productivity is related both to soil quality and to the water quality available for irrigation. In general, salt content, sodium concentration, the occurrence of nutrients and trace elements, alkalinity, acidity,

and water hardness should be the subject of the irrigation water quality assessment. Salinity across the globe contributes to the depletion of fertile soils every year. Richards (1954); Singh *et al.*, (2009) believes that the suitability of groundwater for irrigation depends on the nature of the mineral elements in the water and their impacts on both the soil and plants as cited by (Rawat *et al.*, 2018).

Ayers and Westcot (1985) reports that knowledge of both quantity and quality is needed in the identification of water availability for irrigation; however, quality needs have often been overlooked, especially in developing countries. Quality should generalize how significantly a water source meets the intended user's needs and must be measured on the basis of its suitability for the proposed use. Irrigated agriculture is dependent on an adequate water supply of usable quality. Just as every water is not suitable for human beings, in the same way, every water is not suitable for plant life. Water containing impurities, which are injurious to plant growth, is not satisfactory for irrigation, and called unsatisfactory water (Tadesse *et al.*, 2011).

Water quality is based on its suitability for use. Maximum yields can be obtained under proper soil and management conditions if the water quality is good. The salt problem in soils arises when there are more soluble salts in the water applied for irrigation that accumulate in the root zone as the plants consume water, thus reducing yields. In various parts of the world, especially in arid and semi-arid regions, severe water scarcity is occurring. Groundwater over dependence to meet ever increasing demands in the domestic, agricultural and industrial sectors has contributed to the over exploitation of groundwater supplies in these regions. The suitability of irrigation water is determined by the concentrations of some of the elements that contribute to groundwater's unique conductance. In particular, higher sodium concentrations cause soil dispersion and swelling, which is eventually unfavorable, resulting in surface crusting, decreasing surface penetration rates and reducing soil hydraulic conductivity (Hanson and Grattan, 2006).

Milnes (2011) states that groundwater contamination due to salinization is a major problem that can be triggered by different processes, such as seawater intrusion, agrochemical contamination, geogenic contamination and irrigation induced salinization. Gupta *et al.* (2009); Jacintha *et al.* (2017); Rawat and Singh (2018) claims that first because of geochemical reaction in the aquifer and soils the consistency of groundwater deteriorates

twice and secondly, when it is supplied for irrigation by improper canals/drainages. Therefore, a routine assessment of irrigation water quality should be carried out. Besides water quality, various factors like type of soil, type of crop, crop pattern, precipitation etc. play a significant role in determining the suitability of water for irrigation (Sadashivaiah *et al.*, 2008). Keeping in view the facts it is imperative to review the quality of groundwater for irrigation.

2.8.1 Electrical Conductivity(EC)

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).

Table 2.4 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 concentration
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

2.8.2 Sodium Adsorption Ratio (SAR)

The ratio of sodium ions to calcium and magnesium ions can be used to prognosticate the degree to which irrigation water tends to enter the cation exchange reactions in soil (Richards, 1954). This ratio, called the sodium adsorption ratio (SAR), is used to determine the sodium hazard for irrigation waters. Since, sodium hazard increases as SAR increases;

therefore, the suitability of water for irrigation decreases. The effect of irrigation water on soil infiltration rates is dependent upon the interaction between the flocculating effects of specific conductance and the dispersion effects of sodium. Soils can tolerate irrigation waters with large SAR values if the specific conductance values are also large (Hanson and Grattan, 2006).

Todd and Mays (2004) believes that as sodium concentration can decrease soil permeability and soil structure, SAR is a measure of the suitability of water for irrigation use. SAR is a measure of alkali/sodium hazard to crops and it was estimated by the formula given in Eq. (2.1).

$$SAR = \frac{(Na^+)}{\sqrt{(Ca^{2+}+Mg^{2+}) \times .5}} \dots\dots\dots (2.2)$$

Where [Na⁺], [Ca²⁺] and [Mg²⁺] 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 2.5 Irrigation water classification based on SAR (Richards, 1954).

SAR	Water class
< 10	Excellent
10 to 18	Good
18 to 26	Permissible
> 26	Unsuitable

2.8.3 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 Mg²⁺ present in waters affects the soil quality converting it to alkaline and decreases crop yield (Joshi *et al.*, 2009).

Szabolcs (1964) proposed MH value for irrigation water as given by the formula expressed in Eq. (2.3).

$$MH = \frac{[Mg^{2+}]x100}{[Ca^{2+}+Mg^{2+}]} \dots\dots\dots (2.3)$$

Where, all the ionic concentrations of the elements are expressed in meq/l. MH values >50 are considered harmful and unsuitable for irrigation purposes.

2.8.4 Residual Sodium Carbonate (RSC)

RSC has been calculated to determine the hazardous effect of CO₃²⁻ and HCO₃⁻ on the quality of water for irrigation purpose (Eaton, 1950). The RSC value was calculated using the formula given in Eq. (2.4).

$$RSC = [CO_3^{2-} + HCO_3^{-}] - [Ca^{2+} + Mg^{2+}] \dots\dots\dots (2.4)$$

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 Ca²⁺ and Mg²⁺(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 2.6 Suitability of groundwater for irrigation according to RSC (reddy and reddy, 2011).

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.

2.8.5 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 2.5). Groundwater having Kelley's ratio more than one is generally considered as unfit for irrigation.

$$KR = \frac{[Na^+]}{[Ca^{2+}+Mg^{2+}]} \dots\dots\dots (2.5)$$

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

2.9 Aquachem Water Quality Database

Aquachem is a groundwater software package designed for anyone with water data. This software is ideally suited for water requiring management, analysis and reporting of groundwater quality data. Aquachem analysis tool cover a wide range of function and calculations used for analyzing, interpreting and comparing water quality data. These tools include simple unit transformation, charge balances, statistics and simple mixing to more complex function such as correlation matrices. These powerful analytical capabilities are complemented by an extensive selection of commonly used geochemical plots and graphs to represent the chemical characteristics of water quality data.

2.10 Hydro-geochemical Facies

Graphical representation of collected samples major dissolved constituents (major cations and major anions) helps in understanding its hydro chemical evolution, grouping and areal distribution (Belkhiri and Mouni, 2012; Mostafa *et al.*, 2017)

Piper diagram is a graphical representation made in such a way that the milli-equivalent percentage of the major cations and anions are plotted in a separate triangle. These points plotted in triangular fields are projected further in the central diagram field, which enables to provide the overall character of water. Piper (1944) plot are utilized to understand the hydrochemistry of the water and process involved in it.

2.11 Principal Component Analysis

PCA technique extracts the eigenvalues and eigenvectors from the covariance matrix of original variables. The PCs are the uncorrelated (orthogonal) variables, obtained by multiplying the original correlated variables with the eigenvector, which is a list of coefficients (loadings or weightings). Thus, the PCs are weighted linear combinations of

the original variables. PC provides information on the most meaningful parameters, which describe whole data set affording data reduction with minimum loss of original information (Helena *et al.*, 2000). It is a powerful technique for pattern recognition that attempts to explain the variance of a large set of inter-correlated variables and transforming into a smaller set of independent (uncorrelated) variables (principal components). Liu *et al.* (2003) classified the factor loadings as ‘strong’, ‘moderate’, and ‘weak’ corresponding to absolute loading values of > 0.75 , $0.75 - 0.50$ and $0.50 - 0.30$, respectively.

3 MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted at Botor Tolay district. Botor Tolay district located in Jimma Zone, Oromiya National Regional State, Ethiopia, located 240 km southwest of Addis Ababa the capital city of Ethiopia. Botor Tolay district is lying between Latitude 7°65' – 7°83' North and Longitude of 36°89' – 36°96' East and with an elevation between 1552 - 2650 m above sea level. The mean minimum and maximum annual temperature ranges between 20°C and 32°C respectively. The district is among the recently established district and having a mountainous area with full of ups and downs topography.

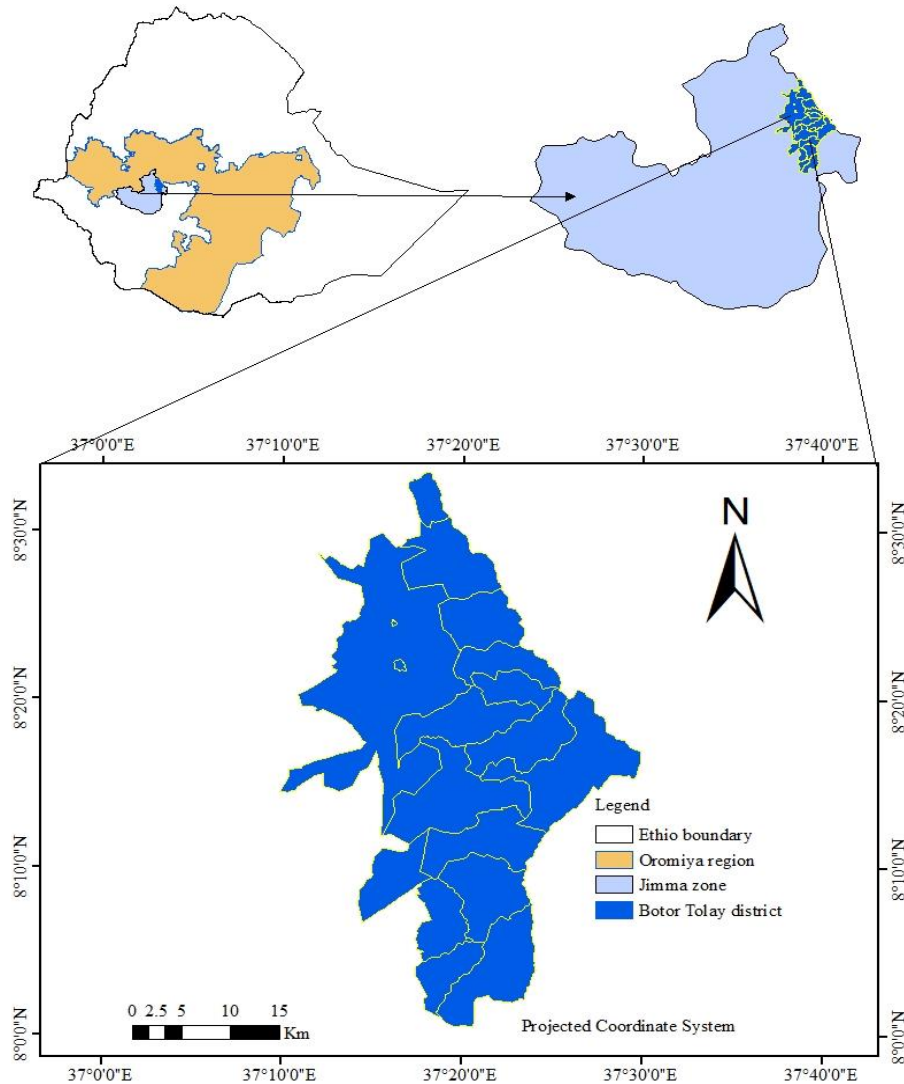


Figure 3.1 Location map of Botor Tolay district.

3.2 Research Design and Period

Laboratory based study design and D8 algorithm method was used on evaluating the physico-chemical groundwater quality and potential pollution risk analysis of the study area. 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. The study was carried out from the beginning of March, 2021 to end of November, 2021.

3.3 Types of Data

3.3.1 Primary Data

The primary data were data generated from the lab analysis and data collected from item or individual respondents directly. These data includes; water sample from different sample and GPS location of sample site.

3.3.2 Secondary Data

Secondary data used were data which had been collected by certain people or agency, which includes; books, journal, research reports and DEM.

3.4 Sampling

Representative sampling type was applied in the study area to collect the groundwater sample from different peasant associations of the district. Representative sample is a group or set chosen from a larger statistical population according to specified characteristics. For the sample selection, important criteria was considered. Sources closer to polluting sources, like intensive agricultural activities, towns and sources which reflect impact on the resident or users and sources which are bounded or closer to vegetation were considered. Totally about 16 sample were collected for the study from peasant association of the district of which 5 schemes were boreholes, 2 protected springs, 2 hand dug wells and 7 were shallow wells. The sampling was carried out with one liter plastic bottle and the bottle was soaked with 10% HCl for 24 h and then thoroughly cleaned and rinsed with distilled water. Water sampling were carried out once and collected from pumping well after a minimum of 10 minutes of purging prior to sampling.

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

Sample code	Site name	Source type	Absolute location of each water source		
			Easting	Northing	Elevation
S1	Dimtu 1	Protected spring	316897	924567	1619
S2	Shawaber	Hand dug well	319795	918844	1540
S3	Haro	Protected spring	314920	900621	1798
S4	Dimtu 2	Deep well	316954	924535	1618
S5	Keta Dire	Deep well	316826	925532	1620
S6	Boso	Shallow well	318301	925810	1609
S7	Laga Botor	Deep well	318704	923161	1551
S8	Kiticho	Shallow well	319302	922815	1527
S9	Yatu	Deep well	317313	927360	1621
S10	Cora	Hand dug well	317330	896810	1728
S11	Wayu	Deep well	316330	919108	1622
S12	Odoluge	Shallow well	316440	919112	1628
S13	Gudatu	Shallow well	324708	914846	1537
S14	Kalicha	Shallow well	318274	908800	1618
S15	Germa	Shallow well	317356	936007	1623
S16	Dile	Shallow well	320657	910766	1584

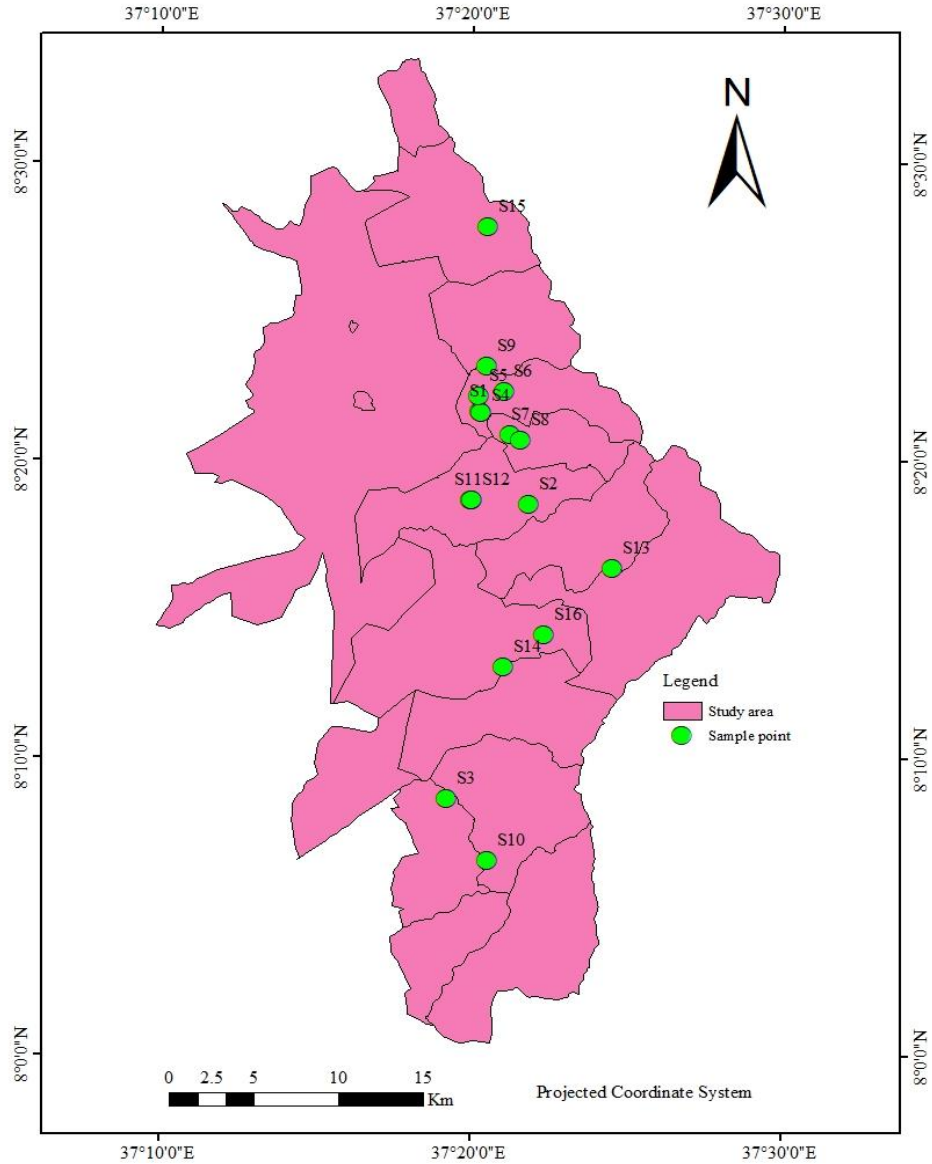


Figure 3.2 Map of sampling points.

3.5 Sample Preservation

The purpose is to minimize any physical, chemical, and/or biological change that may takes place in a sample from the time of sample collection to sample the sample analysis. After collecting sample were sealed immediately to avoid exposure to air and labelled according to location name systematically. Finally sample were transported in a cool box with ice at 4°C to laboratory and placed in refrigerator. Each sample were preserved by keeping their maximum holding time until the beginning of laboratory measurement process for each parameter.

3.6 Study Variables

Independent variables of the study were factors which were measured, manipulated or selected to determine its relationship to an observed phenomena which comprises physicochemical parameters such as temperature, pH, electrical conductivity, total dissolved solid, turbidity, total alkalinity, total hardness, calcium, magnesium, carbonate, bicarbonate, sodium, potassium, nitrate, iron, manganese, chloride, fluoride and sulfate.

Dependent variables of the study were factors which were observed and measured to determine the effect of the independent variables and were response variables or output. In this study the dependent variables were suitability of groundwater wells for drinking and irrigation purposes and potential pollution risk of groundwater wells.

3.7 Materials

The following materials were used.

Table 3.2 Materials.

S/N	Materials	Purpose
1	Aquachem	Used for analysis and interpretation of data
2	ArcGIS version 10.3	To display maps and images from stored data
3	Burette	For titration of sample
4	DEM	For representation of elevation data to represent terrain, commonly of a planet
5	Desiccator	Used for cooling and preserving moisture sensitive items
6	Evaporating dishes	To determine total dissolved solids
7	Filter paper	For filtration of water sample
8	Forceps and tongs	For grasping and holding objects
9	Funnel	Used for guiding liquid or powder into a small opening
10	GPS	To locate a position
11	Measuring cylinder	used to measure the volume of a liquid
12	Multi parameter	Measure several parameters simultaneously
13	Note book and pen	To record data
14	photo camera	To take picture
15	Standard flask	For measuring and preparation of reagents
16	UV-Spectrophotometer	To determine color and concentration of water and wastewater sample.
17	Wash bottle	Used to rinse various pieces of laboratory equipment

3.8 Chemicals and Reagents

The following chemicals and reagent were used.

Table 3.3 Chemicals and Reagents.

S/N	Chemicals and Reagents	Purpose
1	Buffer solution	To maintain the pH of the solution and for calibration of lab equipment
2	EDTA solution (0.02 M)	For determination of hardness
3	Eriochromeblack-T (indicator)	Used in complexometric titrations, e.g. in the water hardness
4	Mixed indicator	To determine acidity
5	Murexide indicator	Colorimetric reagent for calcium and rare earth metals
6	Phenolphthalein indicator	For determination of alkalinity of sample
7	Potassium chromate indicator	For determination of chlorides of sample
8	Sodium hydroxide (1N)	For determination of acidity of sample
9	Standard iron solution	For iron determination of sample
10	Standard manganese solution	For manganese determination of sample
11	Standard silver Nitrate Solution (0.0141N)	Used in chloride determination, used as titrant
12	Standard sulphuric acid solution (0.02N)	For alkalinity determination, used as titrant
13	Stock fluoride solution	Used to determine fluoride of a sample
14	Stock potassium solution	For determination of potassium of a sample
15	Stock sodium solution	Used to determine sodium of a sample

3.9 Analysis of Water Sample

Field level measurement of different parameters like pH, temperature, TDS, turbidity and EC were analyzed immediately by using a digital portable multi-parameter probe (HQ40d Model). On laboratory, chemicals such as chloride, carbonate and bicarbonate calcium, magnesium, iron and manganese were estimated by volumetric titration methods. Sodium

and potassium were determined by flame photometer and finally nitrate, sulfate and fluoride were estimated by Spectrophotometer.

Upon successful water sample analysis, interpretation of all physicochemical data were carried out using AquaChem (Version 2014.2) package software, Principal component analysis and Microsoft excel package (Version 2013). The analyzed data were presented by using table and graphs and all the results were compared with standard limits recommended by (WHO, 2004).

3.10 Pollution Risk Assessment

For the groundwater sample potential pollution risk assessment, GPS locations of groundwater sample wells were used. Flow direction was determined according to the simple D8 algorithm, whereby flow is routed to the adjacent cell with the greatest elevation drop. With this algorithm, a flow direction matrix is computed where each grid cell is assigned a value (1 – 8), corresponding to the eight cardinal directions, routing the flow to the appropriate adjacent cell.

3.10.1 Model Validation

Model validation was done by using spatial analyst tool called aspect, which is driven from a raster surface. The aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbour. Aspect can be thought of the slope direction. The value will be the compass direction of the aspect

3.11 Data Quality Assurance and Quality Control

According to Greenberg (1984), proper quality assurance procedures and precautions were taken to ensure the reliability of the results. Proper disinfection of container and calibration of lab equipment were carried out. Triplicate measurements were performed and $x \pm \sigma$ were reported. For the sake of data quality assurance Ion Balance Error (IBE) calculated and samples whose IBE >5% were discarded.

$$IBE = \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions} \times 100 \dots \dots \dots 3.1$$

3.12 Ethical Consideration

Official letter was written from Jimma University Institute of Technology to Botor Tolay District Water, Mineral and Energy office to ask permission for the collection of water

samples and GPS point locations of groundwater sources that were used in the document and document were acknowledged properly.

3.13 Plan for Dissemination

The final result of this study will be presented to Jimma Institute of Technology Faculty of Civil and Environmental Engineering, Environmental Engineering Chair and will be disseminated to Botor Tolay district and other governmental and non-governmental organizations which are concerned with the study findings. Publication in internationally peer reviewed journals will be considered.

4 RESULTS AND DISCUSSIONS

4.1 Physical Parameters

4.1.1 Temperature

The temperature of collected groundwater samples ranged from 19.13 – 24.60°C with an average value of 22.51°C (Table 4.18) The lowest temperature (19.13°C) was observed at location S10 hand dug well while maximum temperature (24.60°C) was observed at S4 deep well (Figure 4.1).

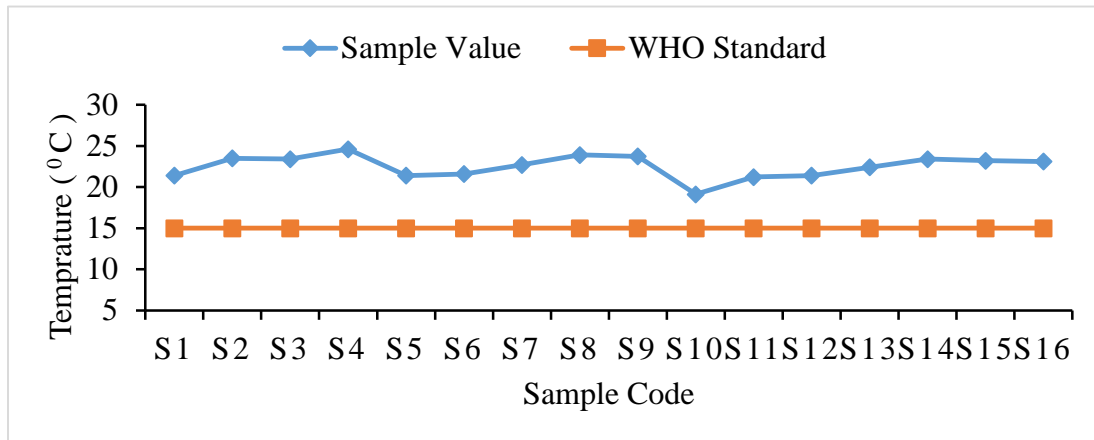


Figure 4.1 Comparison of temperature value of the sample with WHO (2004) standard

The standard value recommended for groundwater temperature by WHO (2004) should not exceeds 15°C. But the temperatures of all groundwater samples of the study area were above the standard value recommended by WHO (2004). The lowest and highest temperature value of the study area were found due to topography which was in line with (Bhattacharjee *et al.*, 2010) which states that Season and topography influences the temperature (Bhattacharjee *et al.*, 2010). At higher temperatures, the rate of chemical reactions usually increases. Water, particularly groundwater, will remove more minerals from the underlying rock at higher temperatures and would have greater electrical conductivity (Perlman and USGS, 2013). According to WHO (2004) temperature of groundwater samples in study area were not suitable for drinking purpose.

Table 4.1 Area coverage of interpolated temperature.

Temperature ($^{\circ}\text{C}$)	Area	
	km ²	%
19.13 – 20.44	40.42	4.16
20.44 – 21.75	113.59	11.69
21.75 – 23.06	511.12	52.63
23.06 – 24.60	306.18	31.52

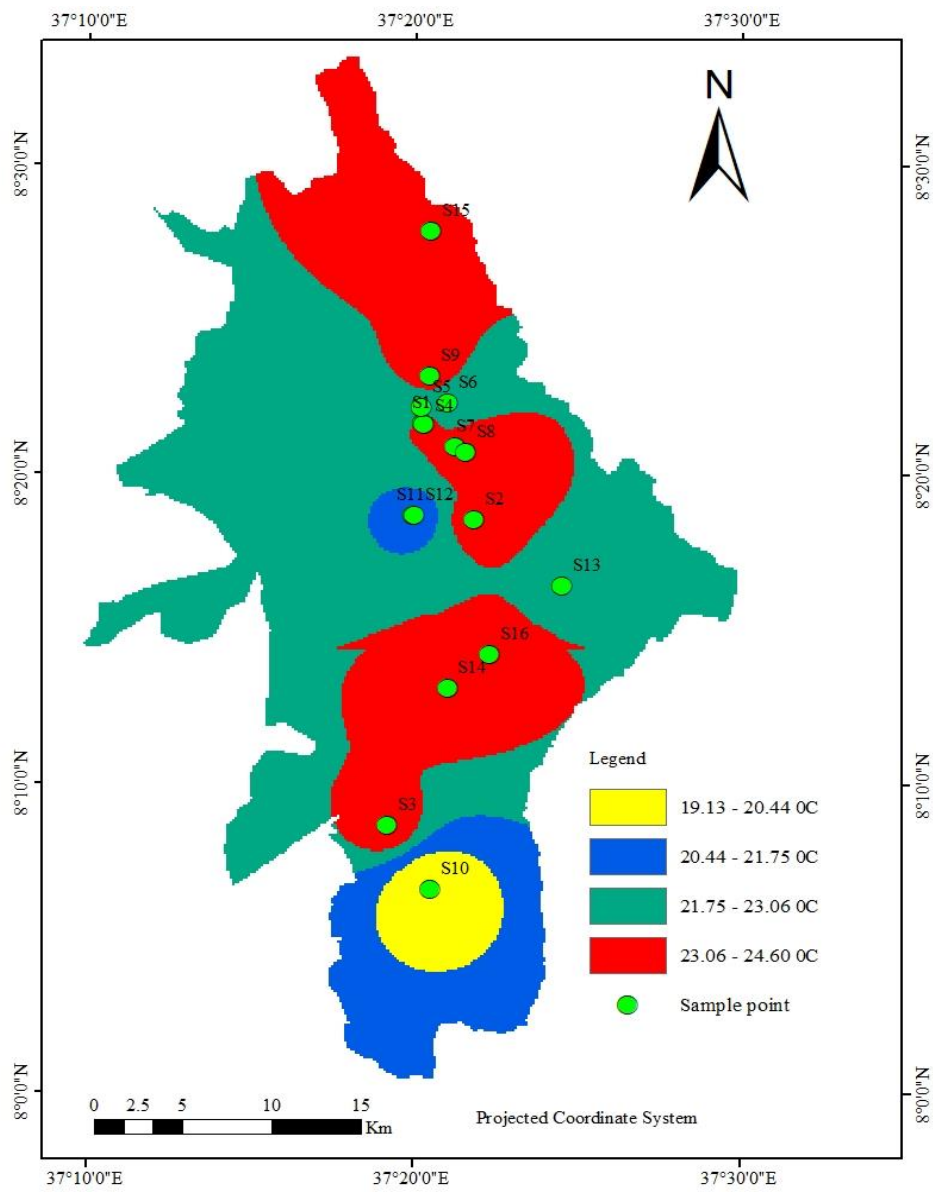


Figure 4.2 Spatial map of the temperatures of the groundwater samples.

4.1.2 pH

The pH of the groundwater samples varied from 6.60 – 7.54 with an average value of 7.13 (Table 4.18). The lowest and highest value of the pH reading were observed at S2, which is a hand dug well and at S9, which is a deep well with pH value of 6.60 and 7.54 respectively (Figure 4.3).

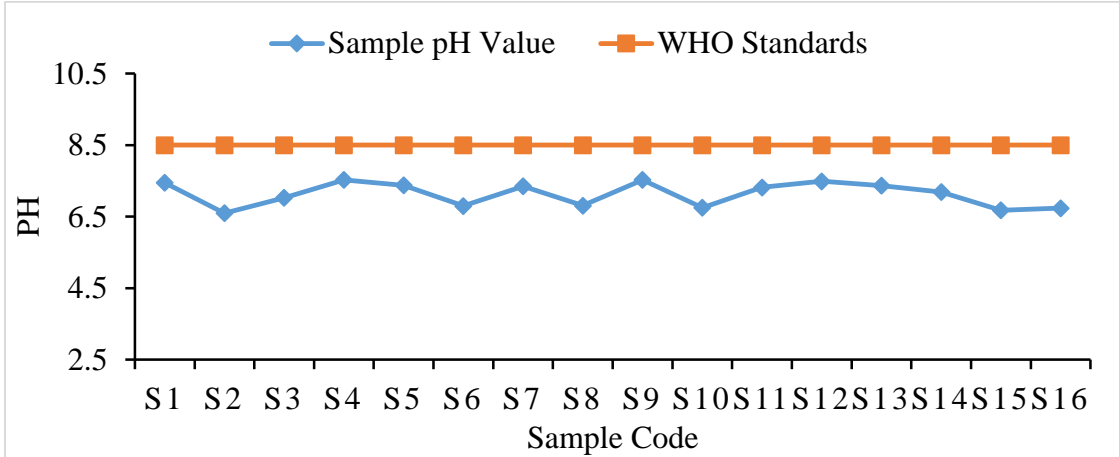


Figure 4.3 Comparison of groundwater samples pH values with WHO (2004) standard.

The permissible pH value for drinking water is from 6.5 – 8.5 (WHO, 2004). The result depicts that the groundwater sources of the study area is slightly basic in nature and the value were within the limit of WHO (2004) standards. Therefore, the pH of groundwater samples in the study area was suitable for drinking purpose.

Table 4.2 Area coverage of interpolated pH concentration.

pH	Area	
	km ²	%
6.60 – 6.83	161.63	16.64
6.83 – 7.06	250.62	25.80
7.06 – 7.29	303.62	31.26
7.29 – 7.53	255.44	26.30

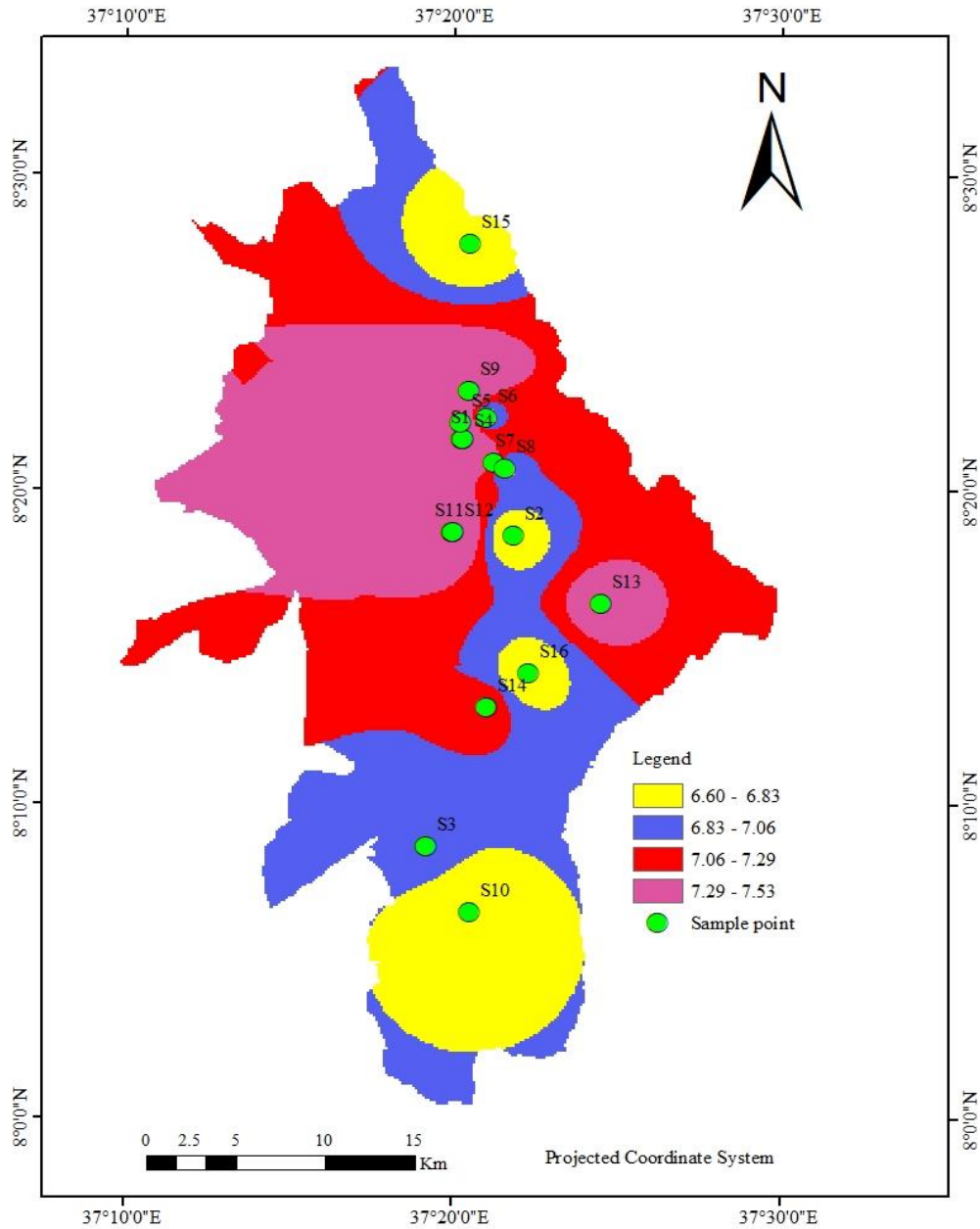


Figure 4.4 Interpolated map pH of the groundwater samples.

4.1.3 Electric Conductivity

The electrical conductivity, EC, of groundwater samples ranged from 142.3 at S3 spring to 1651 $\mu\text{S}/\text{cm}$ at S7 deep well groundwater sources with a mean value of 699.33 $\mu\text{S}/\text{cm}$ (Table 4.18). The lowest and highest value of the EC reading were observed at S3, which is a protected spring and at S7, which is a deep well with EC value of 142.3 $\mu\text{S}/\text{cm}$ and 1651 $\mu\text{S}/\text{cm}$ respectively (Figure 4.5).

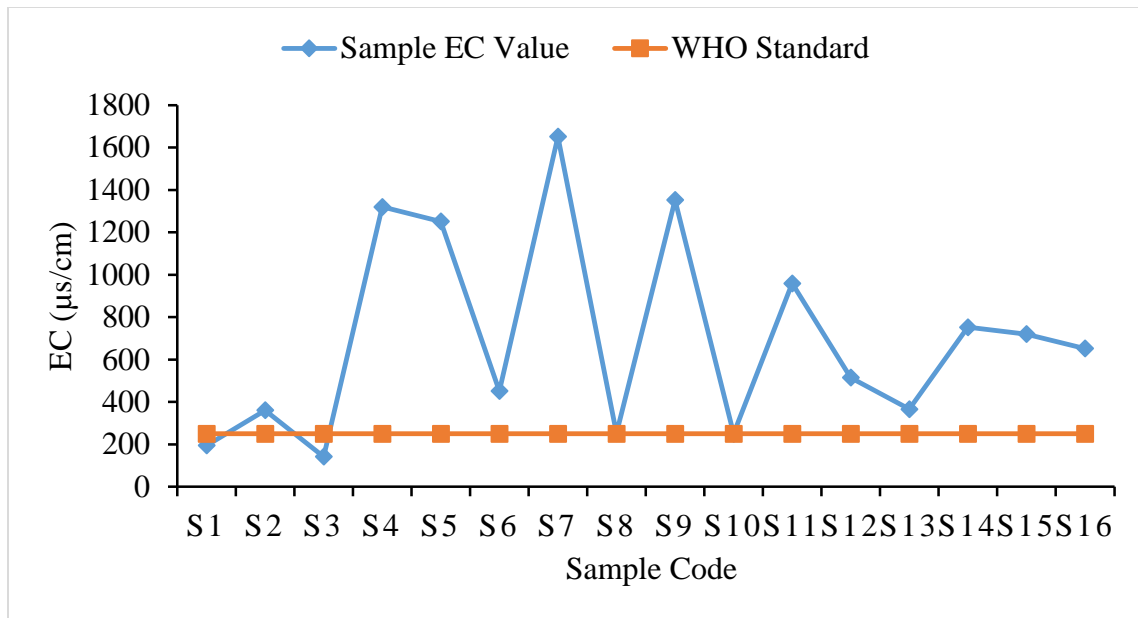


Figure 4.5 Comparison of groundwater samples EC values with WHO (2004) standard.

According to WHO (2004) the desirable limit of for drinking purpose is 250 $\mu\text{S}/\text{cm}$. Lower EC, 142.3 $\mu\text{S}/\text{cm}$ in the study area indicates lower enrichment of salts in the groundwater. The highest EC, 1651 $\mu\text{S}/\text{cm}$ may due to an abundance of dissolved salts due to poor irrigation management, minerals from rain water runoff and municipal discharges (Tesfalem *et al.*, 2019). Since the sample coded with S7 well is found Botor town so the reason for the high EC may be wastewater discharged from the town. From the sampled groundwater sources of the area 12.5 % of the sample was below the desirable limit EC set by WHO (2004) standards therefore, suitable for drinking purpose and 87.5% of the sample was above the recommended value implying suitable for drinking purposes.

Table 4.3 Area coverage of interpolated EC concentration.

EC ($\mu\text{S}/\text{cm}$)	Area	
	km^2	%
141.77 – 513.62	221.58	22.81
513.62 – 885.48	187.08	19.26
885.48 – 1257.34	213.42	21.97
1257.34 – 1651.20	349.30	35.96

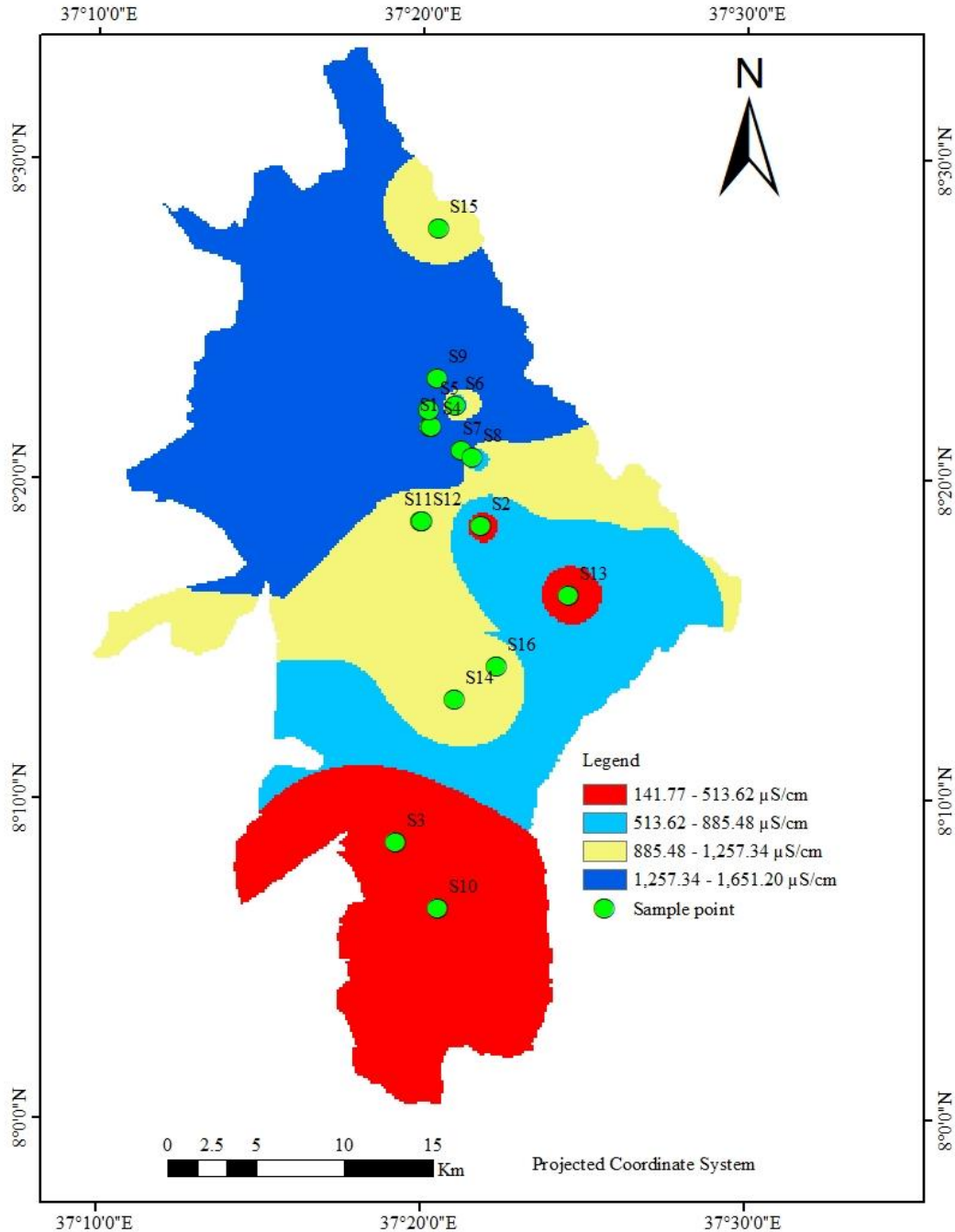


Figure 4.6 Interpolated map of EC of the groundwater samples.

4.1.4 Total Dissolved Solid

The total dissolved solid, TDS, values of the water samples varied from 115.1 – 1231.0 mg/l with an average value of 485.37 mg/l (Table 4.18). The lowest TDS was observed at location S10 (115.1 mg/l) and the highest (1231.0 mg/l) was observed at location S10 of hand dug well and S7 of deep well groundwater sources respectively (Figure 4.6).

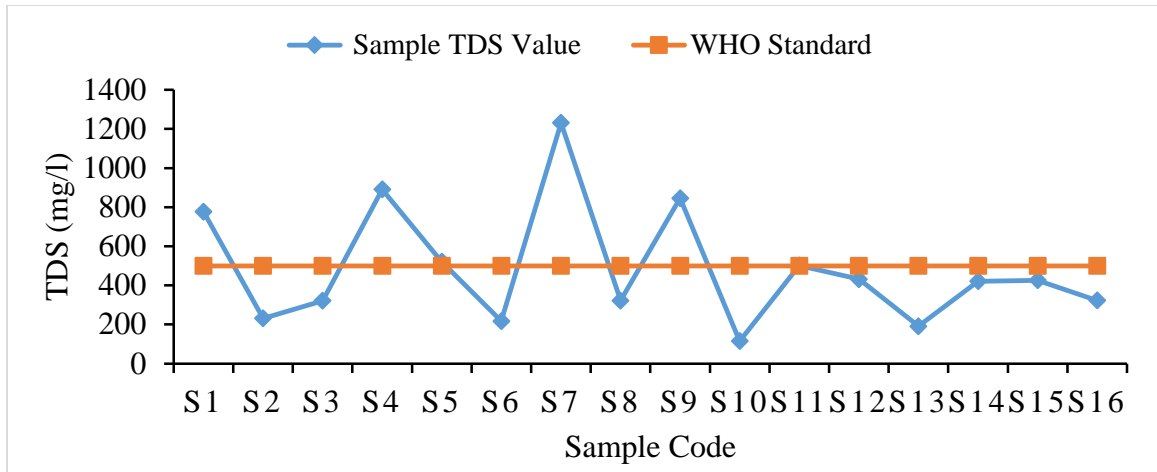


Figure 4.7 Comparison of groundwater samples TDS values with WHO (2004) standard.

The presence of excessive solids in water may be due to intensive agricultural activities and discharged of domestic wastewater and geological parameters. The lowest TDS, in hand dug well may be because of its location since it is surrounded by vegetation which is free from any agricultural practice and wastewater discharges from nearby town whereas the highest TDS, in deep well may be because of agricultural practice and wastewater discharges from the Botor town and geological parameters which varies from place to place and depth of groundwater wells. From the sampled groundwater sources 37.5% of the sample exceed the desirable limits 500 mg/l of WHO (2004) for drinking purpose which were not suitable for drinking purposes and 62.5 % of the sampled groundwater sample were within the recommended standards and suitable for drinking purpose.

Table 4.4 Area coverage of interpolated TDS concentration.

TDS (mg/l)	Area	
	km ²	%
115.24 – 391.53	174.08	17.92
391.53 – 667.83	289.18	29.78
667.83 – 944.12	213.66	21.99
944.12 – 1231.42	294.39	30.31

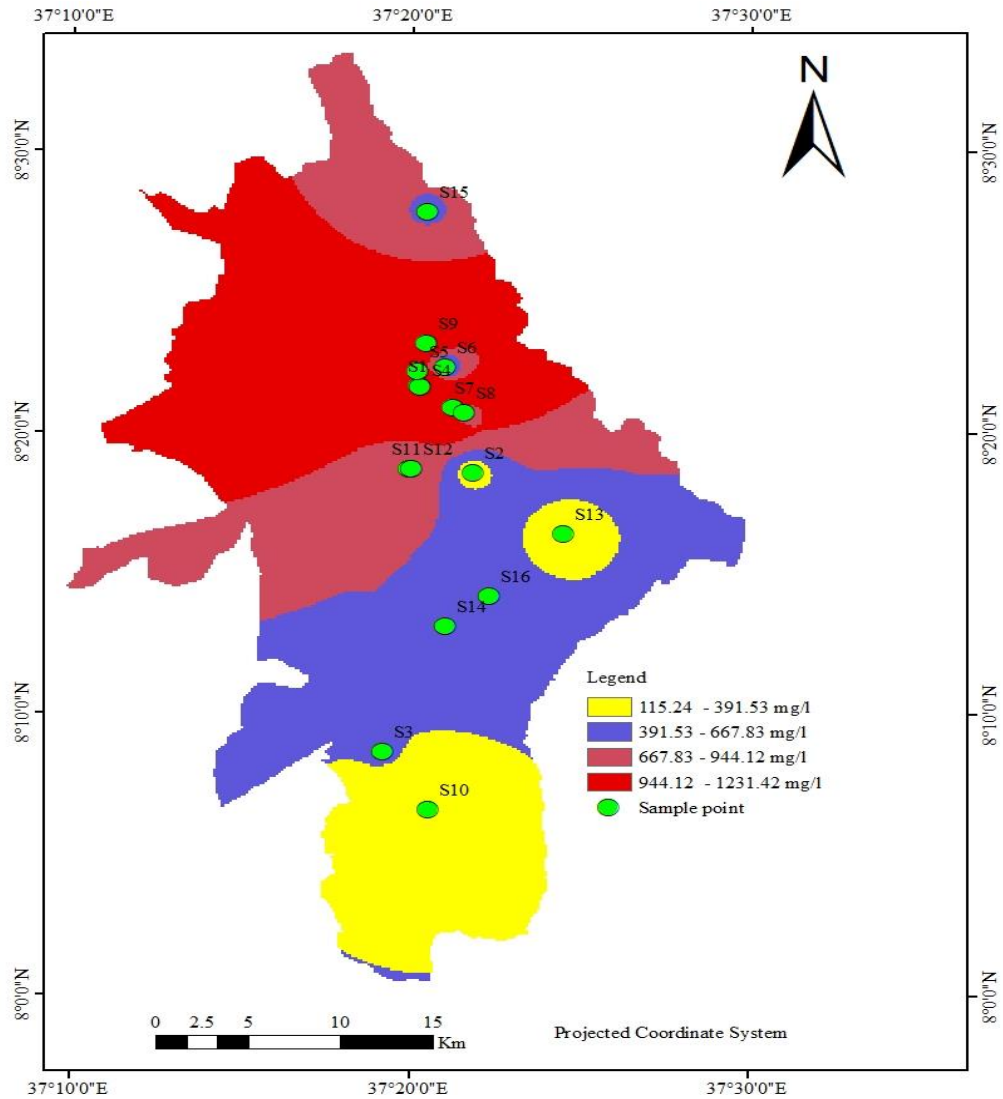


Figure 4.8 Interpolated map of TDS of the groundwater samples.

4.1.5 Turbidity

Turbidity value in the groundwater samples ranged from 2.4 – 54.7 NTU, with an average value of 20.52 NTU (Table 4.18). The lowest (2.4 NTU) and highest (54.7 NTU) turbidity were observed at location S14 and S9 shallow and deep well groundwater sources respectively (Figure 4.8).

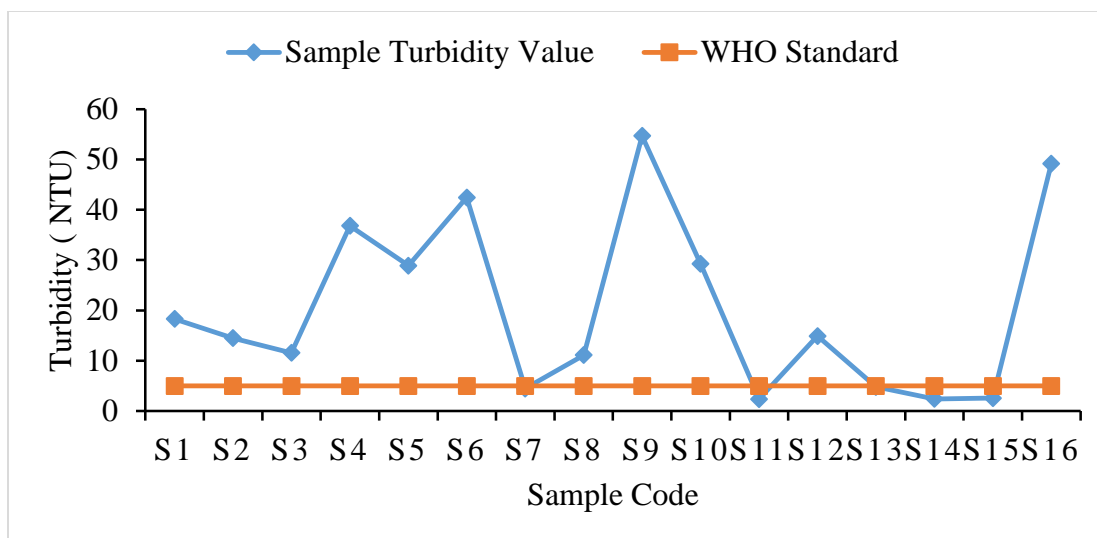


Figure 4.9 Comparison of water samples turbidity values with WHO (2004) standard
 The high value of water sample turbidity may be due to the presence of particulate matter present in water source, suspension of sediment in the distribution system, the presence of inorganic particulate matter in some groundwater or sloughing of bio-film within the distribution system (WHO, 2004). From the total sampled groundwater sources of the study area 68.75% of the sample exceed the maximum acceptable limits of 5 NTU recommended by (WHO, 2004) for drinking purpose and hence not suitable for drinking purpose whereas the TDS of the 31.25% of the sample were below the maximum acceptable limits and suitable for drinking purpose.

Table 4.5 Area coverage of interpolated turbidity.

Turbidity (NTU)	Area	
	km ²	%
115.24 – 391.53	87.93	9.05
391.53 – 667.83	402.47	41.44
667.83 – 944.12	419.06	43.14
944.12 – 1231.42	61.85	6.37

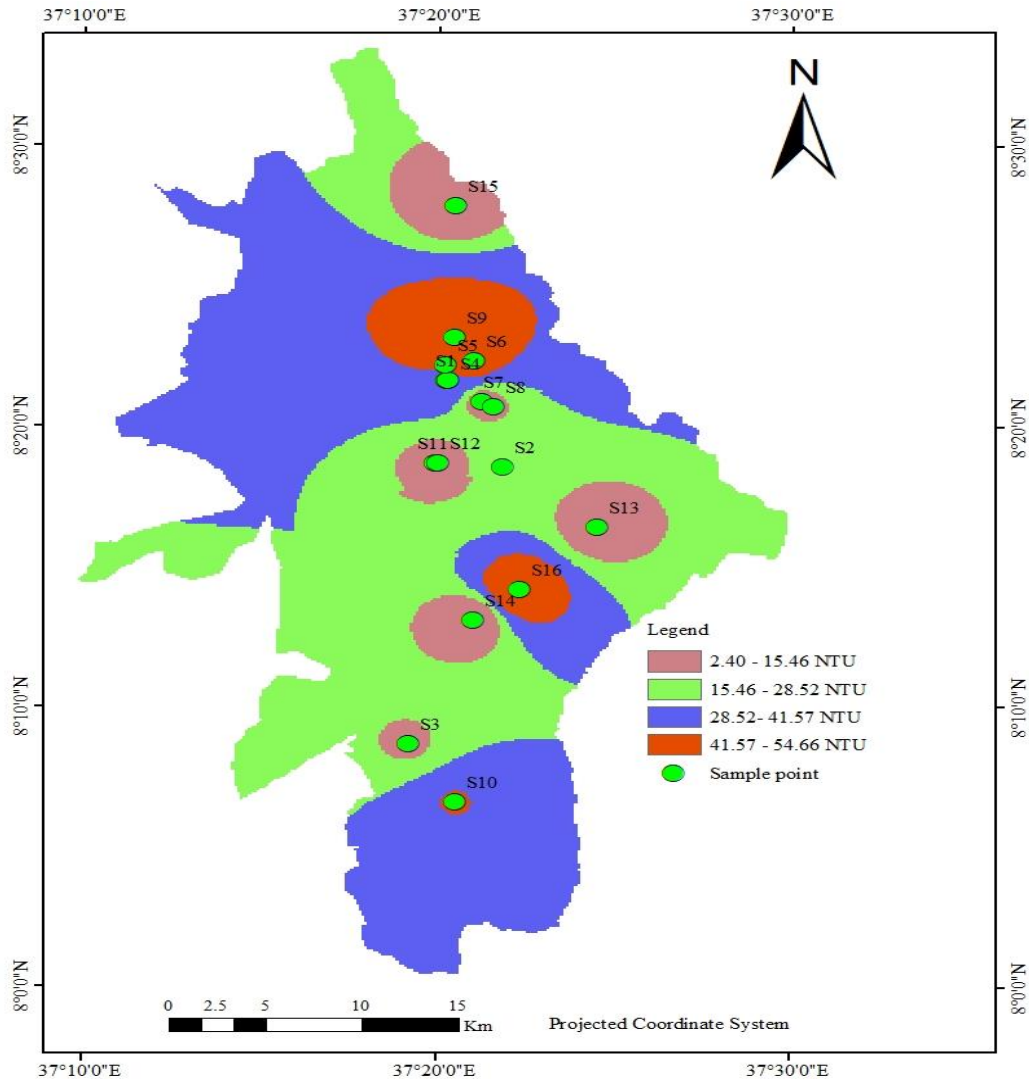


Figure 4.10 Interpolated map of turbidity of the groundwater samples.

4.2 Chemical Parameters

4.2.1 Total Hardness

The total hardness, TH, values ranged from 42.9 – 275.2 mg/l (Table 4.18). The lowest (42.9 mg/l) and highest (275.2 mg/l) value were at location S2 hand dug well and S14 shallow well groundwater respectively (Figure 4.11) with mean 126.02 mg/l. The observed values of TH were lower than the desirable limit of 300 mg/l, WHO (2004), indicating that the water from all groundwater wells were suitable for drinking purposes.



Figure 4.11 Comparison of groundwater samples TH values with WHO (2004) standard.

Table 4.6 Classification of hardness and area coverage of interpolated TH (WHO, 2004).

TH (mg/l)	Classification	Area	
		km ²	%
0 – 60	Soft	318.74	32.82
61 – 120	Moderately hard	435.71	44.86
121 – 180	Hard	143.87	14.81
> 180	Very hard	72.99	7.51

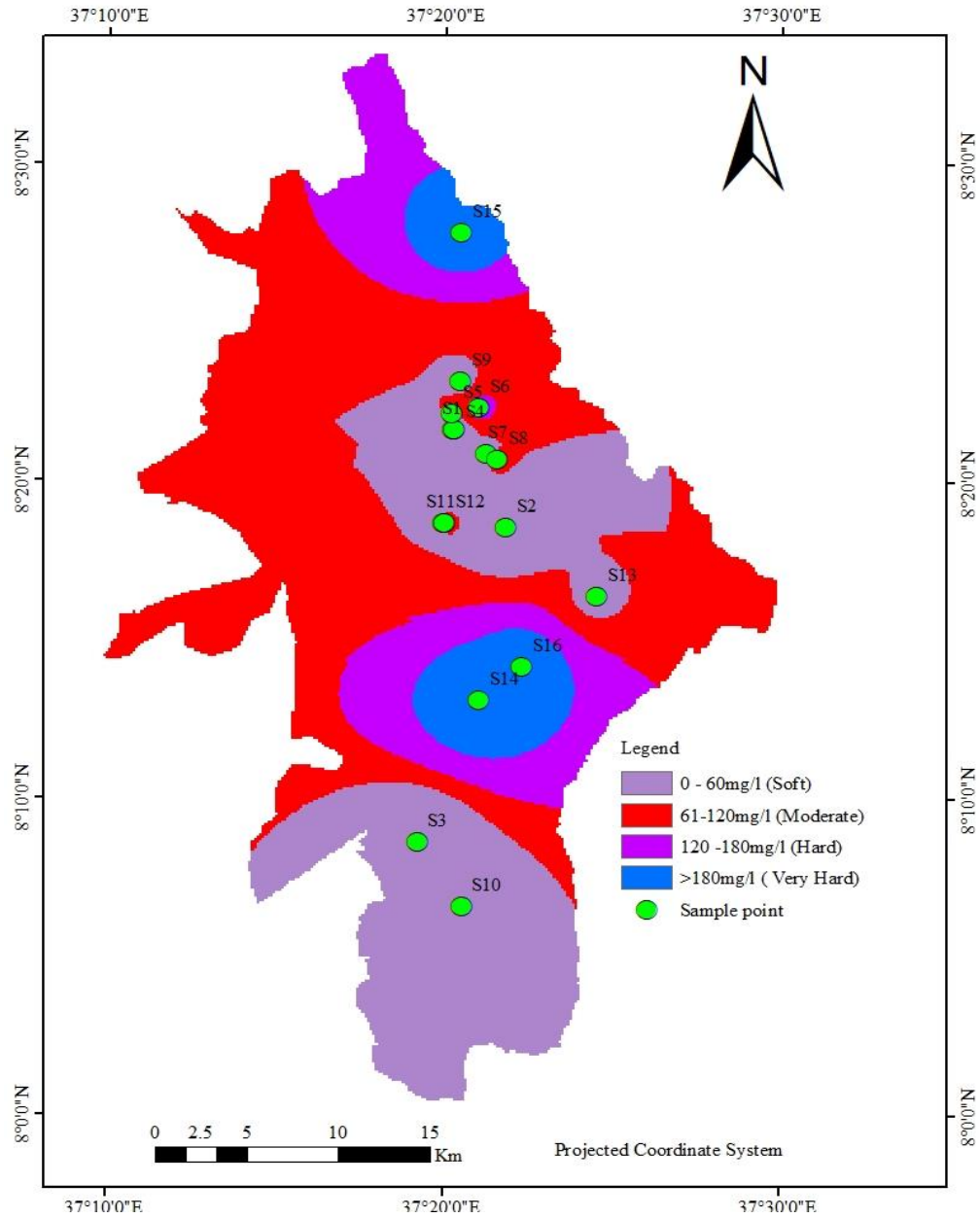


Figure 4.12 Interpolated map of TH of the groundwater samples.

4.2.2 Total Alkalinity

The total alkalinity, TA, of water samples were found in the range of 43.13 – 632.2 mg/l (Table 4.18). The lowest and highest values of alkalinity were observed at location S10 hand dug well and S9 deep well groundwater with alkalinity value of 43.13 and 632.2 mg/l respectively (Figure 4.13) with a mean of 238.59 mg/l.

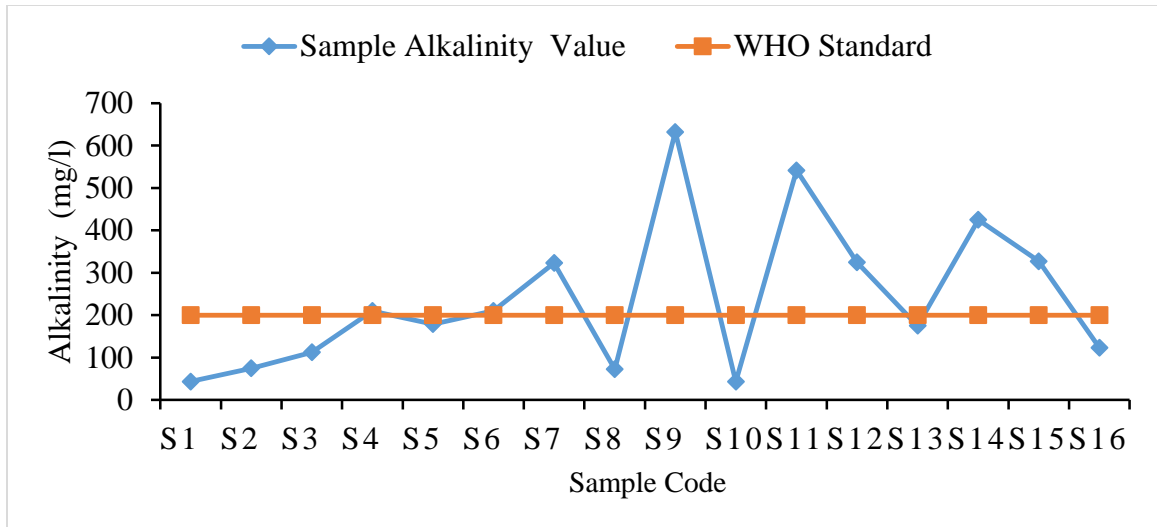


Figure 4.13 Comparison of groundwater samples TA values with WHO (2004) standard.

The high content resulted may be due to the soil background, waste discharge in to the drainage and microbial decomposition of organic matter in the groundwater. It maybe also due to the low water table and lower temperature bringing down the rate of decomposition of salts to the minimum, thereby increasing the alkalinity. High alkalinity in water bodies leads to sour taste and salinity (Tesfalem *et al.*, 2019). Out of the total sampled groundwater 50% of the sample were within the desirable limit 200 mg/l of WHO (2004) standards of alkalinity for drinking water purpose hence were suitable for drinking purpose while the other 50% of the groundwater sample were above the desirable limit of WHO (2004) standards and were unsuitable for drinking purpose.

Table 4.7 Area coverage of interpolated TA concentration.

TA (mg/l)	Area	
	km ²	%
43.13 – 189.59	188.98	19.46
189.59 – 335.98	309.07	31.82
335.98 – 482.38	433.03	44.58
482.38 – 632.20	40.23	4.14

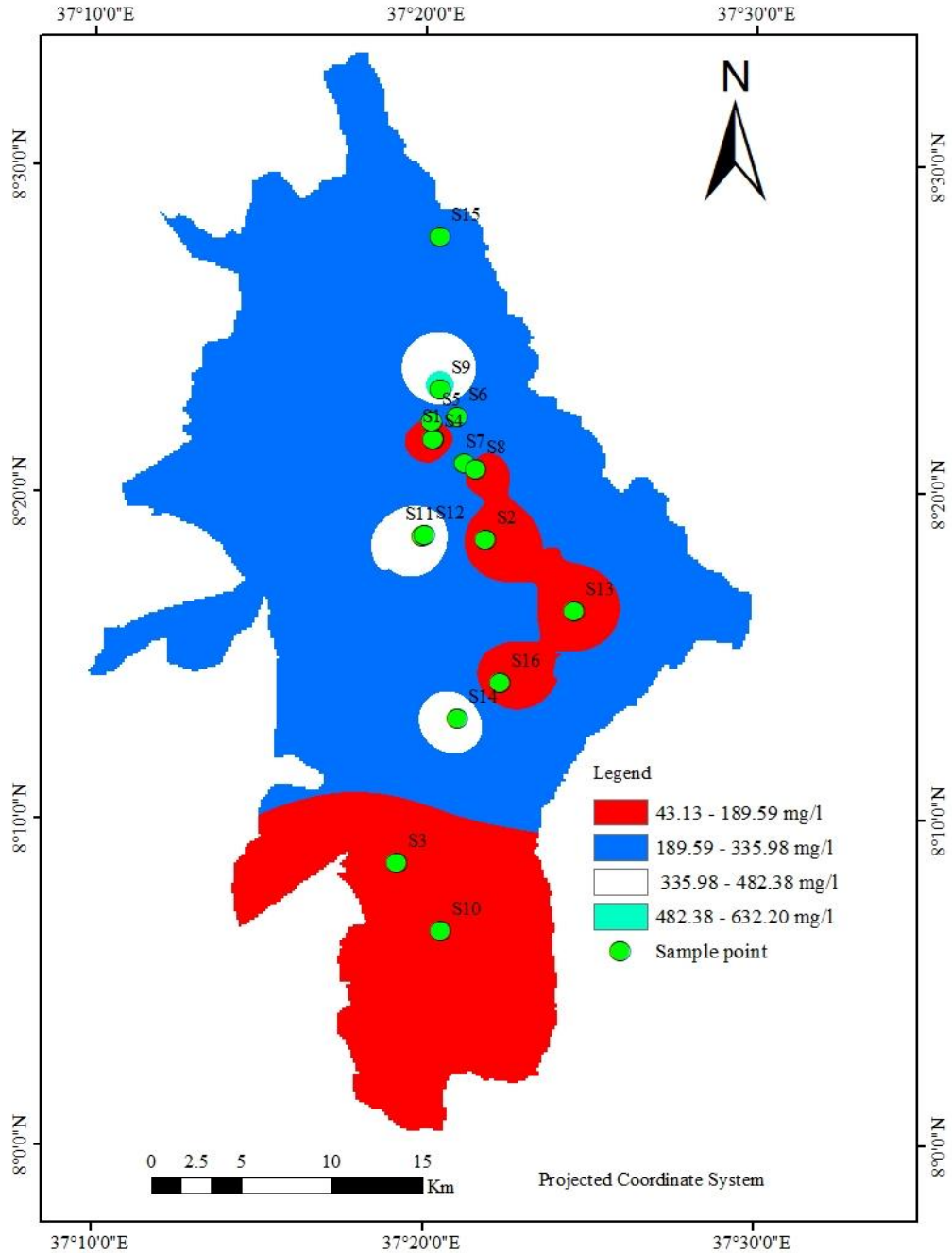


Figure 4.14 Interpolated Map of TA of the Groundwater Samples.

4.2.3 Calcium

The concentration of calcium, Ca^{2+} , in the study area ranged from 5.28 – 153.5 mg/l with a mean value of 44.06 mg/l (Table 4.18). The lowest (5.28 mg/l) and highest (153.5 mg/l) calcium value were observed at location S10 and S15 hand dug and shallow well groundwater respectively (Figure 4.15).

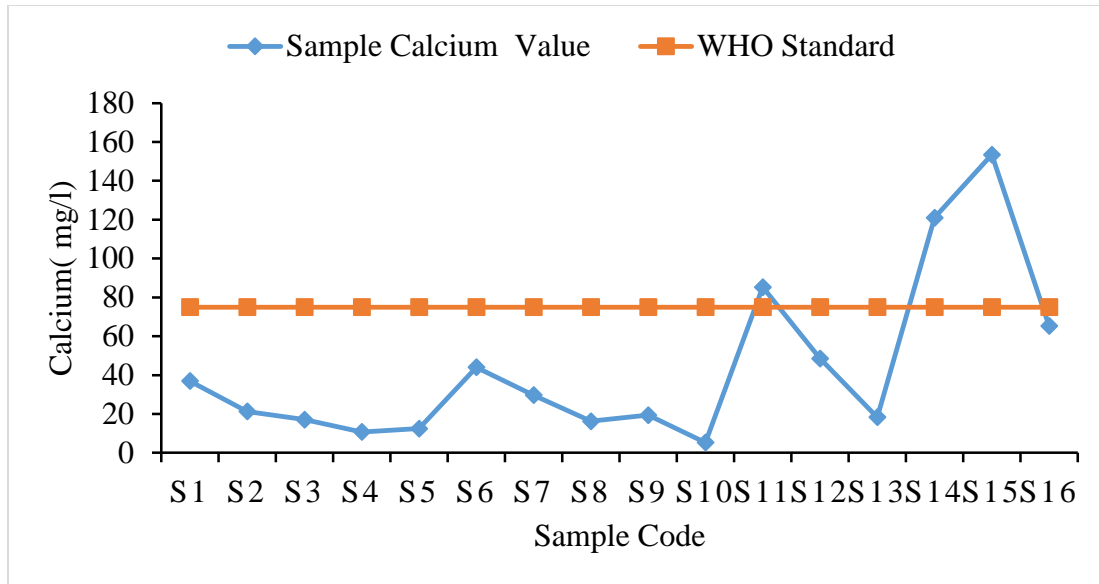


Figure 4.15 Comparison of groundwater samples Ca²⁺ values with WHO (2004) standard.

Higher values of Ca²⁺ are related to sewage and weathering calcium rich rocks in the geophysical locations around the study area. If calcium rich water is used for drinking frequently, it may lead to arise heart diseases and kidney stone formation (Tesfalem *et al.*, 2019). From the sampled groundwater 81.25% of the sample lies within the desirable limit of WHO (2004) standards (75 mg/l), hence suitable for drinking purpose whereas 18.75% of the total water sample were above the recommended value and were not suitable for drinking purpose.

Table 4.8 Area coverage of interpolated Ca²⁺ concentration.

Calcium (mg/l)	Area	
	km ²	%
5.18 – 42.33	386.71	39.81
42.33 – 79.38	396.03	40.77
79.38 – 116.42	144.80	14.91
116.42 – 153.46	43.77	4.51

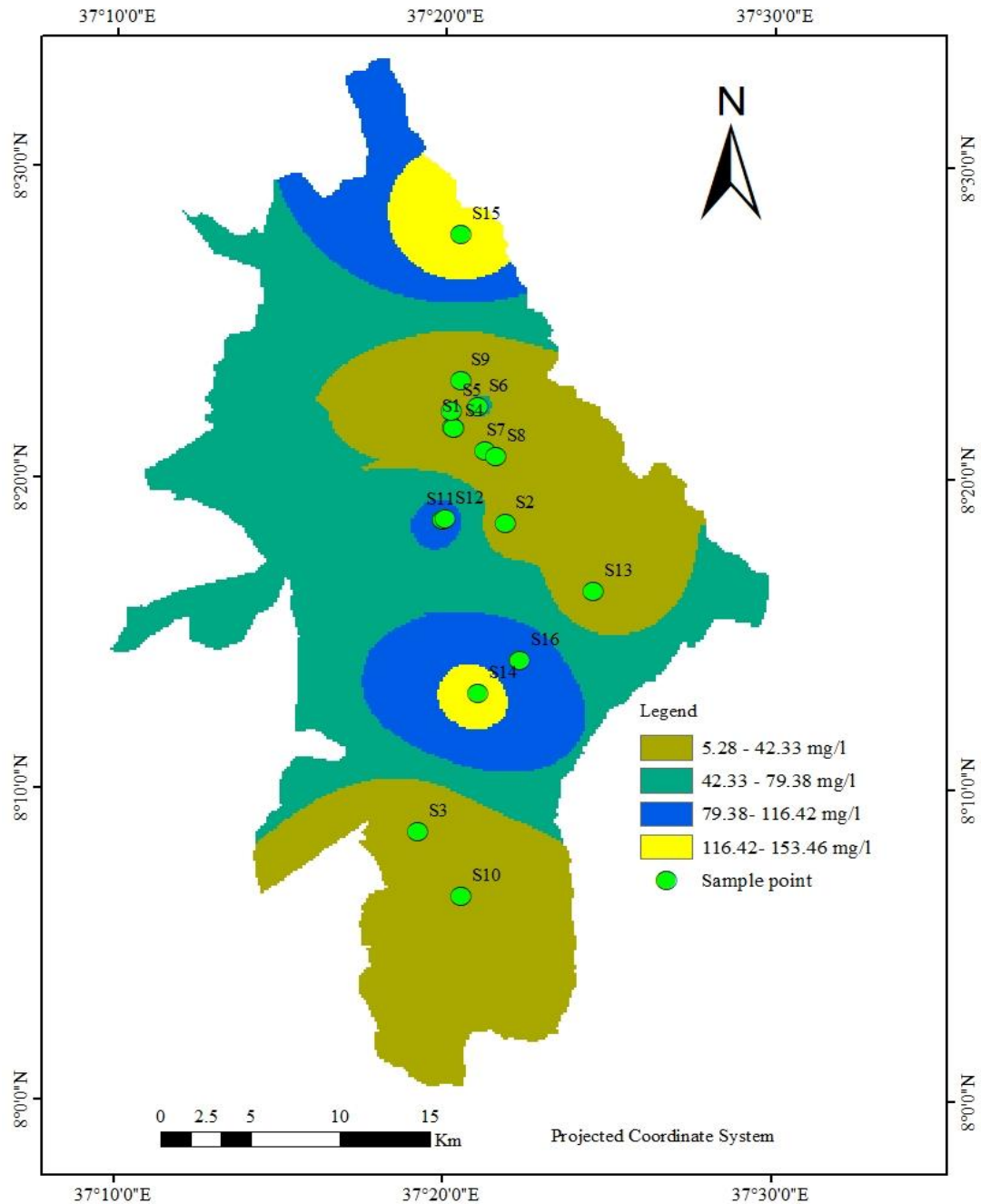


Figure 4.16 Interpolated map of Ca^{2+} of the groundwater samples.

4.2.4 Magnesium

The concentration of magnesium, Mg^{2+} , in the study area ranged from 3.17 – 124.8 mg/l with a mean value of 31.67mg/l (Table 4.18). The lowest (3.17 mg/l) and highest (124.8 mg/l) magnesium value were observed at location S10 and S14 hand dug and shallow well groundwater respectively (Figure 4.17).

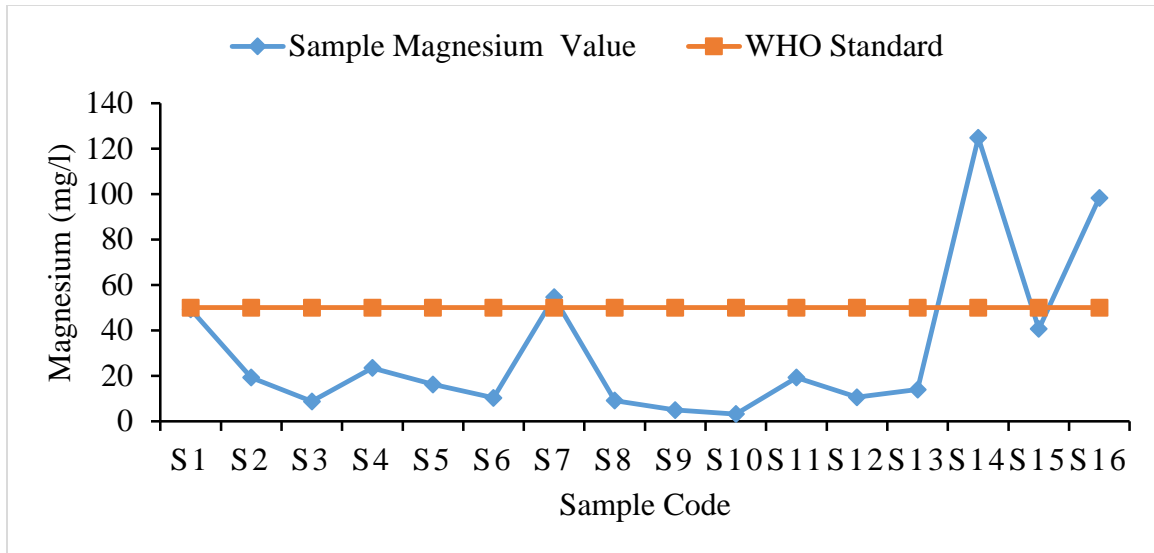


Figure 4.17 Comparison of groundwater samples Mg²⁺ Values with WHO (2004) standard.

Most of the groundwater sample were within the desirable limit of WHO (2004) standards except sample S7, S14 and S16. The high value of the magnesium may be due to the dissolution of different magnesium containing rocks such as dolomite (calcium magnesium carbonate); and magnesite (magnesium carbonate) on the sub surface of the earth which can add hardness to a water sample and can cause encrustation in water supply structure and adverse effect on domestic use (WHO, 2006). Excess concentration of Mg²⁺ can contribute to mental state changes, lack of appetite, extremely low blood pressure and irregular heartbeat (Rasheed and Abdulgafar, 2014). Accordingly, 18.75% of the water sample were unsuitable and 81.25% of the sample were suitable for drinking purpose.

Table 4.9 Area coverage of interpolated Mg²⁺ concentration.

Magnesium (mg/l)	Area	
	km ²	%
3.18 – 33.58	577.71	59.48
33.58 – 63.98	261.08	26.88
63.98 – 94.39	86.57	8.91
94.39 – 124.79	45.95	4.73

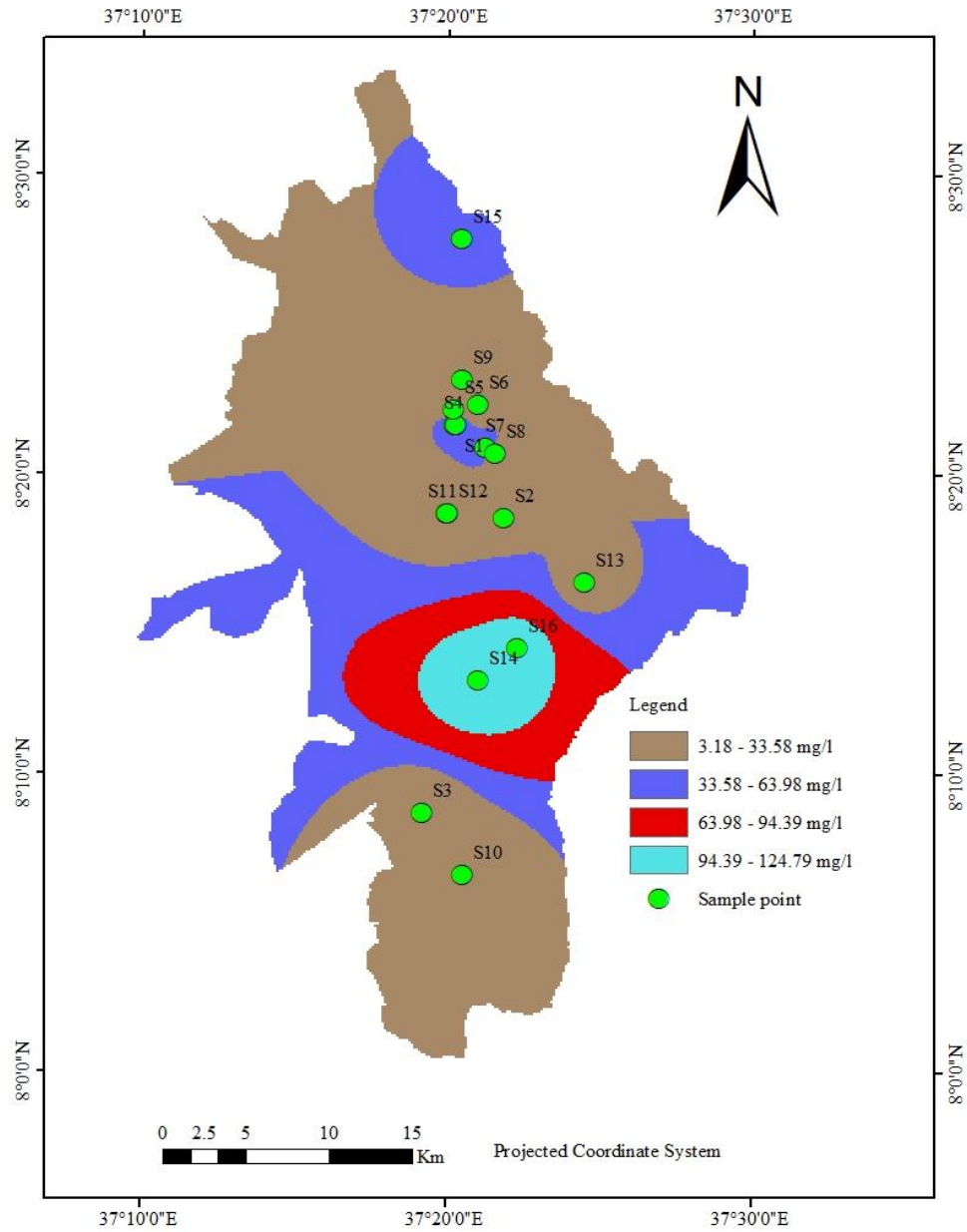


Figure 4.18 interpolated map of Mg^{2+} of the groundwater samples.

4.2.5 Chloride

The chloride ion, Cl^- , concentration found in the study area ranged from 5.13 – 39.93 mg/l with average value of 20.14 mg/l (Table 4.18). According to WHO (2004) the desirable limit of chloride is 250 mg/l. All the groundwater samples of the study area were within the desirable limit. The origin of chloride ion in groundwater is from weathering rocks, domestic and discharged industrial wastes, municipal effluence (Tesfalem *et al.*, 2019).

Therefore, all the groundwater samples would not pose any health problem and were suitable for drinking purpose.

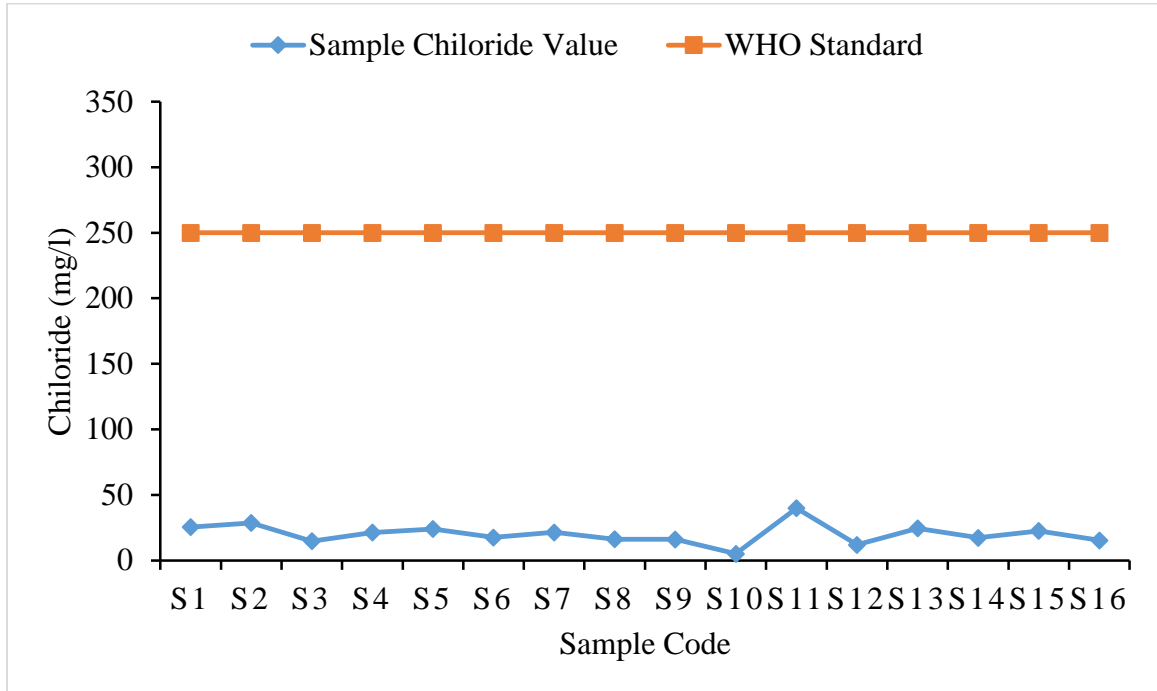


Figure 4.19 Comparison of groundwater samples Cl⁻ values with WHO (2004) standard.

Table 4.10 Area coverage of interpolated Cl⁻ concentration.

Chloride (mg/l)	Area	
	km ²	%
5.13 – 12.65	143.31	14.75
12.65 – 20.16	190.91	19.65
20.16 – 27.68	517.91	53.32
27.68 – 39.93	119.18	12.27

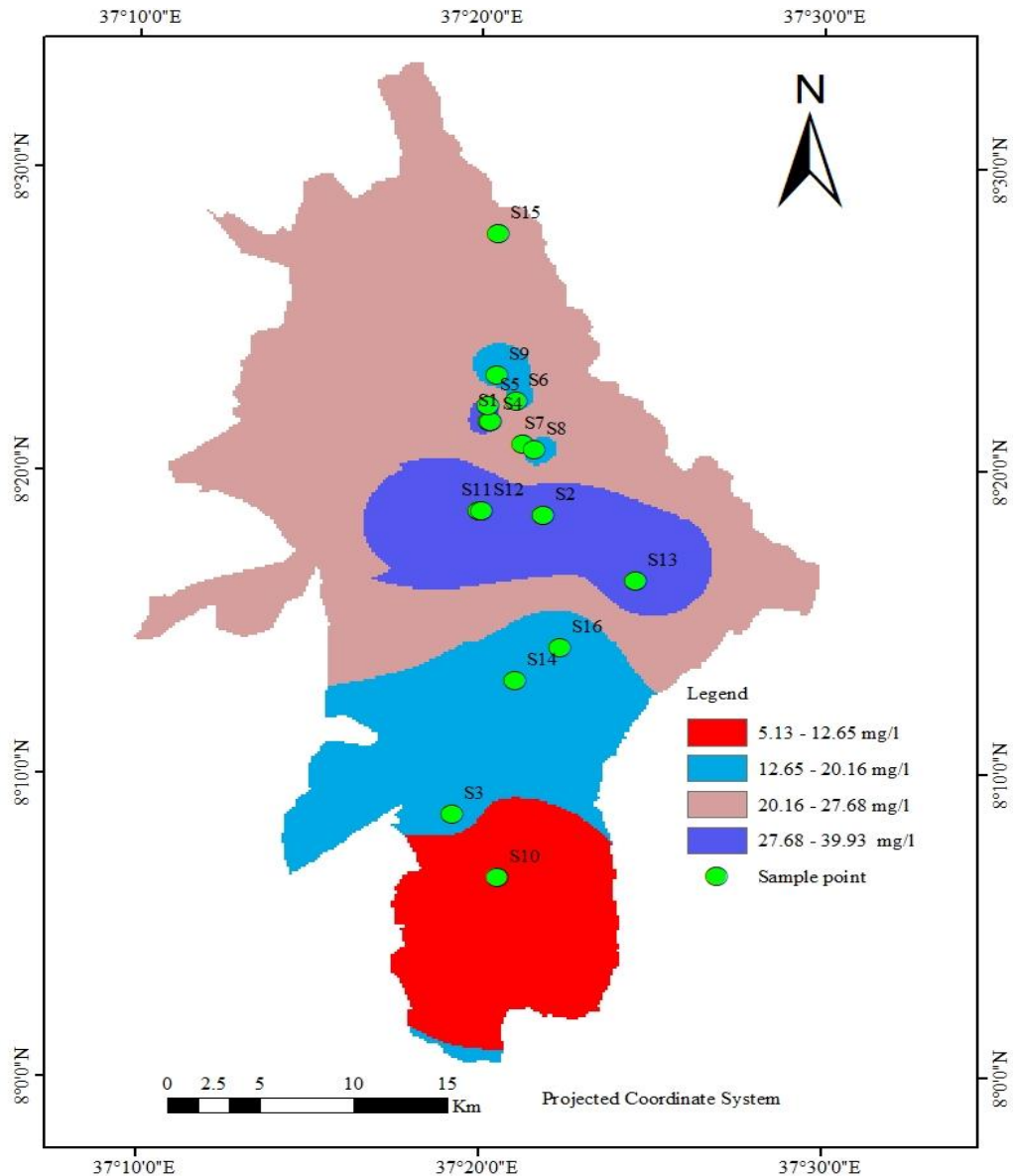


Figure 4.20 Interpolated map of Cl⁻ of the groundwater samples.

4.2.6 Sulphate

The sulphate, SO₄²⁻, value of the water sample of the study area ranged from 0 – 21.9 mg/l with average value of 4.64 mg/l (Table 4.18). The lowest and highest value were observed at location S6, S10, S11, and S15 with concentration value of 0mg/l and at location S₁₆ with concentration value of 21.9mg/l respectively (Figure 4.21). Shah (2017) concludes that (SO₄²⁻) is commonly present in natural water as a result of chemical dissolution, dissolving minerals containing sulfur and oxidizing sulfates and sulfur. According to WHO (2004), standards the desirable limit of SO₄²⁻ is 200 mg/l. Therefore, the SO₄²⁻ value of the

water sample of the area lies within the limit showing that all the water sample were suitable for drinking purpose.

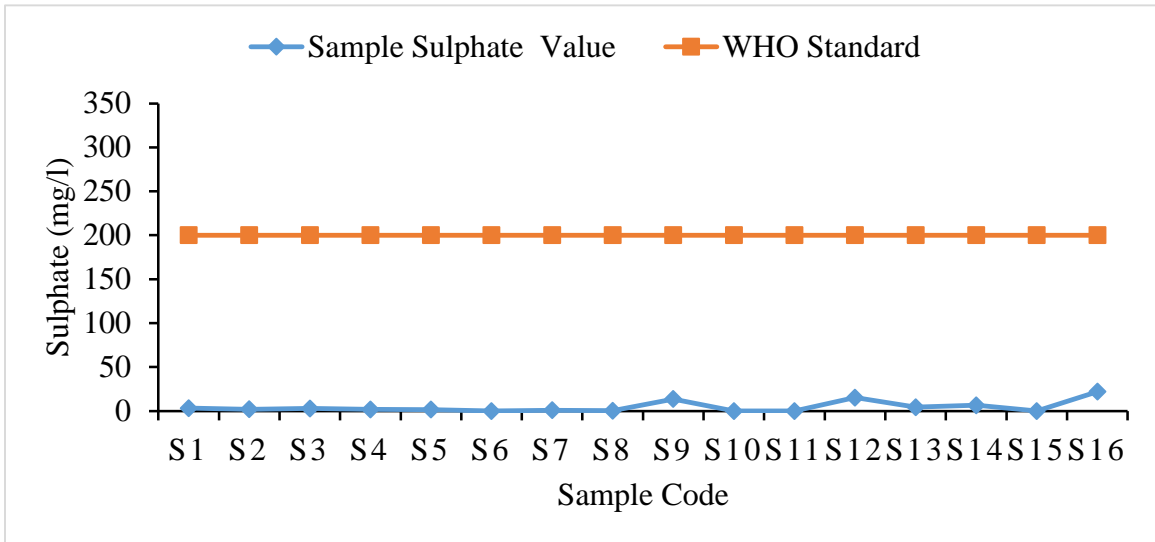


Figure 4.21 Comparison of water samples SO₄²⁻ values with WHO (2004) standard.

Table 4.11 Area coverage of interpolated SO₄²⁻ concentration.

Sulphate (mg/l)	Area	
	km ²	%
0.00 – 5.45	458.85	47.24
5.45 – 10.90	378.96	39.02
10.90 – 16.35	110.94	11.42
16.35 – 21.86	22.56	2.32

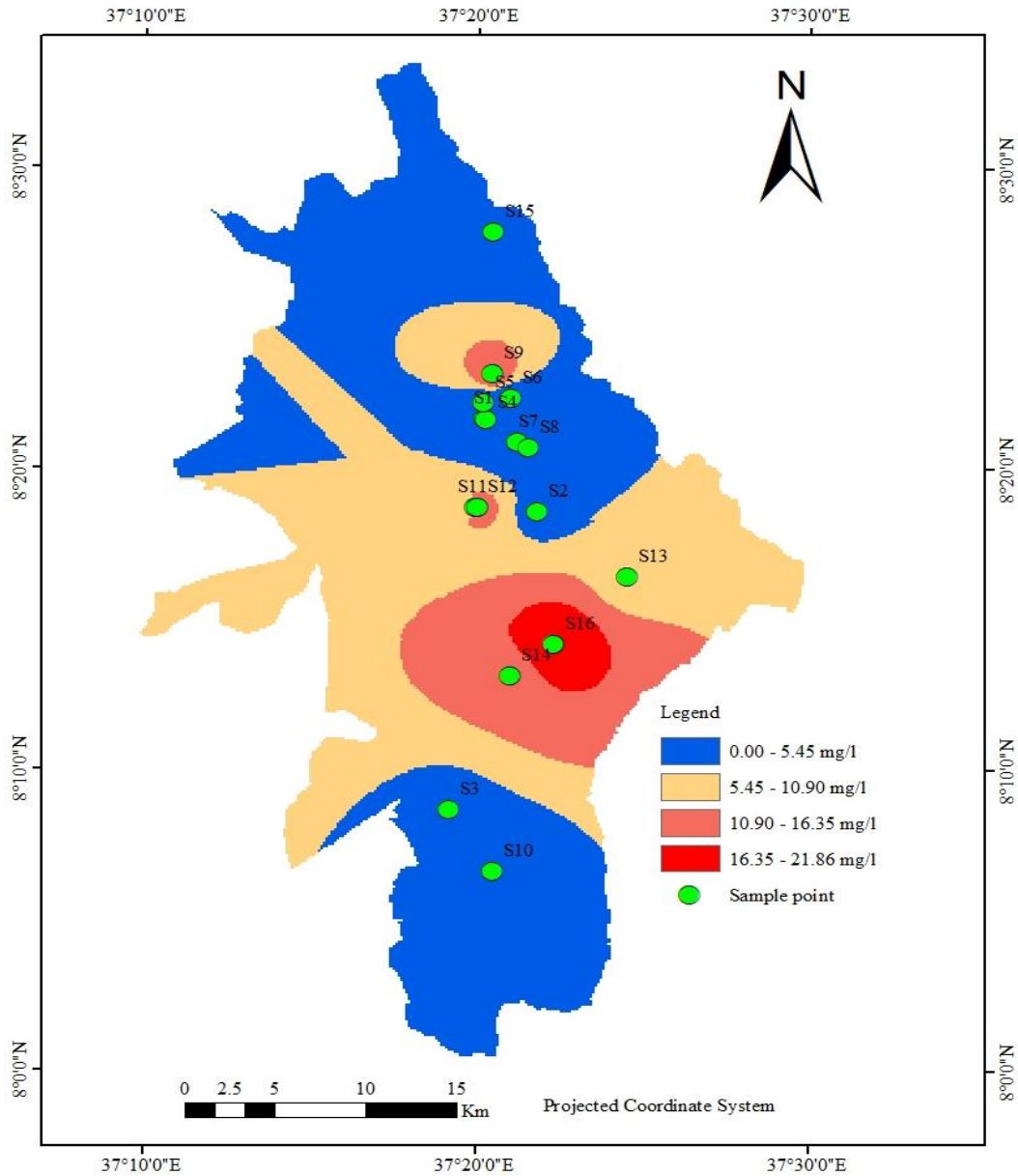


Figure 4.22 Interpolated map of SO_4^{2-} of the groundwater samples.

4.2.7 Carbonate

There were no carbonate, CO_3^{2-} , concentration found in all water sample of study area. This may be due to the absence of magmatic, volcanic rock and carbonate-rich sedimentary rocks, principally formed from deposition of biogenic marine materials (Wedepohl, 1978). Also no anthropogenic sources of carbonate such as limestone applied to fields to increase soil pH and effluents of wastewater from industry. Therefore, the water sample of the study area are suitable for drinking purpose.

4.2.8 Bicarbonate

The bicarbonate, HCO_3^- , of water samples were found in the range of 45.20 – 952.52 mg/l with a mean value of 339.84 mg/l (Table 4.18). The lowest and highest value of bicarbonate were observed at location S10 hand dug well and S9 deep well groundwater with value of 45.20 and 952.2 mg/l respectively (Figure 4.23).

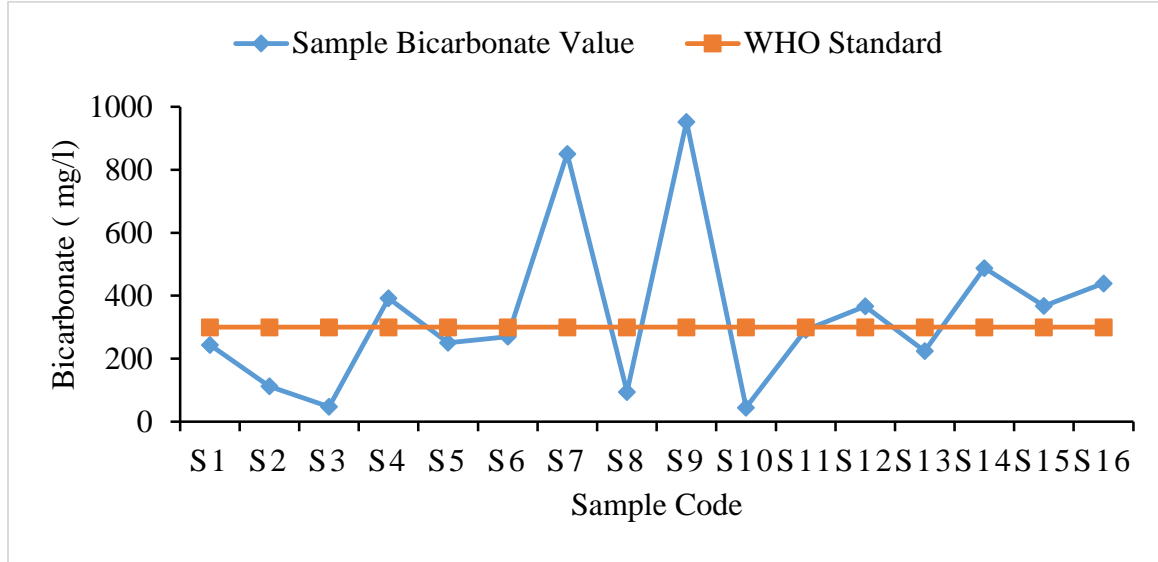


Figure 4.23 Comparison of water samples HCO_3^- values with WHO (2004) standard.

The WHO (2004) desirable limit of bicarbonate is 300 mg/l. High content of HCO_3^- in water bodies leads to alkalinity and salinity. The potential sources of HCO_3^- include the presence of organic matter in the oxidized aquifer to produce carbon dioxide that supports mineral dissolution (Khashogji and El Maghraby, 2013). From the total sampled groundwater 43.75% of the sample exceeds the recommended limit indicating that not suitable for drinking purpose whereas 56.25% of the sample lies within the allowable limit implying suitable for drinking purpose.

Table 4.12 Area coverage of interpolated HCO_3^- concentration.

Bicarbonate (mg/l)	Area	
	km ²	%
45.20 – 271.56	212.58	21.88
271.56 – 497.89	306.71	31.57
497.89 – 724.23	432.56	44.53
724.23 – 952.52	19.46	2.02

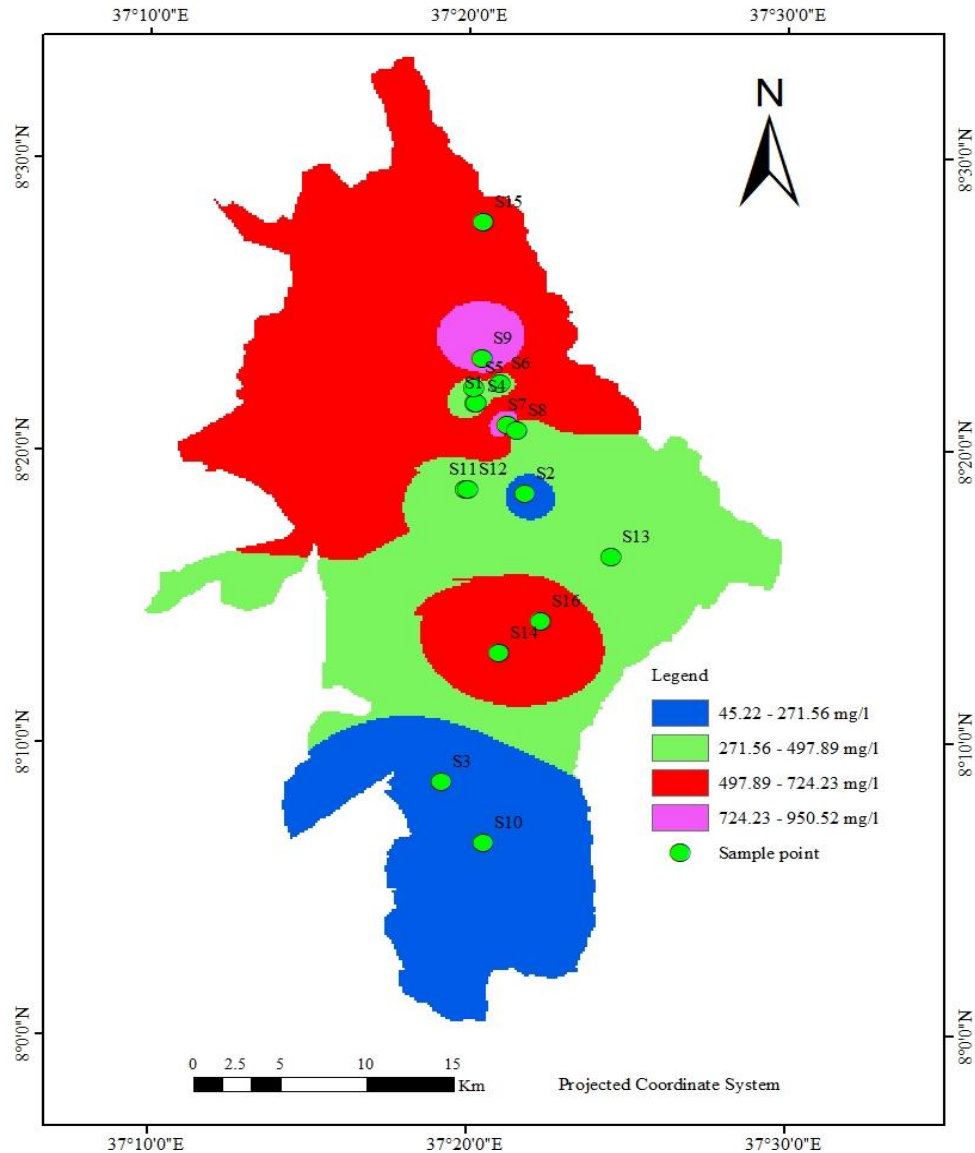


Figure 4.24 Interpolated map of HCO_3^- of the groundwater samples.

4.2.9 Fluoride

The fluoride, F^- , value of the water samples of the study area ranged from 0.27 – 9 mg/l with average value of 1.88 mg/l (Table 4.18). The lowest (0.27 mg/l) and highest (9 mg/l) value were observed at location S10 hand dug well and S4 deep well groundwater sources respectively (Figure 4.25). F^- is found naturally in groundwater and soil, but some anthropogenic activities increase the concentration of F^- with fluorinated industrial waste (iron, steel, glass, aluminum), or agricultural activities by using the phosphate fertilizers and certain pesticides (Gupta *et al.*, 2015; Srivastav *et al.*, 2018; Gupta *et al.*, 2019; Maurya

et al., 2019). The presence of F^- in drinking water has some health benefits for consumers such as, reducing dental cavities, but dental and skeletal fluorosis may result from excessive ingestion of this anion or its presence at high concentrations ($> 1.5 \text{ mg/l}$) (Yadav *et al.*, 2015; Guissouma *et al.*, 2017; Raj and Shaji, 2017).

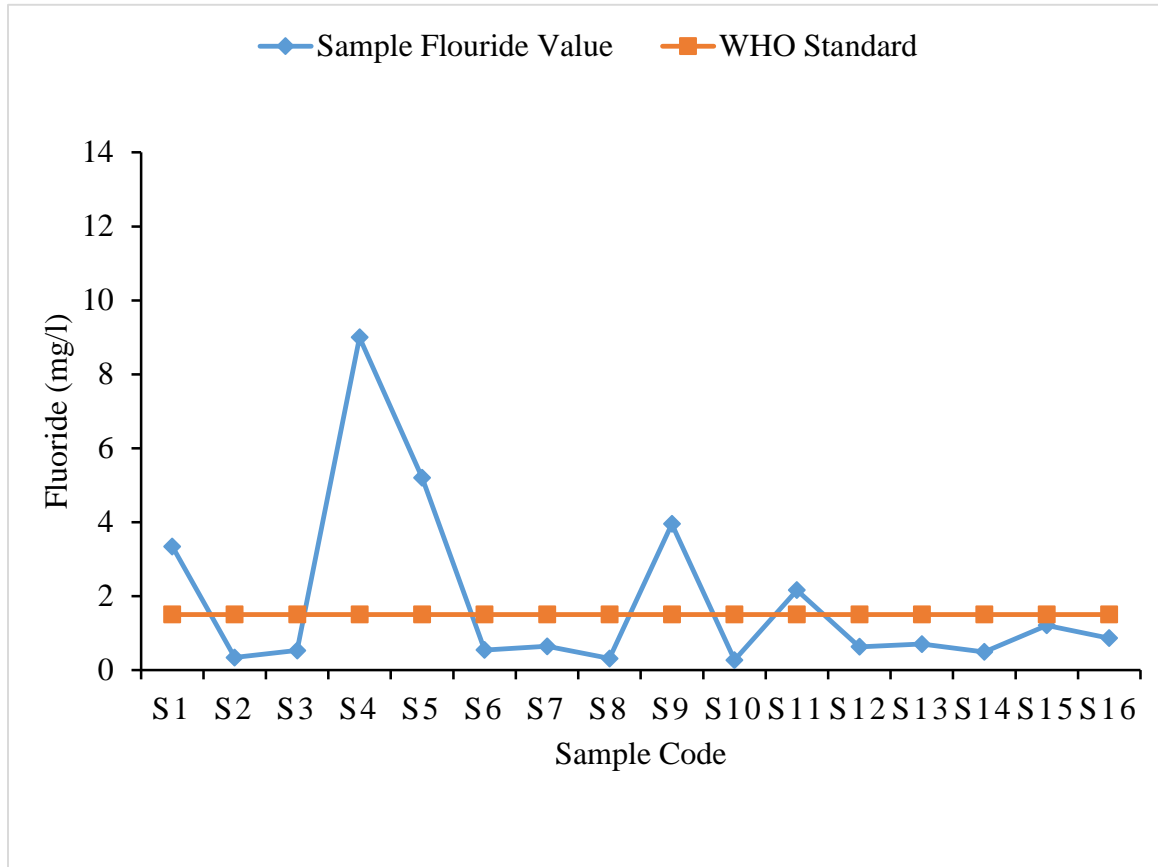


Figure 4.25 Comparison of water samples F^- values with WHO (2004) standard.

Water and rock interactions at a given temperature, pressure and chemical conditions determines conductivity, pH, calcium, and bicarbonate which are important chemical parameters for the dissolution F^- to groundwater from F^- rich minerals. The high F^- in some of the water sample of the study area may due to alkaline medium, high concentration of bicarbonate, and moderate conductivity are favorable for F^- dissolution (Ahmed, 2014). The high F^- concentration in S4 deep well which is found in keta town may be because of agricultural activities and dissolution of F^- rich minerals. In the study area, from the total water samples 31.25% of the sample exceeds the desirable limit implying that not suitable

for drinking purpose and 68.75% of the total sample lies within the recommended value thus suitable for drinking purpose.

Table 4.13 Area coverage of interpolated F⁻ concentration.

Fluoride (mg/l)	Area	
	km ²	%
0.27 – 2.35	417.48	42.98
2.35 – 4.44	230.59	23.74
4.44 – 6.52	265.65	27.35
6.52 – 9.00	57.59	5.93

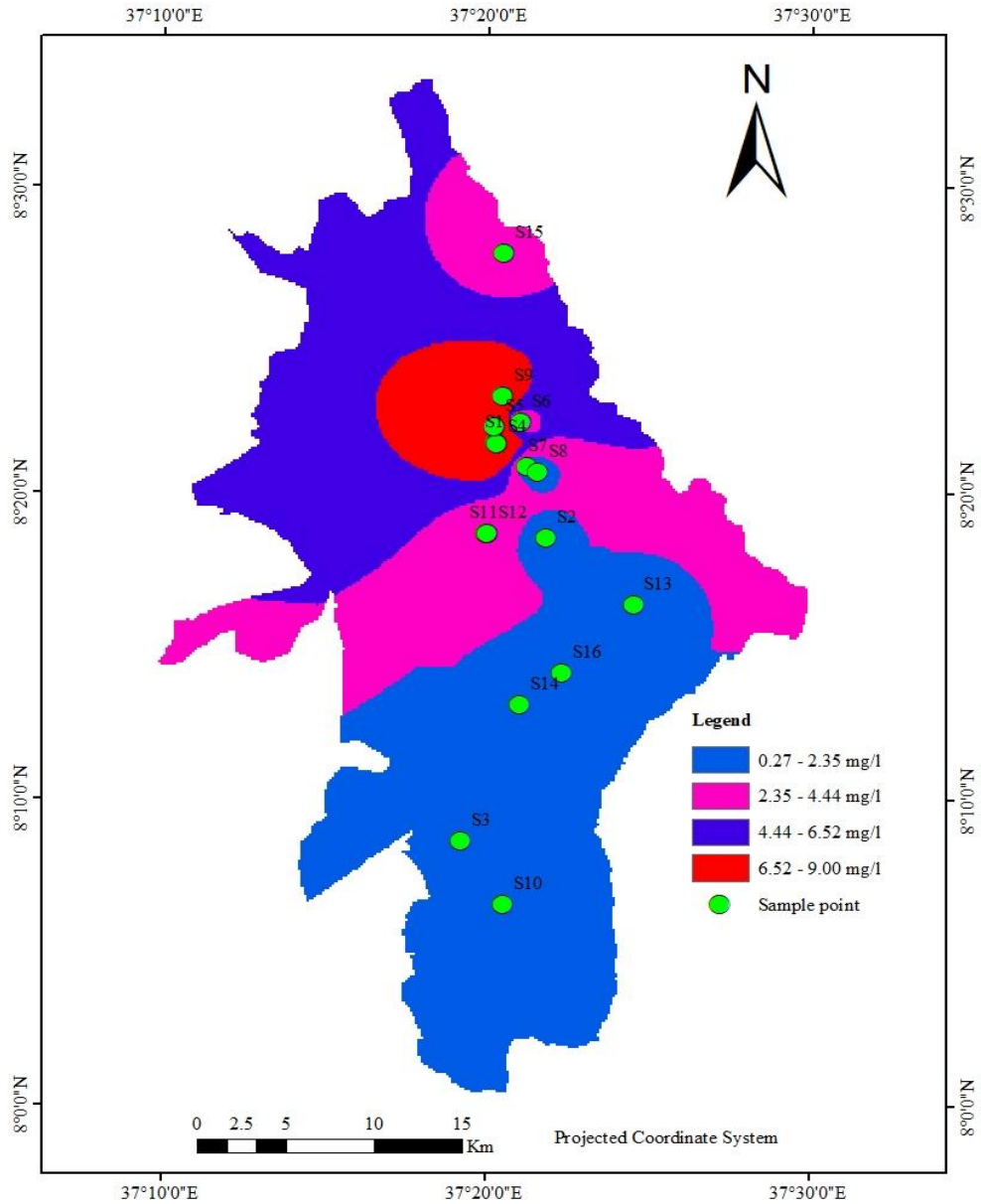


Figure 4.26 Interpolated map of F⁻ of the groundwater samples.

4.2.10 Sodium

The sodium ion, Na⁺, value of the water samples of the study area ranged from 11.03 – 452.60 mg/l with an average value of 136.76 mg/l (Table 4.18). The lowest (11.03 mg/l) and highest (452.60 mg/l) value were observed at location S10 hand dug well and S7 deep well groundwater wells respectively (Figure 4.27).

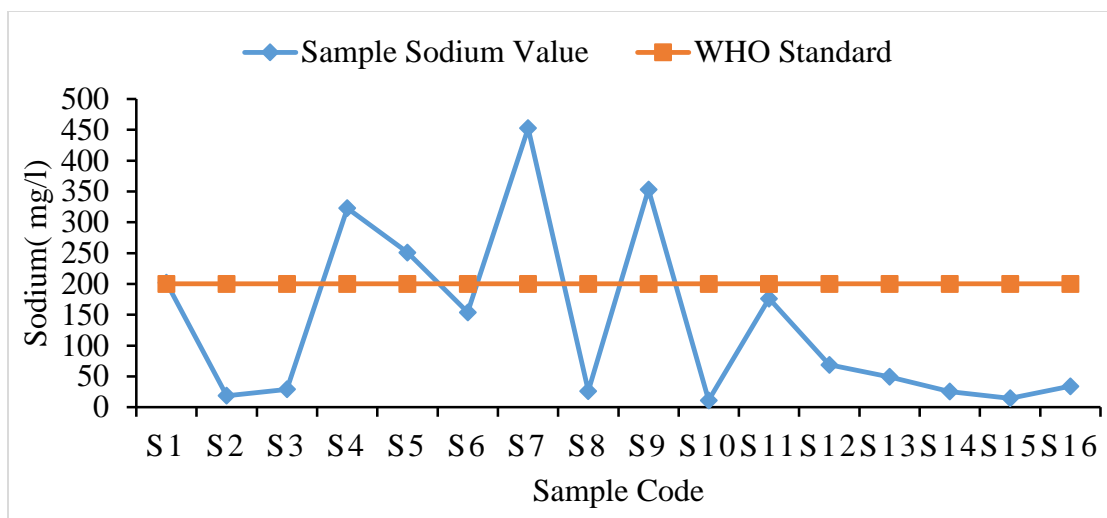


Figure 4.27 Comparison of water samples Na⁺ values with WHO (2004) standard.

The WHO (2004) standard of Na⁺ in drinking water is 200mg/l. High concentrations of Na⁺ more than 200 mg/l makes water unsuitable for domestic use (unacceptable taste), causes foaming in the presence of suspended matter, and accelerating scale formation and corrosion in boiler (Todd, 1980; Udom, 1999). Large amounts of Na⁺ can all be added to water by saline intrusion, mineral deposits, sewage effluents, and salt used in road de-icing (WHO, 1996). In the study area 31.25% of the total sample exceeds the WHO (2004) standard showing that do not fit for drinking purpose and 68.75% of the total sample lies within the limit depicting that suitable for drinking purpose.

Table 4.14 Area coverage of interpolated Na⁺ concentration.

Sodium (mg/l)	Area	
	km ²	%
11.03 – 120.25	400.70	41.25
120.25 – 229.44	218.59	22.50
229.44 – 338.64	250.27	25.77
338.64 – 452.64	101.75	10.48

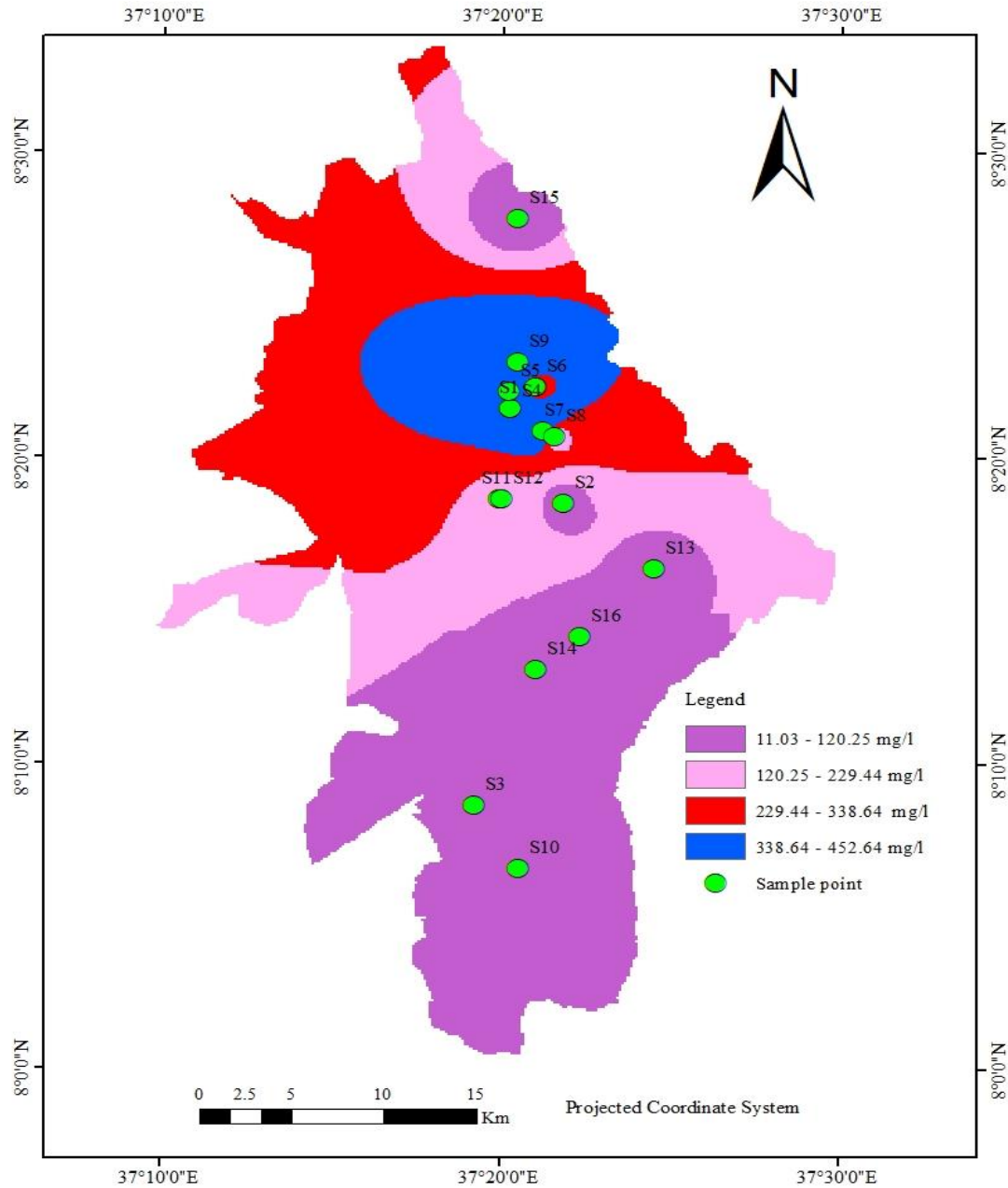


Figure 4.28 Interpolated map of Na⁺ of the groundwater samples.

4.2.11 Potassium

The potassium ion, K⁺, value of the water samples of the study area ranged from 2.13 – 14.87 mg/l with average value of 7.79 mg/l (Table 4.18). The lowest (2.13 mg/l) and highest (14.87 mg/l) value were observed at location S10 hand dug well and S4 deep well groundwater wells respectively (Figure 4.29). According to WHO (2004) the desirable limit of the K⁺ is 10 mg/l. The high concentration of K⁺ is related to chemical wastes, clay

materials and some fertilizers in the agricultural fields (Brhane, 2018). From the total samples 81.25% of the sample lies within the desirable limit which are suitable for drinking purpose and sample S4, S5 and S6 having a percentage of 18.75 exceeds the recommended value implying that not suitable for drinking use.

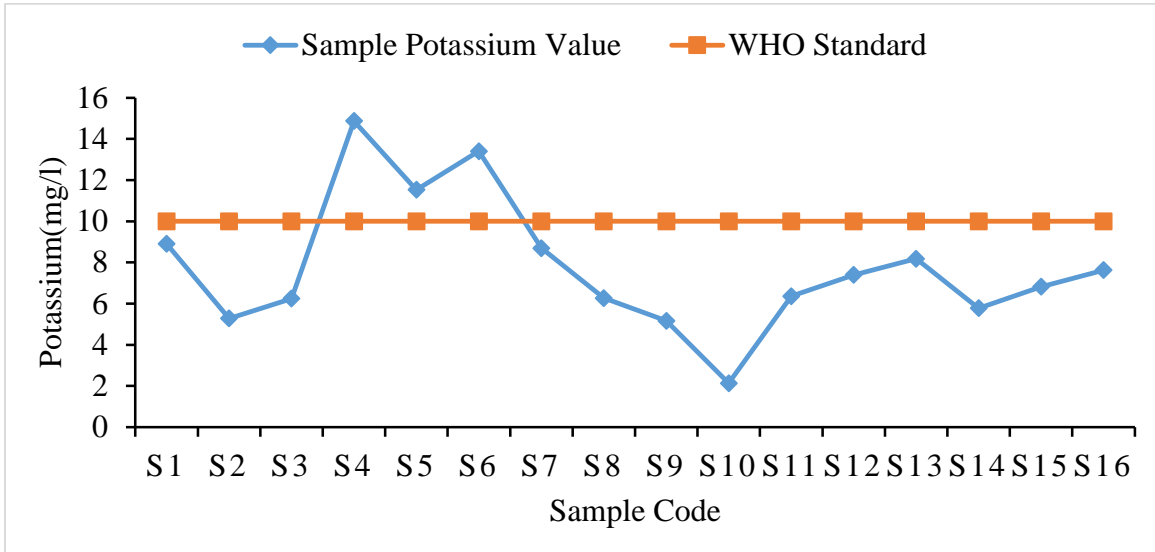


Figure 4.29 Comparison of groundwater samples K⁺ values with WHO (2004) standard.

Table 4.15 Area coverage of interpolated K⁺ concentration.

Potassium (mg/l)	Area	
	km ²	%
2.13 – 5.21	141.82	14.60
5.21 – 8.29	210.46	21.67
8.29 – 11.38	356.45	36.70
11.38 – 14.87	262.58	27.03

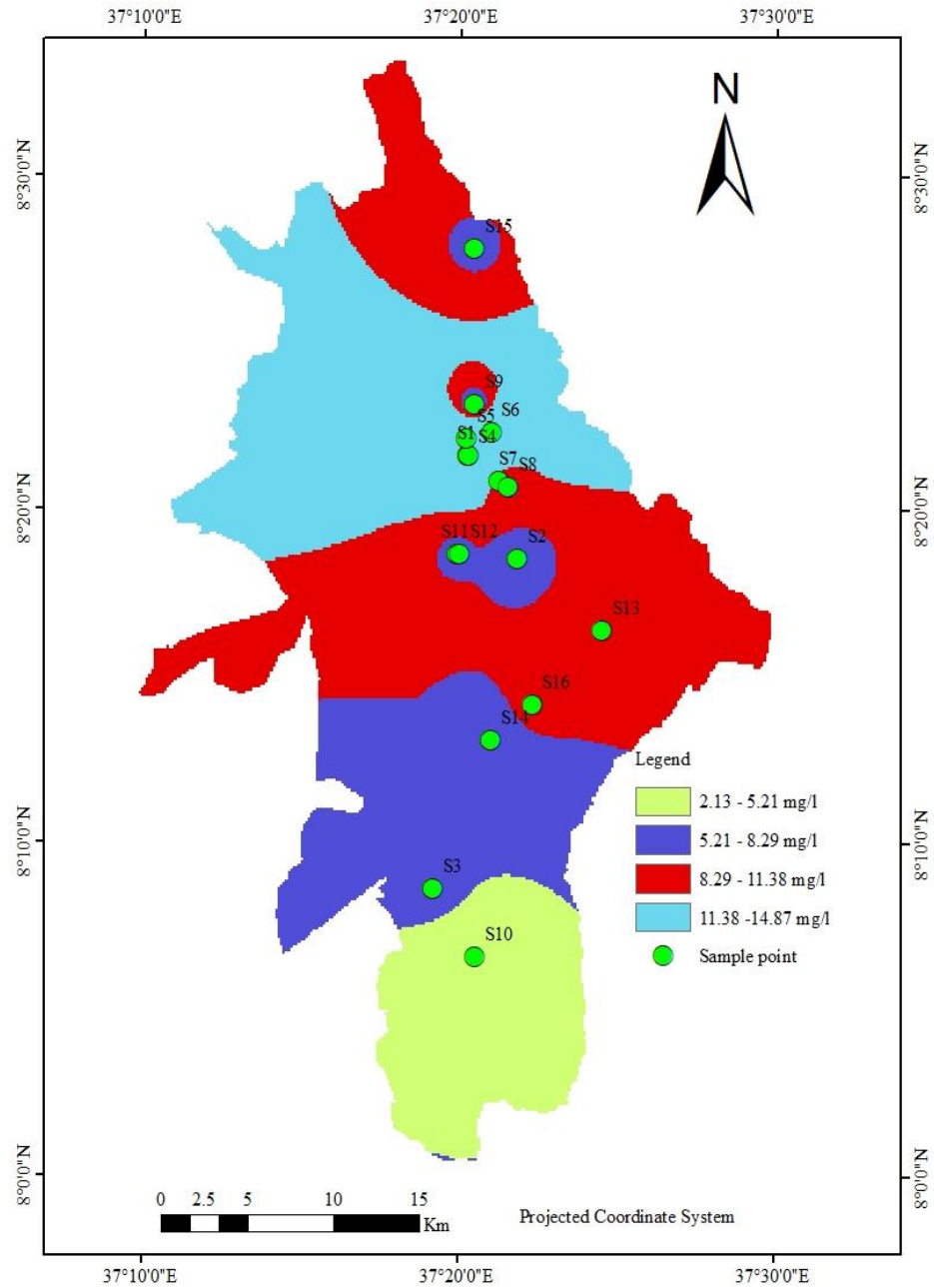


Figure 4.30 Interpolated map of K^+ of the groundwater samples.

4.2.12 Nitrate

The nitrate ion, NO_3^- , value of the groundwater samples of the study area ranged from 0.30 – 4.91 mg/l with average value of 2.54 mg/l (Table 4.18). The lowest (0.30 mg/l) and highest (4.91 mg/l) concentration were observed in S11 and S8 deep well and shallow well groundwater wells respectively (4.31). The According to WHO (2004) the desirable limit of the NO_3^- is 10 mg/l. From the point of view of suitability of the groundwater sample for

drinking purpose, all the groundwater sample of the study area were suitable for drinking purpose.

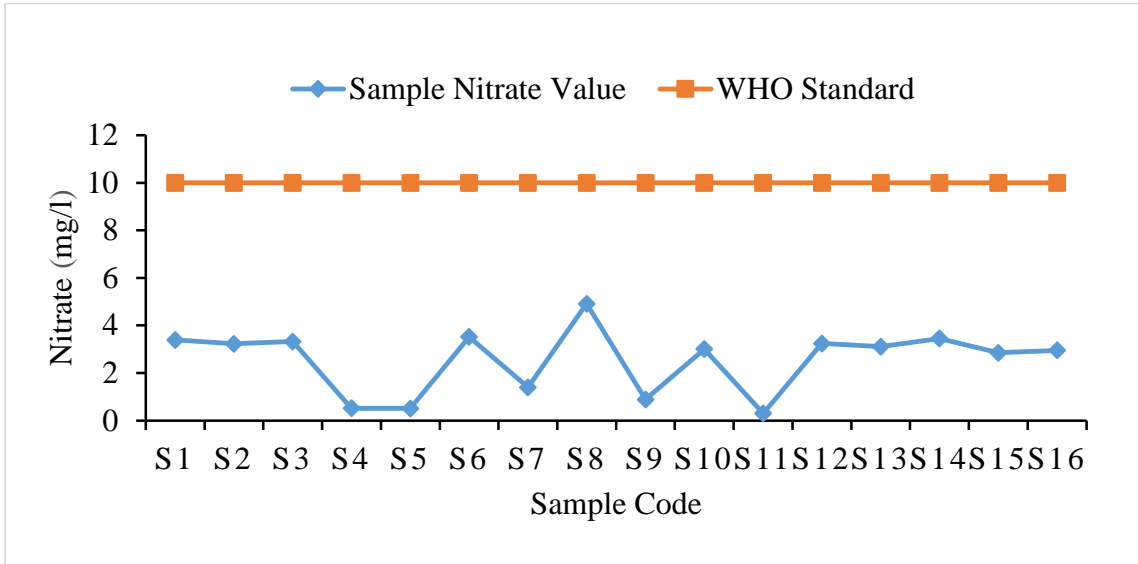


Figure 4.31 Comparison of water samples NO₃ values with WHO (2004) standard.

Table 4.16 Area coverage of interpolated NO₃ concentration.

Nitrate (mg/l)	Area	
	km ²	%
0.30 – 1.61	270.36	27.84
1.61 – 2.70	169.96	17.50
2.703 – 3.79	156.46	16.10
3.79 – 4.91	374.53	38.56

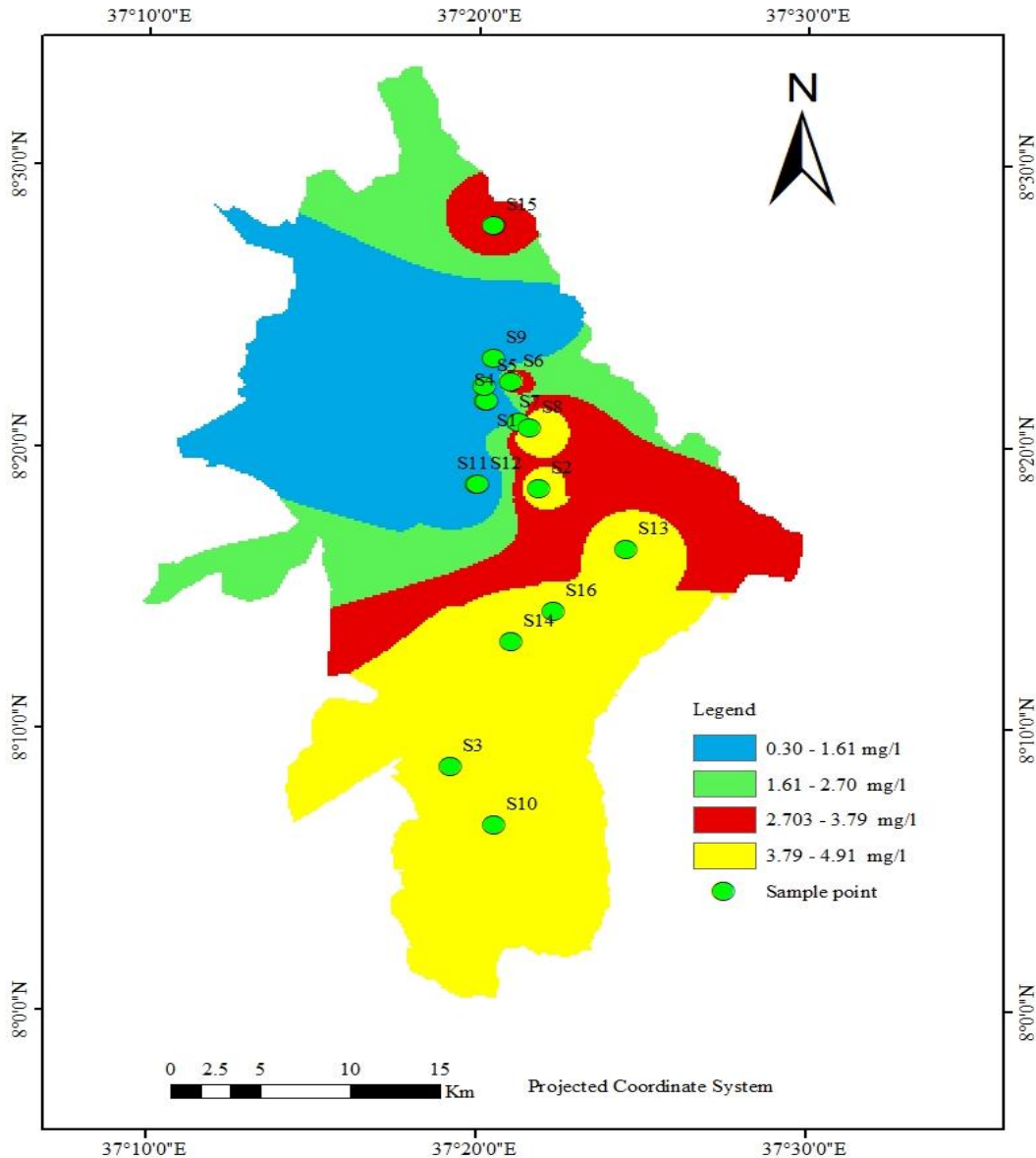


Figure 4.32 Interpolated map of NO₃⁻ of the groundwater samples.

4.2.13 Manganese

The manganese ion, Mn²⁺, value of the groundwater samples of the study area ranged from 0.02 – 0.28 mg/l with average value of 0.13 mg/l (Table 4.18). The lowest (0.02 mg/l) and highest (0.28 mg/l) concentration were observed in S5 and S9 deep well groundwater wells respectively (Figure 4.33).

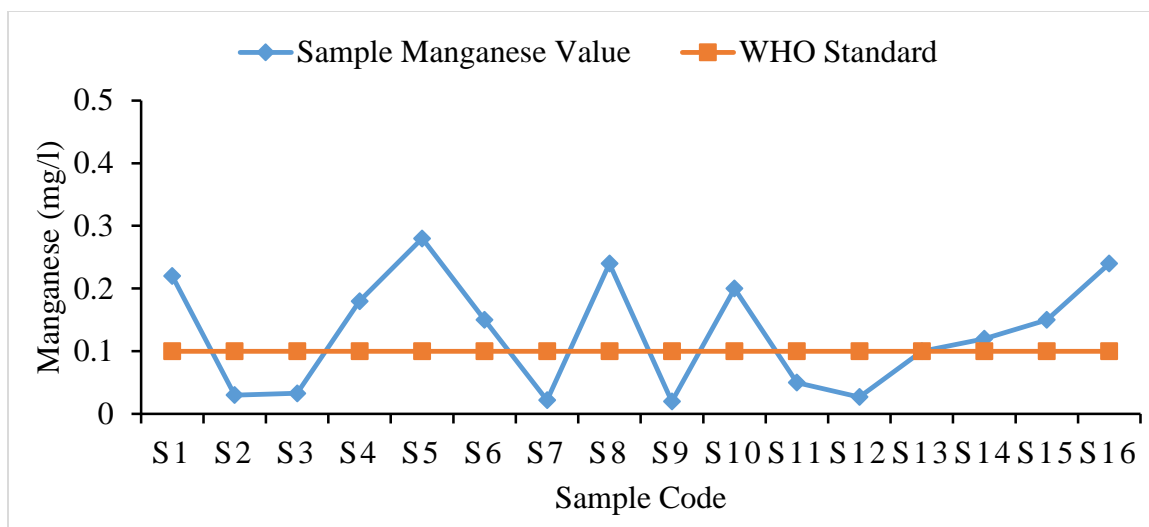


Figure 4.33 Comparison of water samples Mn²⁺ values with WHO (2004) standard.

The WHO (2004) desirable limit of manganese for drinking use is 0.1mg/l. The high concentration of Mn²⁺ may be due to the erosion of Mn²⁺ that occurs naturally in many surface water and groundwater sources and in soils into these waters (WHO, 2011). The concentration of Mn²⁺ in drinking water above 0.5 mg/l is beyond our body's tolerable limit and results in esthetic effect generation (Alhibshi *et al.*, 2014; Shrivastava, 2014). From the analyzed samples 56.25% of the sample showed values above the WHO (2004) water quality limit, therefore, not used for drinking whereas 43.75% of the total sample were within the limit and can be used for drinking purpose without any restriction.

Table 4.17 Area coverage of interpolated Mn²⁺ concentration.

Manganese (mg/l)	Area	
	km ²	%
0.00 – 0.08	80.41	8.28
0.08 – 0.14	366.59	37.74
0.14 – 0.21	460.88	47.45
0.21– 0.28	63.43	6.53

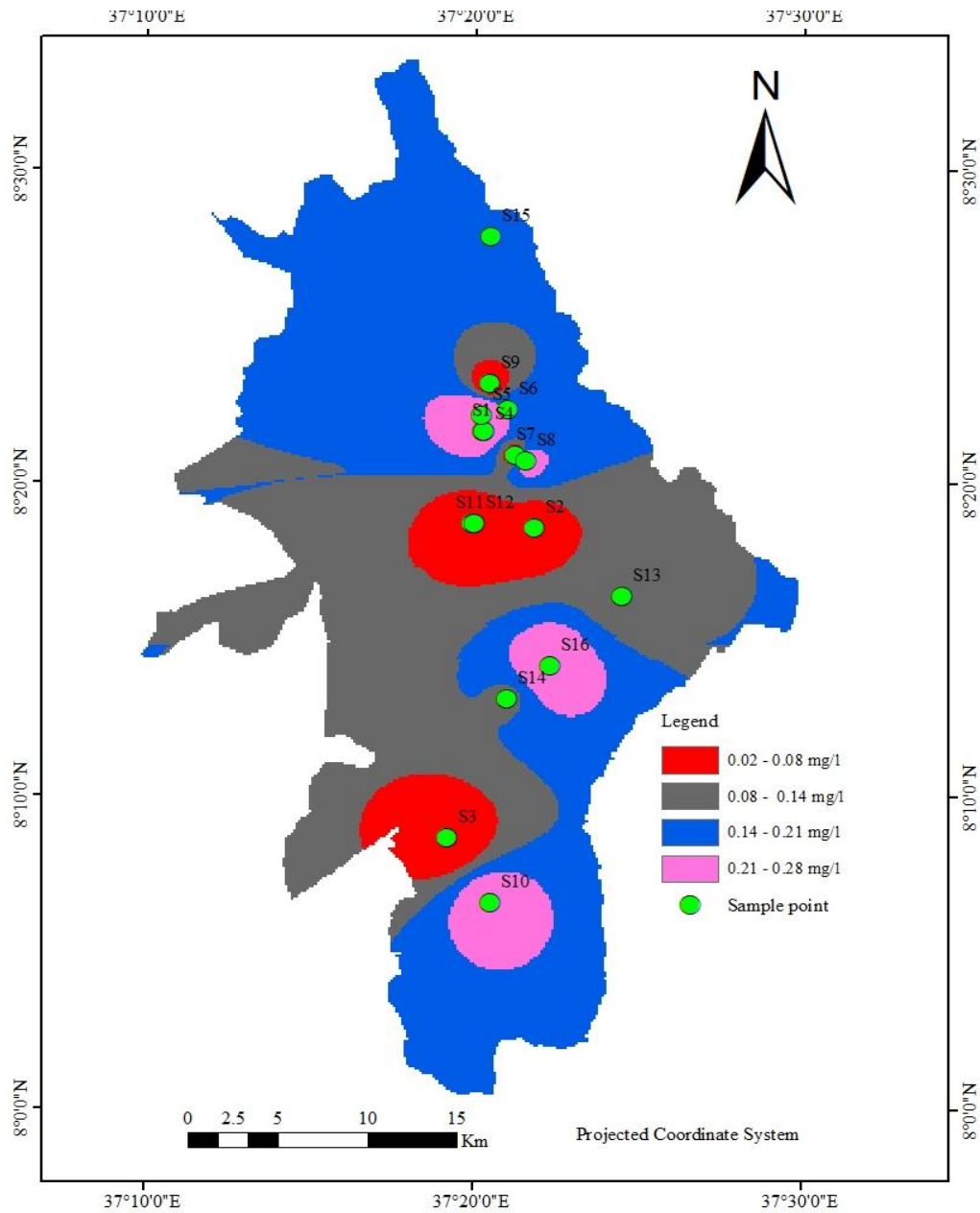


Figure 4.34 Interpolated map of Mn^{2+} of the groundwater samples.

4.2.14 Iron

The iron, Fe^{2+} , value of the groundwater samples of the study area ranged from free in S12 and S13 – 0.32 mg/l in S6 and S15 (Table 4.18). All the analyzed samples depicts that iron value were within the desirable limit based on the WHO (2004) water quality standard except for samples S6 and S15. Therefore, from the drinking purpose point of view, all most all of the groundwater samples of the study are is suitable for drinking purpose except sample S6 and S15.

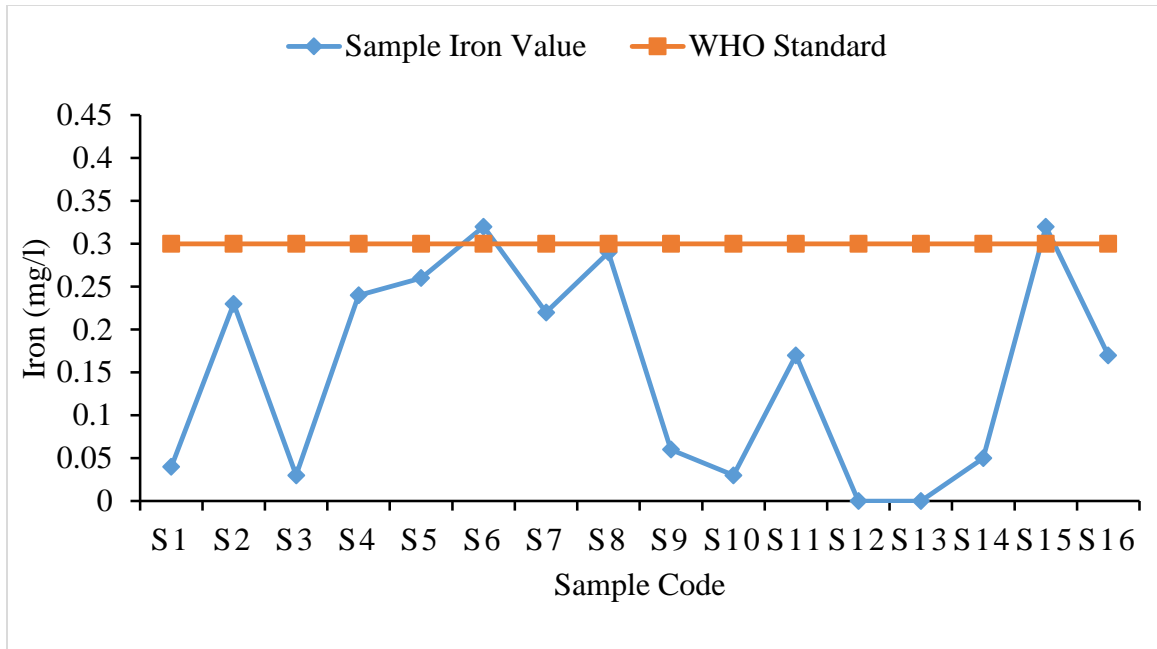


Figure 4.335 Comparison of groundwater samples Fe^{2+} values with WHO (2004) standard.

Table 4.18 Area coverage of interpolated Fe^{2+} concentration.

Iron (mg/l)	Area	
	km ²	%
0.00 – 0.08	298.52	30.73
0.08 – 0.16	223.43	23.01
0.16 – 0.23	337.92	34.79
0.23 – 0.32	111.44	11.47

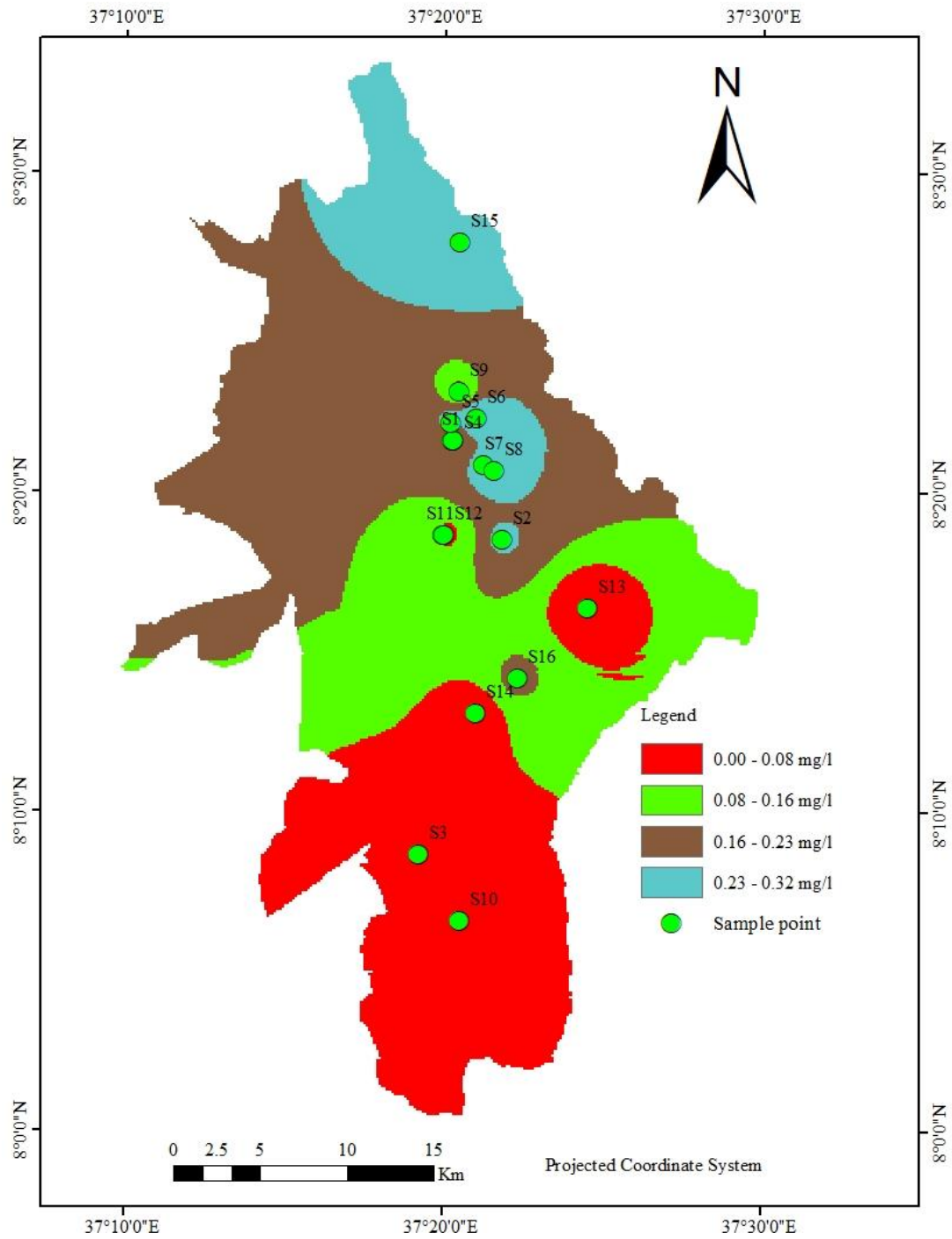


Figure 4.346 Interpolated map of Fe²⁺ of the groundwater samples.

Table 4.19 Minimum, maximum and mean physico-chemical parameters of groundwater samples in the study area and WHO standard.

Parameter	Range	Average	WHO (2004)
Temp. (°C)	19.13 – 24.60	22.51	15
pH	6.60 – 7.54	7.13	6.5- 8.5
E.C (µS/cm)	142.3 – 1651.0	699.33	250
TDS (mg/l)	115.1 – 1231.0	485.37	500
Turbidity (NTU)	2.40 – 54.7	20.52	5
TH (mg/l)	42.9 – 275.2	126.02	300
TA (mg/l)	43.13 – 632.2	238.59	200
Ca ²⁺ (mg/l)	5.28 – 153.5	44.06	75
Mg ²⁺ (mg/l)	3.17 – 124.8	31.67	50
Cl ⁻ (mg/l)	5.13 – 39.93	20.14	250
SO ₄ ²⁻ (mg/l)	0 – 21.9	4.64	200
CO ₃ ⁻ (mg/l)	0 – 0	0	0
HCO ₃ ⁻ (mg/l)	45.2 – 952.2	339.84	300
F ⁻ (mg/l)	0.27 – 9.0	1.88	1.5
Na ⁺ (mg/l)	11.03 – 452.6	136.76	200
NO ₃	0.30 – 4.91	2.54	10
K ⁺ (mg/l)	2.13 – 14.87	7.79	10
Mn ²⁺ (mg/l)	0.02 – 0.28	0.13	0.1
Fe ²⁺ (mg/l)	0 – 0.32	0.15	0.3

4.3 Hydro-geochemical Facies

The groundwater samples of the study area were dominated by sodium type followed by no dominant type, magnesium type and calcium type whereas the major anions of all the water sample were dominated by bicarbonate type. The groundwater in the area was majorly Ca-HCO₃⁻ facies followed by Na-HCO₃⁻, mixed type (Na-Ca-HCO₃⁻) facies and in between the mixed type and Ca-HCO₃⁻ facies in their order of dominance respectively (Figure 4.37).

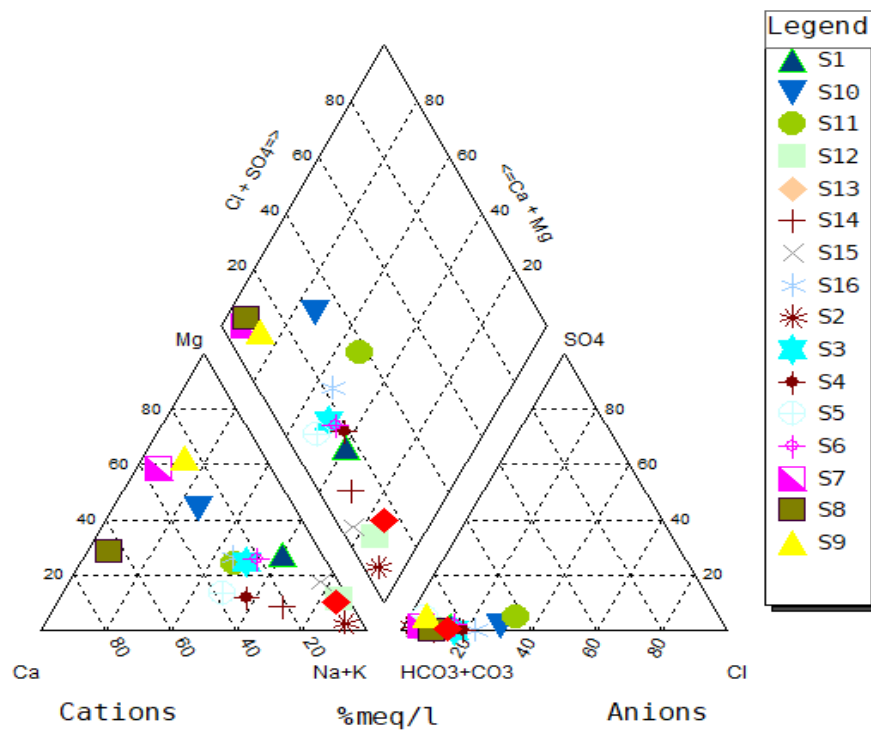


Figure 4.357 Piper diagram of groundwater samples in the study area.

The geochemical facies in the piper diagram supports the dominance of weak acid over strong acids and the contents of alkalis (Na^+ and K^+) are higher than those of the alkaline earths (Ca^{2+} and Mg^{2+}).

Table 4.20 Groundwater type of the water sample in the study area.

Sample code	Site name	Source type	Water type
S1	Dimtu 1	Protected spring	Na-Mg-HCO ₃
S2	Shawaber	Hand dug well	Mg-Ca-Na-HCO ₃
S3	Haro	Protected spring	Na-Ca-Mg-HCO ₃
S4	Dimtu 2	Deep well	Na-HCO ₃
S5	Keta Dire	Deep well	Na-HCO ₃
S6	Boso	Shallow well	Na-Ca-HCO ₃
S7	Laga Botor	Deep well	Na-Mg-HCO ₃
S8	Kiticho	Shallow well	Na-Ca-Mg-HCO ₃
S9	Yatu	Deep well	Na-HCO ₃
S10	Cora	Hand dug well	Na-Ca-Mg-HCO ₃
S11	Wayu	Deep well	Na-Ca-HCO ₃
S12	Odoluge	Shallow well	Na-Ca-HCO ₃
S13	Gudatu	Shallow well	Na-Mg-Ca-HCO ₃
S14	Kalicha	Shallow well	Mg-Ca-HCO ₃
S15	Germa	Shallow well	Ca-Mg-HCO ₃
S16	Dile	Shallow well	Mg-Ca-HCO ₃

4.4 Principal Component of the Groundwater Samples

For the study, the Scree plot showed a pronounced change of slope after the five eigenvalue. The first PC1 accounting for 29.7 % of the total variance explains the greatest variance and had strong positive loadings of Na⁺, TDS, EC, HCO₃⁻ and pH and moderate positive loadings of F⁻ and TA. PC2 accounts 18.2% of the total variance characterized by highly strong positive loading of TH, Mg²⁺ and Ca²⁺. PC3 with a total variance of 14% is characterized by strong positive loadings of Mn²⁺ and moderate loadings of K⁺ and F⁻. PC4, which explains 12.5 of total variance had strong positive loading of turbidity and SO₄²⁻ and had strong negative loading of Cl⁻. PC5, which explains 6.6% total variance had strong and moderate positive loadings of Fe²⁺ and temperature respectively and had moderate negative loadings of pH.

Table 4.21 PC Loadings and explained variance for the first five PCs of the data set.

Variables	PC1	PC2	PC3	PC4	PC5
Temp.	0.264	0.140	-0.095	0.082	0.573
pH	0.802	-0.118	0.054	-0.055	-0.508
EC	0.875	0.090	0.016	-0.010	0.273
TDS	0.890	-0.022	0.024	-0.071	0.064
Turb.	0.195	-0.190	0.325	0.784	0.196
TH	-0.118	0.918	0.100	0.200	0.190
TA	0.639	0.299	-0.509	-0.055	0.064
Ca ²⁺	-0.061	0.861	-0.194	-0.293	0.138
Mg ²⁺	0.088	0.866	0.062	0.083	-0.043
Cl ⁻	0.287	0.035	0.021	-0.754	0.103
SO ₄ ²⁻	0.145	0.355	-0.182	0.751	-0.179
HCO ₃ ⁻	0.808	0.275	-0.308	0.287	0.171
F ⁻	0.645	-0.201	0.566	0.004	0.028
Na ⁺	0.907	-0.251	0.125	-0.013	0.109
K ⁺	0.414	-0.054	0.690	-0.100	0.233
Mn ²⁺	-0.267	0.176	0.859	0.129	-0.001
Fe ²⁺	0.004	0.043	0.370	-0.268	0.850
Eigenvalue	5.043	3.092	2.382	2.132	1.122
Total variance (%)	29.667	18.190	14.015	12.539	6.602
Cumulative % variance	29.667	47.858	61.872	74.411	81.013

Bold values represent strong loadings.

4.5 Groundwater Suitability for Irrigation Purpose

4.5.1 Electrical Conductivity

The electric conductivity, EC, of the study area ranged from 142.3 – 1651 $\mu\text{S}/\text{cm}$ with an average value of 699.33 $\mu\text{S}/\text{cm}$ (Table 4.26). According to Richards (1954), classification of irrigation water based on electrical conductivity 25% of the total sample were classified as excellent water class with electric conductivity less than 250 $\mu\text{S}/\text{cm}$, 25% of the water sample were classified as good water class with electric conductivity ranged 250 – 750 μS

/cm and 50% of the water sample were categorized as permissible water class with electric conductivity ranged 750 – 2250 $\mu\text{S}/\text{cm}$ implying that all the groundwater sample were suitable for irrigation water purpose.

Using GIS software, interpolation method was used to know the suitability of the groundwater source of the study area for irrigation water using the known value of sixteen groundwater sample. The result of suitability evaluation of the study area were shown in Table 4.21 and Figure 4.38.

Table 4.22 Classification of irrigation water based on EC (Richards 1954).

EC Ranges ($\mu\text{S}/\text{cm}$)	Water Class	Area	
		km^2	%
< 250	Excellent	415.00	42.73
250 – 750	Good	551.30	56.76
750 – 2250	Permissible	5.01	0.51

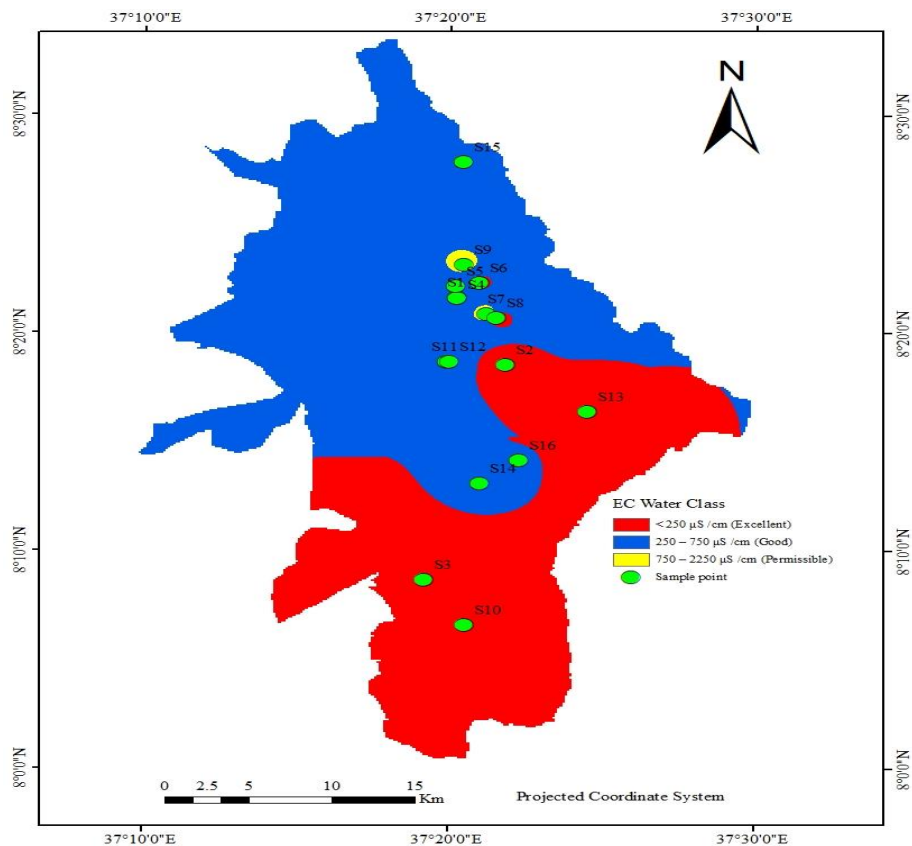


Figure 4.368 Interpolated map of EC of the groundwater samples.

4.5.2 Sodium Adsorption Ratio

The sodium adsorption ratio, SAR, value ranged from 0.27 – 18.01 (Table 4.26). The lowest and highest were observed in S15 shallow well and S9 deep well groundwater sources with SAR value of 0.27 and 18.01 respectively. According to Richards (1954), irrigation water classification based on SAR sample S1, S2, S3, S6, S8, S10, S11, S12, S13, S14, S15 and S16 that means 75% of the total water sample were classified as excellent water class with a SAR value of less than 10 whereas sample S4, S5 and S7 that means 18.75% of the total were classified as good water class with a SAR value ranged 10 – 18 and only sample S9 lies in the permissible water class which was within the range of 18 – 26. Accordingly the groundwater sample of the study area were suitable for irrigation purpose. Using interpolation technique the evaluation SAR value of the study area water source were shown in Table 4.22 and Figure 4.39.

Table 4.23 Classification of irrigation water based on SAR value (Richards 1954).

SAR Value	Water Class	Area	
		km ²	%
Less than 10	Excellent	703.80	72.46
10 – 18	Good	261.56	26.93
18 – 26	Permissible	5.95	0.61

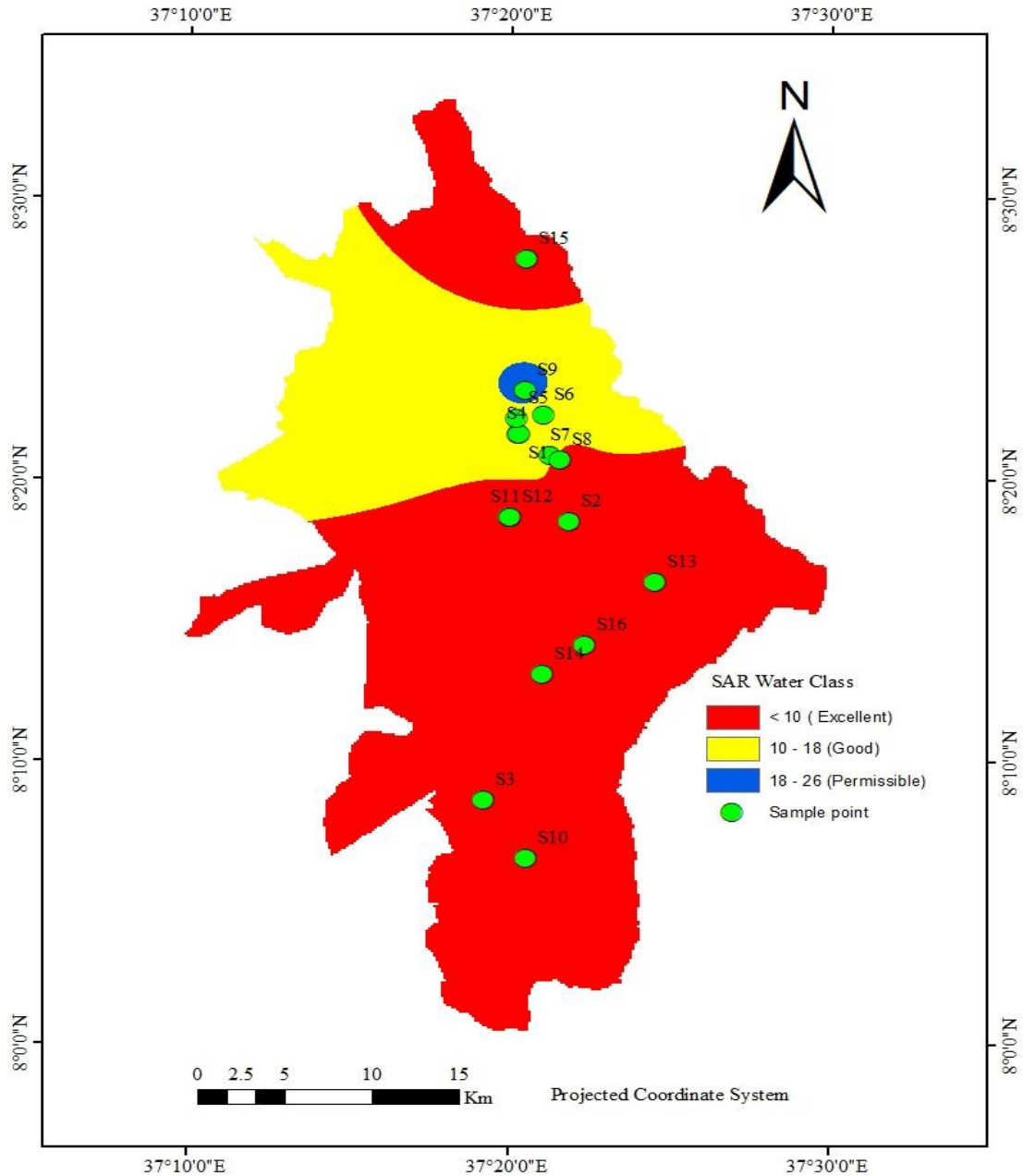


Figure 4.37 Interpolated map of SAR of the groundwater samples.

4.5.3 Magnesium Hazard

The magnesium hazard, MH, value of the groundwater samples ranged from 26.59 – 77.78 (Table 4.26). Water sample S1, S2, S4, S5, S7, S13, S14 and S16 had magnesium hazard value of greater than 50% thus unsuitable for irrigation purpose whereas water sample S3, S6, S8, S9, S10, S11, S13 and S15 had magnesium hazard value of less than 50% implying that suitable for irrigation purpose. More Mg^{2+} present in waters affects the soil quality

converting it to alkaline and decreases crop yield (Joshi *et al.*, 2009). The magnesium hard of the groundwater sample of the study area were interpolated to the study area and results were shown in Table 4.23 and Figure 4.40.

Table 4.24 Classification of irrigation water based on MH (Szabolcs, 1964).

MH Value	Suitability	Area	
		km ²	%
< 50	Suitable	631.09	64.97
>50	Unsuitable (harmful)	340.22	35.03

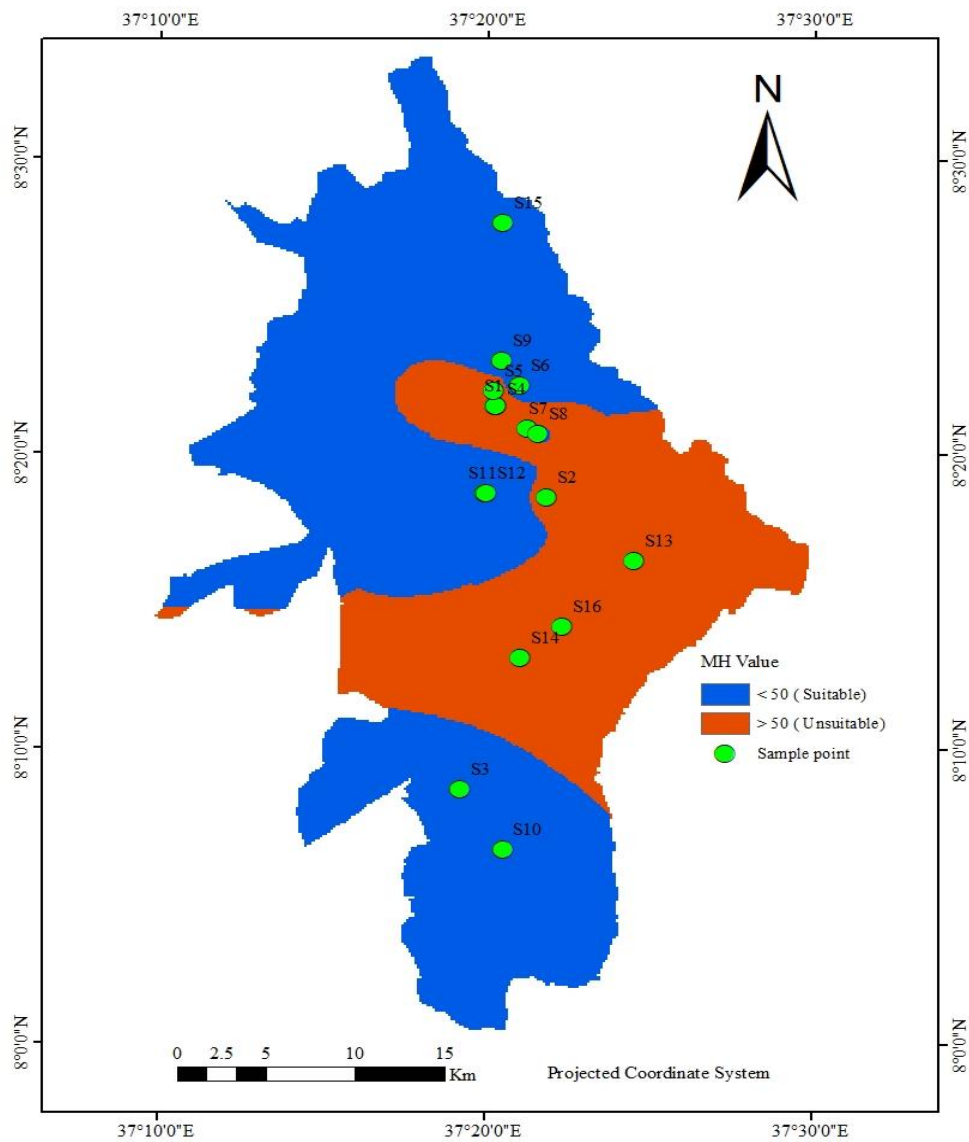


Figure 4.38 Interpolated map of MH of the groundwater samples.

4.5.4 Residual Sodium Carbonate

The residual sodium carbonate, RSC, value of the groundwater samples of the study area ranged from -8.45 – 14.17 with a minimum (-8.45) and maximum (14.17) value of RSC in S14 shallow well and S9 deep well groundwater sources respectively (Table 4.26). Depending on the classification of the groundwater quality for irrigation purpose of the water sample and the study area were classified below (Table 4.24) and (Figure 4.41).

Table 4.25 Suitability of groundwater for irrigation according to RSC (Reddy and Reddy, 2011).

Class	Quality	Groundwater Sample	Area	
			km ²	%
< 0	Very good	S1, S2, S3, S8, S11, S14, S15 and S16	126.21	13.00
0 – 1.25	Good	S10 and S13	462.48	47.61
1.25 – 2.5	Medium	S5 and S6	350.96	36.13
> 2.5	Unsuitable	S4, S7, S9, and S12	31.66	3.26

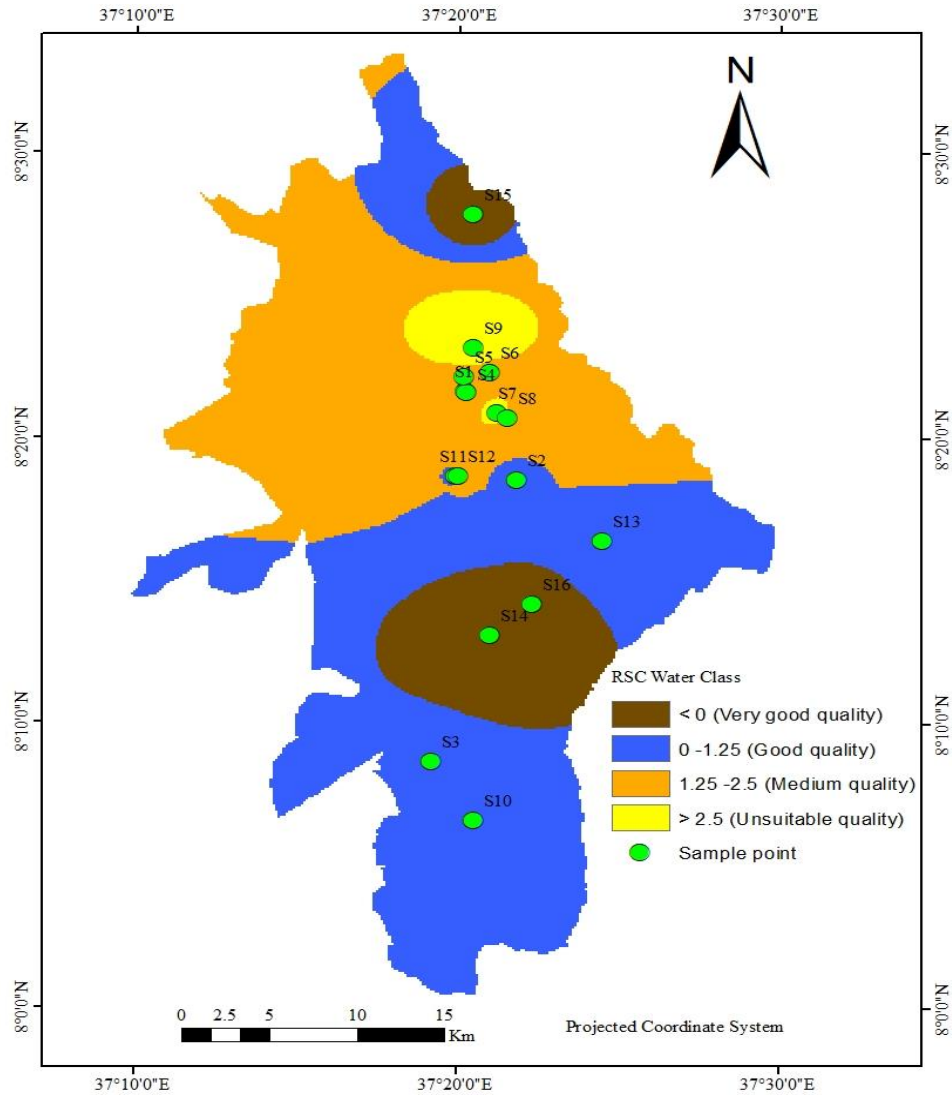


Figure 4.41 Interpolated map of RSC of the groundwater samples.

4.5.5 Kelley's Ratio

According to Kelley *et al.* (1940), the suitability of the groundwater sample and the study area were classified below (Table 4.25) and Figure (4.40).

Table 4.26 Classification of irrigation water quality based on (Kelley *et al.*, 1940).

KR	Water sample	Remark	Area	
			km ²	%
< 1	S2, S8, S10, S12, S13, S14, S15, S16	Suitable	620.48	63.88
> 1	S1, S3, S4, S5, S6, S7, S9, S11	Unsuitable	350.83	36.12

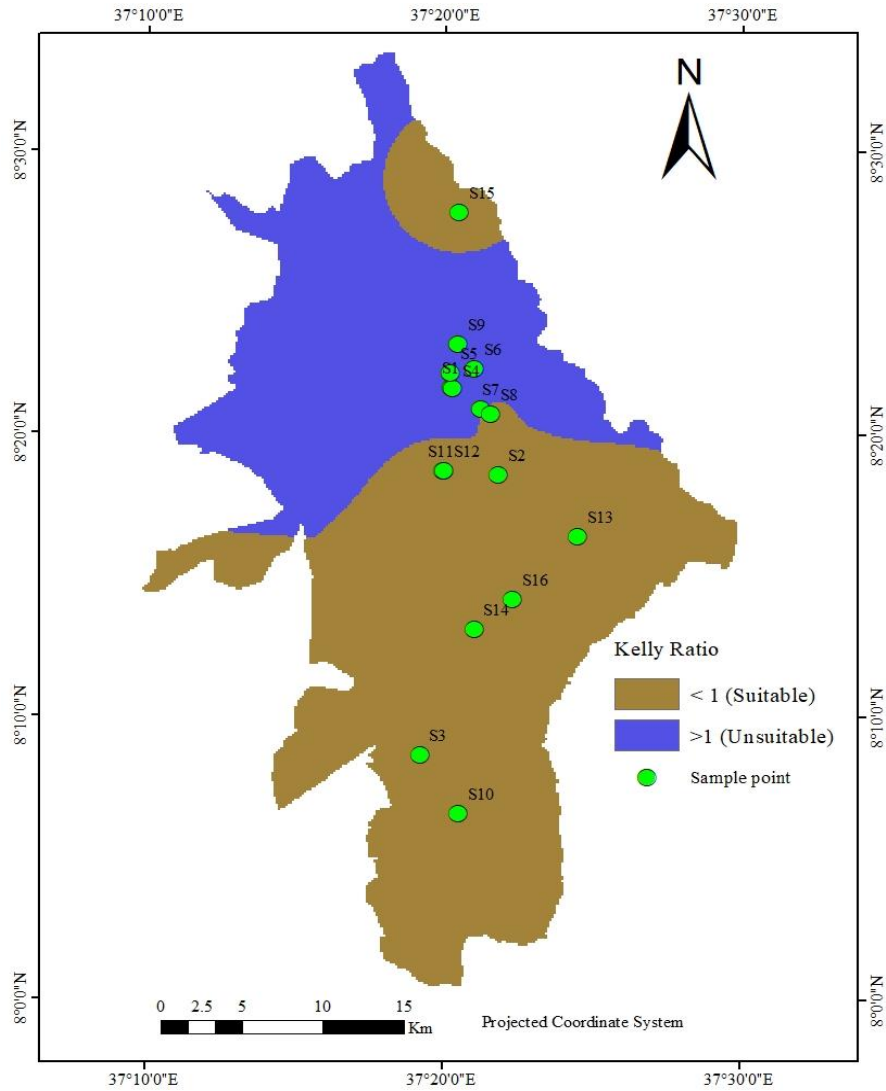


Figure 4.42 Interpolated map of KR of the groundwater samples.

Table 4.27 Minimum and maximum value of irrigation water quality parameters of the study area.

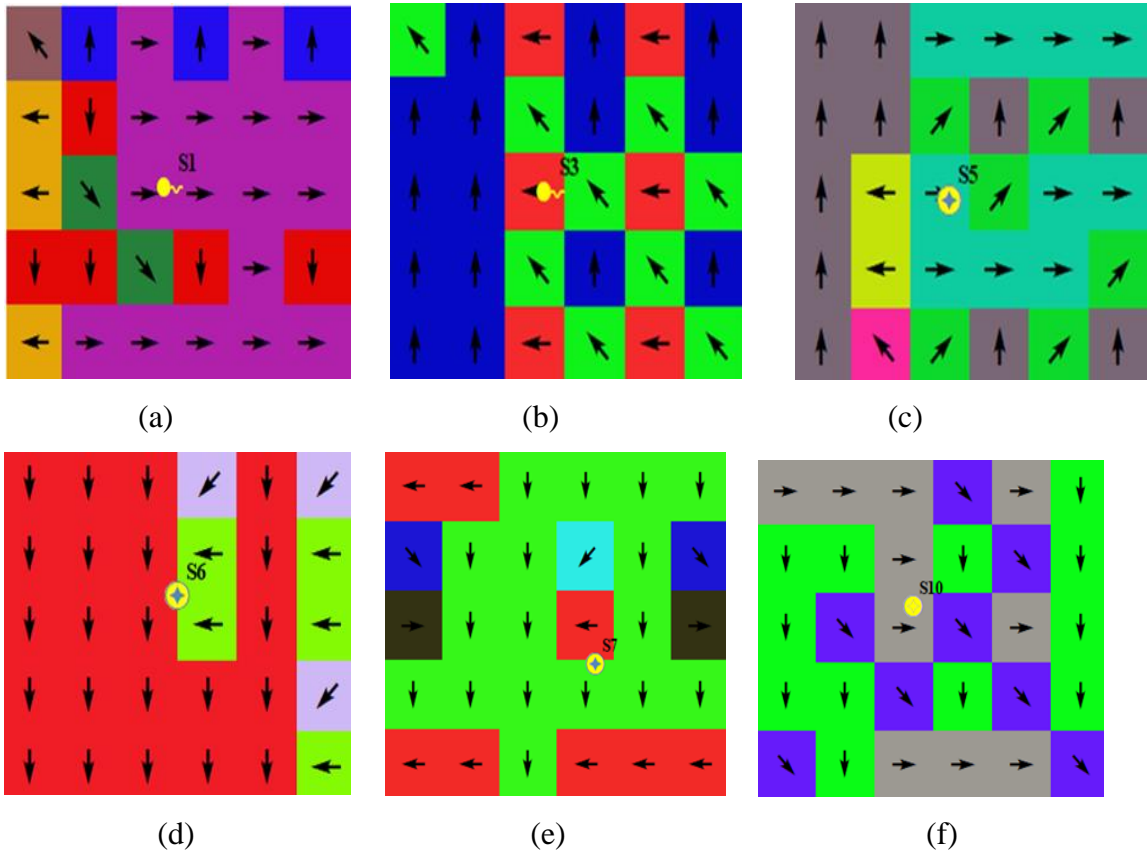
Parameters	Range
Electric Conductivity	141.7 – 1651
Sodium Adsorption Ratio	0.27 – 18.01
Magnesium Hazard	26.59 – 77.78
Residual Sodium Carbonate	-8.45 – 14.17
Kelly Ratio	0.06 – 10.67

4.6 Potential Pollution Risk Assessment

Based on the single flow direction or D8 algorithm methods of flow direction determination results were classified into four classes depending on the pollution risk level as no, low, medium and high potential for pollution.

4.6.1 No Potential for Pollution

From the sampled groundwater samples of study area, sample S1, S3, S5, S6, S7, S10, S14, and S15 were classified as no potential for pollution because no neighboring cells are draining into the center cell sample containing the well point (Figure 4.43) showing that the cell containing the well point are at high elevation than the eight neighboring cells and were located in area where covered by vegetation as well as in light agricultural activities.



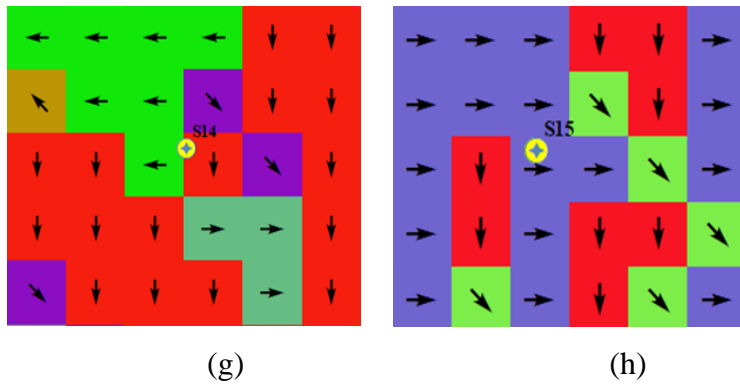


Figure 4.393 Flow pathway of grid cell, containing well points.

4.6.2 Low Potential for Pollution

Groundwater sample point which were classified or assigned under this category were sample S8, S12 and S13 in which only one cell out of eight neighbour cells from south east and west direction respectively were routed to the center cell as shown in (Figure 4.44). Both S8 and S12 were found in light agricultural activities areas whereas sample S13 were found in intensive agricultural activities.

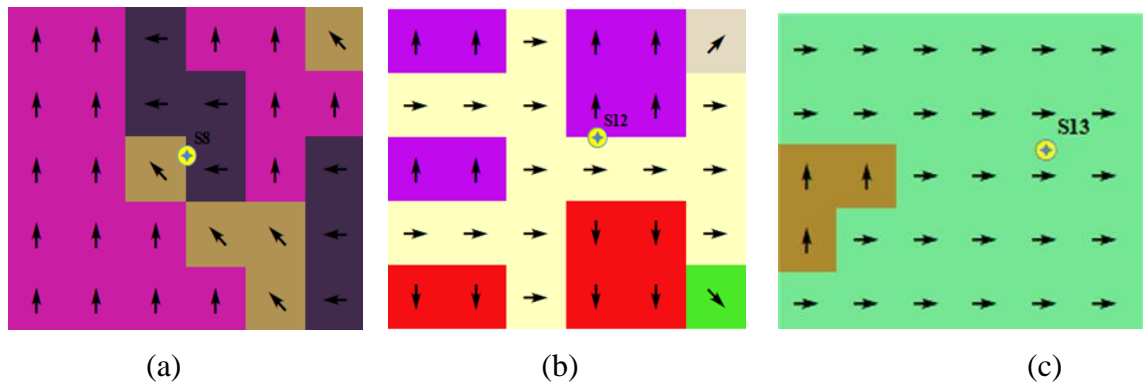


Figure 4.404 Cell receiving only a single inward flows.

4.6.3 Medium Potential for Pollution

Four groundwater samples (S2, S4, S9, and S11) were identified under this category where the center cell, containing the well point were receiving inward flow from a single flow out of eight neighboring cells but with accumulated flows shown in (Figure 4.45). Relatively both sample S4 and S9 were more vulnerable to pollution than S2 and S11 because both were found in town in which cells routing in to the center cell may carry contaminants from open wastewater discharge, leachate from disposal of solid wastes and light agricultural activities.

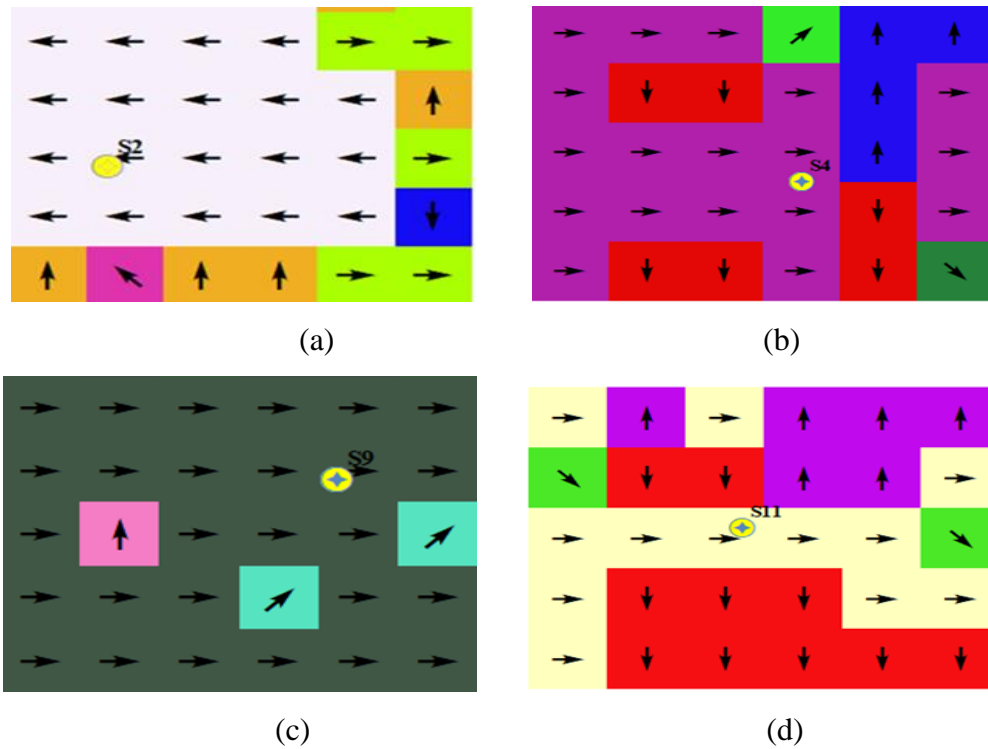
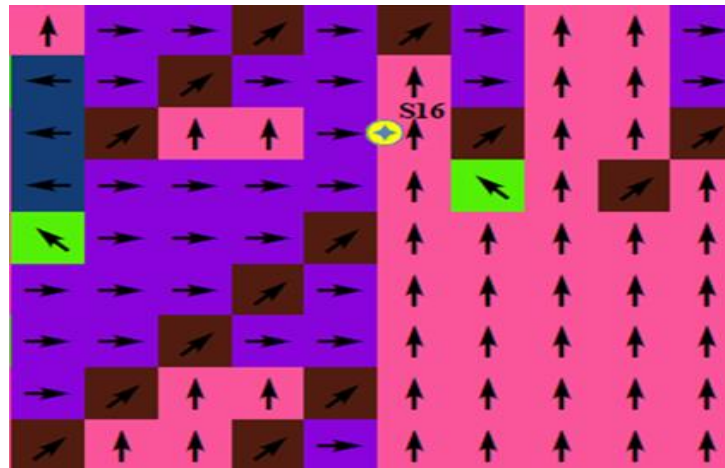


Figure 4.415 Cell receiving a single inward flow with accumulated flows.

4.6.4 High Potential for Pollution

From the total groundwater sampled for the study, only one sample (S16) was identified more prone to pollution where accumulated flow pathways from south, southeast and west direction were routed into the cell containing sample S16 shown in (Figure 46). Sample S16 were found in intensive agricultural area. In the district, blended fertilizer containing nitrogen, phosphorus, sulfur and boron (NPSB), urea (nitrogen, phosphorus and potassium) and herbicide particularly 2 4 D were being used annually to improve productivity and quality of agricultural activities (Source: Botor Tolay District Agricultural Office). Therefore, the potential to be polluted of sample S6 with these materials would be high.



(a)

Figure 4.426 Cell receiving flow from three neighboring cell with accumulated flows.

4.7 Model Validation

The potential pollution risk of all the groundwater sample were analysed and validated using the the flow direction algorithm and aspect respectively and results depict that for all groundwater sample, the flow direction of cell containing groundwater and the aspect or slope direction of the earth surface were found in the same direction showing that modeling of the potential pollution risk of the the grounwater sample were accurate. However, five of the groundwater sample (S1,S2, S3, S4 and S5) were taken out of the whole groundwater sample (Figure 4. 48) to show and compare the flow direction of the cells containing the water sample and the aspect of Digital Elevation Model (Figure 4. 47).

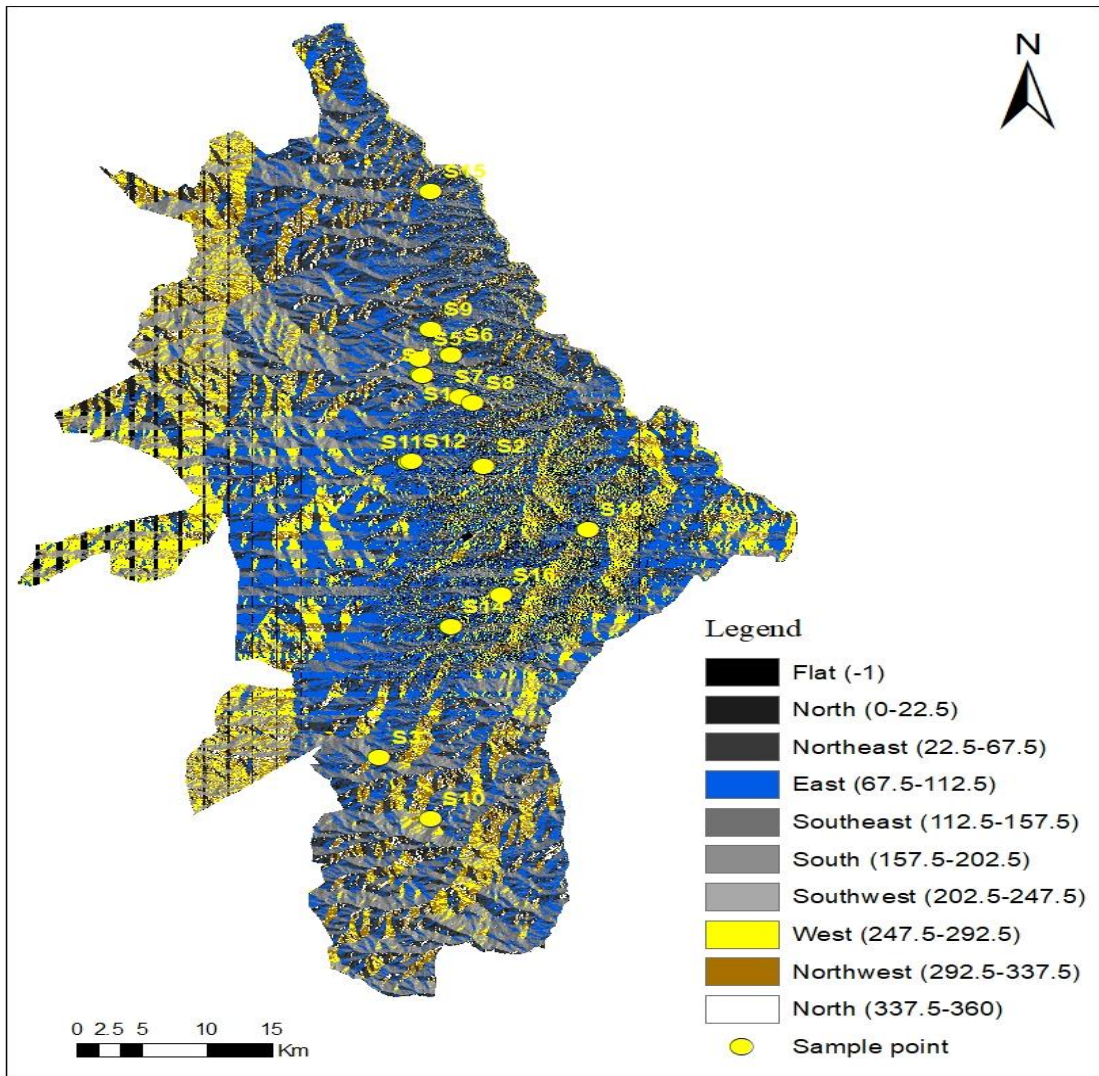
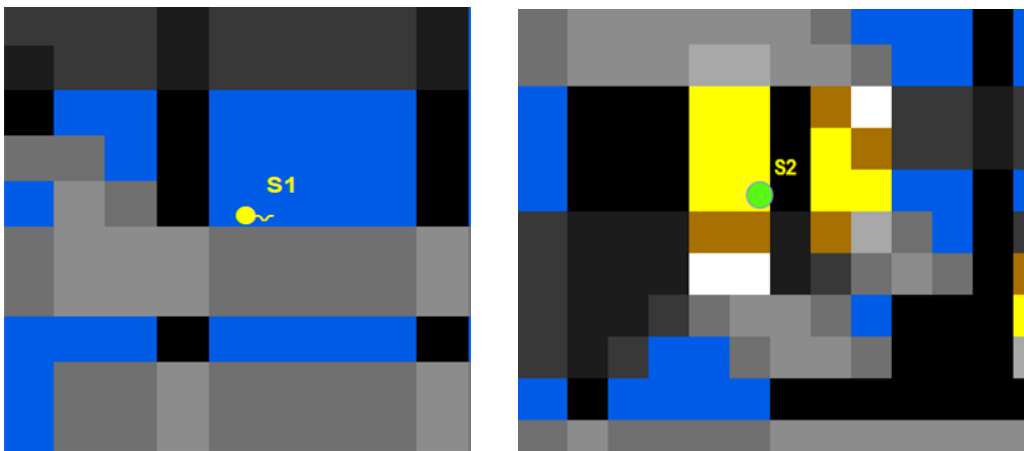


Figure 4.437 Aspect, showing slope direction earth surface of the study area.



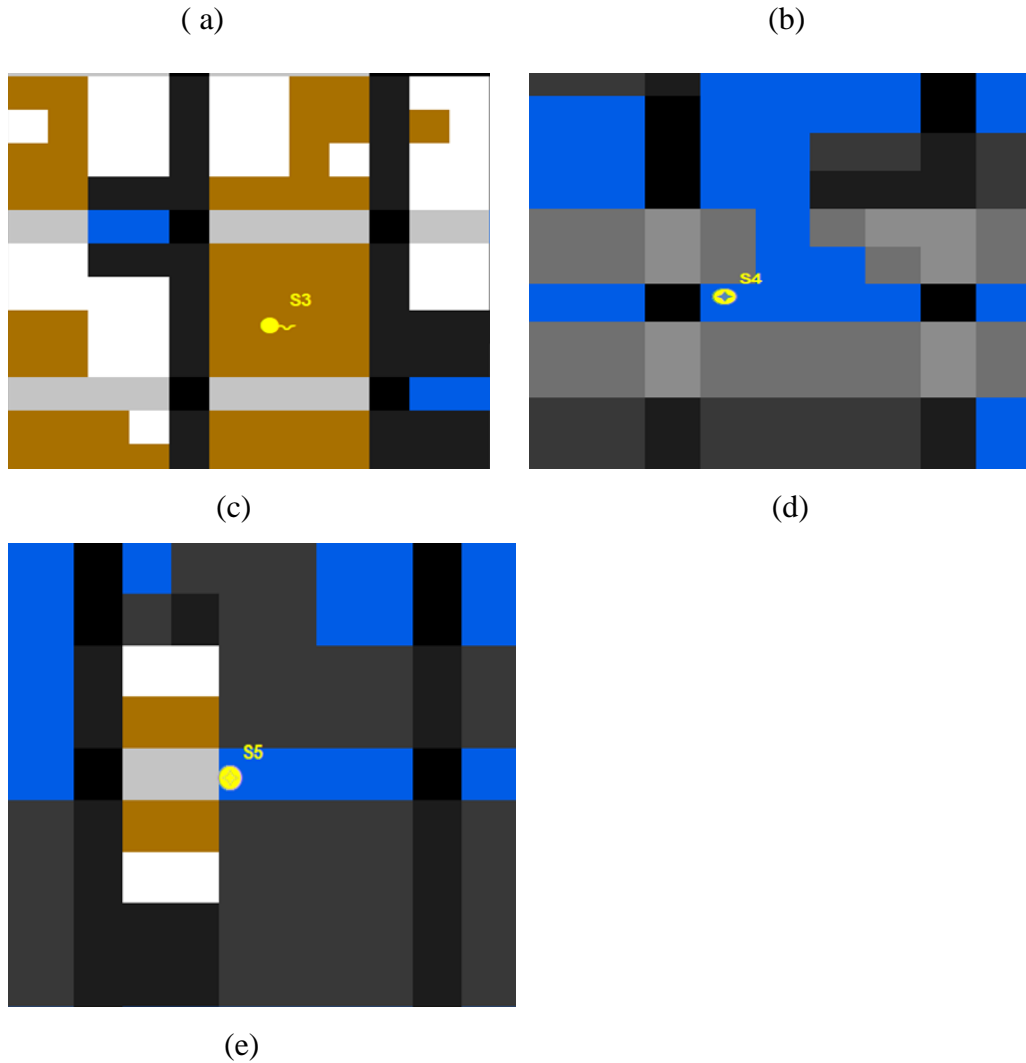


Figure 4.448 Sample clipped from aspect showing cell flow direction.

4.8 Well Depth and Nitrate Concentration of the Water Samples

Nitrate concentration were graphically plotted to show the relationship it had with well depth of the groundwater samples. There was a general trend of decreasing nitrate with increasing well depth across all study area aquifers (Figure 4.49). This reflects the greater susceptibility of protected springs, hand dug wells and shallow groundwaters to overlying landuses, and the dominant effect of natural denitrification processes on deeper groundwaters.

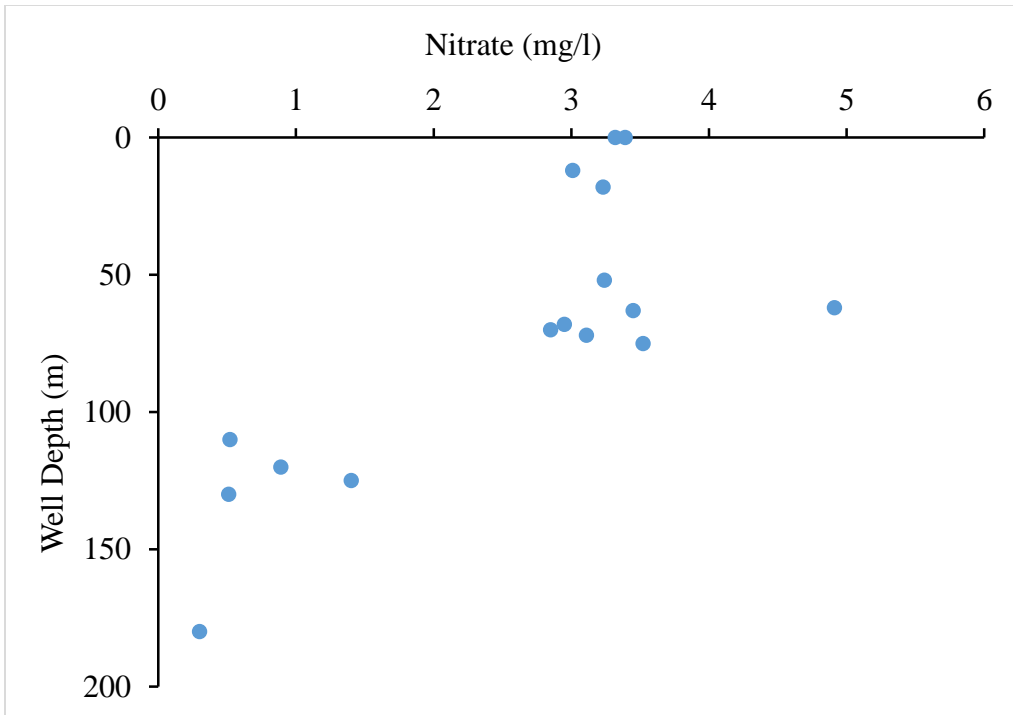


Figure 4.459 Well depth vurses nitrate concentration of groundwater samples.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the current study, the physico-chemical parameters were considered for investigation which include temperature, pH, electrical conductivity, total dissolved solids, turbidity, total hardness, total alkalinity, calcium, magnesium, chloride, sulphate, carbonate, bicarbonate, fluoride, sodium, potassium, manganese and iron were analyzed. The water quality analysis of groundwater samples of the study area had shown that pH, total hardness, carbonate, chlorine, nitrate and sulphate were found within the desirable limit of WHO standard implying that suitable for drinking purpose whereas all the remaining parameters were found beyond the limit of WHO standard depicting that unsuitable from the point view of suitability for drinking.

Piper diagram of groundwater samples of the study area depicts that the major cations of the water sample were dominated by sodium type followed by no dominant type and calcium type whereas the major anions of all the water sample were dominated by bicarbonate type. The hydro chemical facies of the groundwater sample of the area is majorly Ca-HCO_3^- facies followed by Na-HCO_3^- facies, mixed type (Na-Ca-HCO_3^-) facies and in between the mixed type and Ca-HCO_3^- facies in their order of dominance respectively. The geochemical facies in the piper diagram supports the dominance of weak acid over strong acids and the contents of alkalies (Na^+ and K^+) were higher than those of the alkaline earths (Ca^{2+} and Mg^{2+}).

The suitability of groundwater sample for irrigation water were analyzed based on different classification of irrigation water quality including EC, SAR, MH, RSC and KR. Accordingly all groundwater samples were suitable based on EC and SAR classification, on the other hand 50% of the groundwater sample were suitable based on both MH and KR classification and all the groundwater sample are suitable based RSC irrigation water classification except sample S4, S7, S9 and S12.

The potential pollution risk of all the groundwater samples were analysed using the D8 flow direction algorithm and the vulnerability of the groundwater samples were classified based on the degree of vulnerability as no, low, medium and high potential for pollutions and aspect of digital elevation model were used for validation purpose of the D8 flow direction algorithm.

5.2 Recommendations

As per this study, the following points were recommended:

Most of physico-chemical parameters of the groundwater samples of the study area were found above the recommended limit of WHO standards, therefore it was recommended that concerned bodies of the study area should focus on continuous monitoring and factors which were responsible for deterioration of groundwater wells.

The fluoride concentrations of the groundwater samples particularly in keta town were significant than other groundwater samples. There is ongoing project launched by non-governmental agency to treat the fluoride contaminated groundwater by a method called ion exchange method. Thus, it would be wise that responsible bodies should provide all necessary things for the completion of the project.

Concerned body should proceed their protection of groundwater from contaminant not only after construction but also during construction of the groundwater wells through preparing proper location based designs.

Since the suitability of groundwater samples for drinking purpose were governed by the physico-chemical of parameters of the groundwater sample, treatment technologies are required for the rest of the parameters which were having concentration above the recommended values beside the ion exchange methods for removals of fluoride ion from the groundwater wells to make fit for drinking purpose.

The suitability of groundwater samples for irrigation water use based on EC and SAR can be used without any amendment of soil whereas the suitability based on MH, RSC and KR needs amendment of soil to increase crop production of irrigation activities.

The potential pollution risk of the groundwater samples which are vulnerable and already identified samples needs appropriate liquid waste disposal system in town settlement and agricultural input handling and management as well as to conduct additional environmental impact assessment for newly developments.

Responsible body should strength groundwater management and protection including revising of policies, institutional arrangements and technical capacity for risk management by providing priority for pollution exposed groundwater samples.

REFERENCES

- Abdalla, F. and Khalil, R. (2018) Potential effects of groundwater and surface water contamination in an urban area, Qus City, Upper Egypt, *Journal of African Earth Sciences*, 141, pp. 164 –178.
- Abelson, P. H. (1984) Groundwater contamination, *Science*, 224(4650), p. 673.
- Ahmed, A. A. (2009) Using Generic and Pesticide DRASTIC GIS-based models for vulnerability assessment of the Quaternary aquifer at Sohag, Egypt, *Hydrogeology Journal*, 17(5), pp. 1203 –1217.
- Alhibshi, E., Albriky, K. and Bushita, A. (2014) Concentration of Heavy Metals in underground water wells in Gharian district, Libya.
- Ali, H., Khan, E. and Ilahi, I. (2019) Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence Toxicity ,and Bioaccumulation, 2019(Cd).
- Amanambu, A. C., Obarein, O.A., Mossa,J., Li, L., Ayeni, S.S., Balogun, O., Oyebamiji, A. and Ochege, F.U. (2020) Groundwater system and climate change: Present status and future considerations, *Journal of Hydrology*, 589(June), p. 125163.
- Amr H. Mostafa, Raed S. Al-Wasify, Amr M. Sayed and Bakry M. Haroun. (2013). “Microbiological and Physicochemical Evaluation of Groundwater in Egypt. *International Journal of Environment and Sustainability*. 2(2), 1-10.
- Aryal, S. K. and Bates, B. C. (2008) Effects of catchment discretization on topographic index distributions, pp. 150–163.
- Ayers, R. and Westcot, D. (1985) Water quality for agriculture. Available at: <https://www.researchgate.net/profile/Abdelkader> (Accessed: 9 February 2021)
- Bantin, A. B., Wang, H. and Jun, X. (2020) Analysis and Control of the Physicochemical Quality of Groundwater in the Chari Baguirmi Region in Chad.
- Berhanu Kassegne, A. and Leta, S. (2020) Assessment of physicochemical and bacteriological water quality of drinking water in Ankober district, Amhara region, Ethiopia.
- Beven, K. J. and Kirkby, M. J. (2013) A physically based, variable contributing area model of basin hydrology, pp. 37–41.
- Boughriba, M. and Alae-eddine B. 2010. Groundwater vulnerability and risk mapping of

- the Angad transboundary aquifer using DRASTIC index method in GIS environment.
- Brhane, G. K. (2018) ‘Characterization of hydro chemistry and groundwater quality evaluation for drinking purpose in Adigrat area, Tigray, northern Ethiopia, *Water Science*, 32(2), pp. 213–229.
- Burns, R. G. (2016) *Environmental microbiology: A laboratory manual*.
- Chapman, D. (1996) *Water Quality Assessments - A Guide to Use of Biota , Sediments and Water in Environmental Monitoring - Second Edition*.
- Costa-cabral, M. C. and Burges, J. (1994) Digital elevation model networks (DEMON): A model of flow over hillslopes for computation and dispersal areas Specific contributing area, 30(6), pp. 1681–1692.
- Dąbrowska, D., Witkowski, A. J. and Sołtysiak, M. (2018) Application of pollution indices for the spatiotemporal assessment of negative impact of a municipal land fill on ground water (Tychy, Southern Poland), *Geological Quarterly*, 62(3), pp. 496–508.
- Devendra Dohare, Shriram Deshpande and Atul Kotiya. (May, 2014). Analysis of Ground Water Quality Parameters: A Review. International Science Congress Association. 3(5), 26-31.
- District, C., Naik, M.R., Barik, M., Jha, V.N., Sahoo, S.K. and Sahoo, N.K. (2019). Access of Ground Water Quality with Associated Physico-Chemical Parameters. (12), pp: 260–267.
- Eaton, F. M. (1950) Significance of carbonates in irrigation waters, *Soil Science*, 69(2), pp. 123–133.
- Ecjhao, C. and Dandwate, S. R. (2012) Study of Physicochemical Parameters of Groundwater Quality of Kopargaon Area , Maharashtra State , India during Pre-monsoon and Post-monsoon Seasons, 9(1), pp. 15–20.
- El-Naqa, A., Hammouri, N. and Kuisi, M. (2006) GIS-based evaluation of groundwater vulnerability in the Russeifa area, Jordan, *Revista Mexicana de Ciencias Geologicas*, 23(3), pp. 277–287.
- Ezeribe, Oshieke, K. C. and Jauro, A. (2012) Physico-chemical properties of well water samples from some villages in Nigeria with cases of stained and mottle teeth’,

- Science World Journal, 7(1), pp. 1–3.
- Fakhri, Y., Saha, N., Ghanbari, S., Rasouli, M., Miri, A., Avazpour, M., Rahimizadeh, M., Riahi, S.M., Ghaderpoori, M., Keramati, H., Moradi, B., Amanidaz, N. and Khaneghah, A.M. (2018). Carcinogenic and non-carcinogenic health risks of metalloids in tap water from Ilam city, Iran, *Food and Chemical Toxicology*. 118(February). pp: 204–211.
- Gangil, R., Tripathi, R., Patyal, A., Dutta, p. and Mathur, K.N. (2013). Bacteriological evaluation of packaged bottled water sold at jaipur city and its public health significance. *Veterinary World*. 6(1), pp: 27–30.
- Gastmans, D., Chang, H. K. and Hutcheon, I. (2010) Groundwater geochemical evolution in the northern portion of the Guarani Aquifer System (Brazil) and its relationship to diagenetic features, *Applied Geochemistry*, 25(1), pp. 16 – 33.
- Global, F. A. and Usage, G. (2016) Facts About Global Groundwater Usage, pp. 14 –15.
- Greenberg, A. E. (1984) *Advances in Standard Methods for the Examination of Water and Wastewater.*, Proceedings - AWWA Water Quality Technology Conference, pp. 11–13.
- Guissouma, W., Hakami, O., Al-Rajab, A.J. and Tarhouni, J. (2017). Chemosphere Risk assessment of fluoride exposure in drinking water of Tunisia. *Chemosphere*. 177, pp: 102–108.
- van der Gun, J. (2021) Groundwater resources sustainability, *Global Groundwater*.
- Gupta, N., Yadav, K.K., Kumar, V., Kuma, S., Chadd, R.P. and Kumar, A. (2019). Trace elements in soil-vegetables interface: Translocation, bioaccumulation, toxicity and amelioration. A review, *Science of the Total Environment*. 651, pp: 2927–2942.
- Gupta, N., Yadav, K. K. and Kumar, V. (2015) A review on current status of municipal solid waste management in India, *Journal of Environmental Sciences (China)*, 37, pp. 206–217.
- Gupta, P., Vishwakarma, M. and Rawtani, P. M. (2009) Assessment of water quality parameters of Kerwa Dam for drinking suitability, *International Journal of Theoretical and applied sciences*, 1(July), pp. 53–55.
- Hanson, B. R. and Grattan, S. R. (2006) *Agricultural Salinity and Drainage*.

- Helena, B., Pardo, R., Vega, M., Barrado, E., Fernandez, J. and Fernandez, L. (2000) Temporal Evolution Of Groundwater Composition in an Alluvial Aquifer (Pisuerga River , Spain) by Principal Component Analysis, 34(3), pp. 807–816.
- Hidraulicas, I. D. P., Federal, U. and Rs, P. A. (1991) The Prediction Of Hillslope Flow Paths For Distributed Hydrological Modelling using Digital Terrain Models, 5(October 1990), pp. 59–79.
- Holmgren, P. (1994) Multiple Flow Direction Algorithms for Runoff Modelling in Grid Based Elevation Models : A N Empirical Evaluation, 8(November 1992), pp. 327–334.
- Howard, G., Bartram, J., Williams, A., Overbo, A., Fuente, D. and Geere, J.A. (2020). Domestic water quantity, service level and health Second edition.
- IGRAC (2018) Groundwater Overview, UN Water, p. 60.
- International atomic energy agency (IAEA) (2013) Assessing and managing groundwater in Ethiopia, (September 2010), p. 28271.
- Jacintha, T. G., Rawat, K.S., Mishra, A. and Singh, S.K. (2017). Hydrogeochemical characterization of groundwater of peninsular Indian region using multivariate statistical techniques. Applied Water Science. 7(6), pp: 3001–3013.
- Jafari, A., Kamarehie, B., Ghaderpoori, M., Khoshnamvand, N. and Birjandi, M. (2018). The concentration data of heavy metals in Iranian grown and imported rice and human health hazard assessment. Data in Brief. 16, pp: 453–459.
- Jenson, K. and Domingue, O. (1988) Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis, 54(11), pp. 1593–1600.
- Joshi, D. M., Kumar, A. and Agrawal, N. (2009) Assessment of the irrigation water quality of river Ganga in Haridwar district, Rasayan Journal of Chemistry, 2(2), pp. 285–292.
- Kanduti, D., Sterbenk, P. and Artnik, B. (2016) Fluoride: A Review of use and Effects on Health, 28(2), pp. 133–137.
- Kassie, A. E. (2019) Challenges and Opportunities of Irrigation Practices in Ethiopia : A Review, 9(3), pp. 1–12.
- Kaur, L., Rishi, M.S., Sharma, S., Sharma, B., Lata, R. and Singh, G. (2019). Science

Hydrogeochemical characterization of groundwater in alluvial plains of river Yamuna in northern India : An insight of controlling processes. *Journal of King Saud University Science*. 31(4), pp: 1245–1253.

Kebede, S. (2013) *Groundwater in Ethiopia*, Groundwater in Ethiopia.

Khashogji, M. S. and El Maghraby, M. M. S. (2013) Evaluation of groundwater resources for drinking and agricultural purposes, Abar Al Mashi area, south Al Madinah Al Munawarah City, Saudi Arabia, *Arabian Journal of Geosciences*, 6(10), pp. 3929–3942.

Kolekar, S. S. (2017) Physico-chemical analysis of ground water quality parameters – A Review, 10(1), pp. 376–378.

Kozłowski, M. and Sojka, M. (2019) Applying a modified DRASTIC model to assess groundwater vulnerability to pollution: A case study in central Poland, *Polish Journal of Environmental Studies*, 28(3), pp. 1223–1231.

Kumar, M., Shekhar, A. and Jenifer, M. A. (2020) Assessing groundwater quality for drinking water supply using hybrid fuzzy-GIS-based water quality index, *Water Research*, 179, p. 115867.

Lall, U., Josset, L. and Russo, T. (2020) A Snapshot of the World's Groundwater Challenges, pp. 171–196.

Length, F. (2012) Groundwater quality and pollution potential studies around Baikunthpur Area , Rewa District , Madhya Pradesh , India, 4(December), pp. 377–385.

Lezzaik, K., Milewski, A. and Mullen, J. (2018) The groundwater risk index: Development and application in the Middle East and North Africa region, *Science of the Total Environment*, 628–629, pp. 1149–1164.

Li, R. and Merchant, J. W. (2013) Modeling vulnerability of groundwater to pollution under future scenarios of climate change and biofuels-related land use change: A case study in North Dakota, USA, *Science of the Total Environment*, 447, pp. 32–45.

Liu, C., Lin, K. and Kuo, Y. (2003) Application of factor analysis in the assessment of groundwater quality in a blackfoot disease area in Taiwan, 313(02), pp. 77–89.

- Madhnure, P. (2014) Groundwater exploration and drilling problems encountered in basaltic and granitic terrain of Nanded district, Maharashtra, *Journal of the Geological Society of India*, 84(3), pp. 341–351.
- Margat, J. and Gun, J. van der (2013) *Groundwater around the World*, Groundwater around the World.
- Martz, L. W. (1994) Automated extraction of drainage network and watershed data from digital elevation models, 29(6), pp. 901–908.
- Masindi, V. and Foteinis, S. (2021) Groundwater contamination in sub-Saharan Africa: Implications for groundwater protection in developing countries, *Cleaner Engineering and Technology*, 2(December 2020), p. 100038.
- Maurya, P. K., Malik, D.S., Yadav, K.K., Kumar, A., Kumar, S. and Kamyab, H. (2019). Bioaccumulation and potential sources of heavy metal contamination in fish species in River Ganga basin: Possible human health risks evaluation. *Toxicology Reports*. 6(May), pp: 472–481.
- Melesse, A. M., Abtew, W. and Setegn, S. G. (2013) Nile River Basin: Ecohydrological challenges, climate change and hydropolitics, *Nile River Basin: Ecohydrological Challenges, Climate Change and Hydropolitics*, (June 2018), pp. 1–718.
- Milnes, E. (2011) Process-based groundwater salinisation risk assessment methodology: Application to the Akrotiri aquifer (Southern Cyprus), *Journal of Hydrology*, 399(1–2), pp. 29–47.
- Mohsin, M., Safdar, S., Asghar, F. and Jamal, F. (2013). Assessment of drinking water quality and its impact on residents health in Bahawalpur City. *International Journal of Humanities and Social Science*. 3(15), pp: 114–128.
- Mukherjee, I. and Singh, U. K. (2018) Groundwater fluoride contamination, probable release, and containment mechanisms: a review on Indian context, *Environmental Geochemistry and Health*, 40(6), pp. 2259–2301.
- Mwabi, J. K., Mamba, B. B. and Momba, M. N. B. (2013) Removal of waterborne bacteria from surface water and groundwater by cost-effective household water treatment systems (HWTS): A sustainable solution for improving water quality in rural communities of Africa, *Water SA*, 39(4), pp. 445–456.

- N, M. M. (2011) Quality Assessment of Tigris River by using Water Quality Index for Irrigation Purpose, *European Journal of Scientific Research*, 57(1), pp. 14 (15-28).
- Neshat, A., Pradhan, B., Pirasteh, S. and Shafri, H.Z.M. (2014). Estimating groundwater vulnerability to pollution using a modified DRASTIC model in the Kerman agricultural area, Iran. *Environmental Earth Sciences*. 71(7), pp: 3119–3131.
- Nishanthiny, S. C., Thushyanthy, M., Barathithasan, T. and Saravanan S. (2010), Irrigation water quality based on hydro chemical analysis, Jaffna, Sri Lanka, *American-Eurasian J. Agric. & Environ. Sci.*, 7(1), pp. 100–102.
- Oludairo, O. O and Aiyedun, J. O. (2015) Contamination of Commercially Packaged Sachet Water and the Public, *Bangl. J. Vet. Med*, 13(2), pp. 73–81.
- World Health Organization (2008) Guidelines for drinking-water quality: second addendum. Vol. 1, Recommendations. (Accessed: 6 February 2021).
- World Health Organization (2010) Hardness in Drinking water Background document for development of WHO Guidelines for Drinking-water Quality.
- Osaro, F. and Oyaribhor, M. A. . (2011) Bacteriological and Physicochemical Qualities of Ebutte River in Ebutte Community, Uhumwonde Local Government Area, Edo State, Nigeria, *Journal of Applied Sciences and Environmental Management*, 15(4), pp. 663–673.
- Ostrom, L. T. and Wilhelmsen, C. A. (2012) Risk Assessment: Tools, Techniques, and their Applications, *Risk Assessment: Tools, Techniques, and their Applications*. John Wiley and Sons.
- Pan, F., Peters-Lidard, C. D., Sale, M. J. and King, A. W. (2004) A comparison of geographical information systems – algorithms for computing the Topmodel topographic index, 40, pp. 1–11.
- Pavelic, P. (2012) Groundwater availability and use in Sub-Saharan Africa: a review of 15 countries., *Groundwater availability and use in Sub-Saharan Africa: a review of 15 countries*.
- Perlman and United States Geological Survey, 2013. (Accessed: 5 February 2021).
- Raghunath, H.M. (1987). *Groundwater*. Wiley Eastern Ltd., Delhi. References Scientific Research Publishing.

- Raj, D. and Shaji, E. (2017) Geoscience Frontiers Fluoride contamination in groundwater resources of Alleppey , southern India, *Geoscience Frontiers*, 8(1), pp. 117–124.
- Rasheed, A. I. and Abdulgafar, A. K. (2014) Impacts of Artisanal Mining on Some Heavy Metals Concentration in Surface Water in Kutcheri, Zamfara State North-Western Nigeria, *Academic Journal of Interdisciplinary Studies*, 3(7), pp. 74–82.
- Rawat, K. S. and Singh, S. K. (2018) Water Quality Indices and GIS-based evaluation of a decadal groundwater quality, *Geology, Ecology, and Landscapes*, 2(4), pp. 240–255.
- Rawat, K. S., Singh, S. K. and Gautam, S. K. (2018) Assessment of groundwater quality for irrigation use: a peninsular case study, *Applied Water Science*, 8(8), pp. 1–24.
- Reddy, K. and Reddy, T. (2011) Qualitative Characterization of Groundwater Resources For Irrigation. A Case Study From Srikakulam Area, Andhra Pradesh. (Accessed: 9 February 2021).
- Rezaei, H., Ahmad, Z., Bahram, K., Ali, J., Yadolah, F., Farzam, K., Amin, K.M., Mansoureh, F., Mansour, G., Hossein, S. and Naseh, S. (2019). Levels, Distributions and Health Risk Assessment of Lead, Cadmium and Arsenic Found in Drinking Groundwater of Dehgolan's Villages, Iran. *Toxicology and Environmental Health Sciences*. 11(1), pp: 54–62.
- Richard, P., Baguma, A., Bizoza, A., Carter, R., Cavill, S., Foster, S., Foster, T., Jobbins, G., Hope, R., Katuva, J., Koehler, J., Shepherd, A. and Simons, A. (2017). Groundwater and poverty in sub- Saharan Africa a short investigation highlighting outstanding knowledge gaps
- Richards, L. (1954). Diagnosis and improvement of saline and alkali soils. Available at: <https://journals.lww.com> (Accessed: 9 February 2021).
- Roy, R. (2019) An Introduction to Water Quality Analysis', pp. 201–205.
- Sadashivaiah, C., Ramakrishnaiah, C. R. and Ranganna, G. (2008) Hydrochemical Analysis and Evaluation of Groundwater Quality in Tumkur Taluk , Karnataka State , India', 5(3), pp. 158–164.
- Sahu, B. L., Gokul., Banjare, R., Ramteke, S., Khagaeshwar., Patel, S. and Matini, L. (2017). Fluoride Contamination of Groundwater and Toxicities in Dongargaon

- Block, Chhattisgarh, India Article in Exposure and Health. Springer. 9(2), pp: 143–156.
- Saidi, S., Bouri, S., Dhia, H.B. and Anselme, B. (2011). Assessment of groundwater risk using intrinsic vulnerability and hazard mapping: Application to Souassi aquifer, Tunisian Sahel. *Agricultural Water Management*. 98(10), pp: 1671–1682.
- Sayato, Y. (1989a) World Health Organization Guidelines for Drinking-Water Quality, *Eisei Kagaku*, 35(5), pp. 307–312.
- Sayato, Y. (1989b) World Health Organization Guidelines for Drinking-Water Quality, *Eisei Kagaku*, 35(5), pp. 307–312.
- Seibert, J. and McGlynn, B. L. (2007) A new triangular multiple flow direction algorithm for computing upslope areas from gridded digital elevation models, 43, pp. 1–8.
- Selvakumar, S., Ramkumar, K., Chandrasekar, N., Magesh, N.S. and Kaliraj, S. (2017). Groundwater quality and its suitability for drinking and irrigational use in the Southern Tiruchirappalli district, Tamil Nadu, India. *Applied Water Science*. 7(1), pp: 411–420.
- Shah, C. R. (2017) Which Physical, Chemical and Biological Parameters of water determine its quality?, *ResearchGate*, (June), pp. 1–74.
- Shrestha, S., Kafle, R. and Pandey, V. P. (2017) Evaluation of index-overlay methods for groundwater vulnerability and risk assessment in Kathmandu Valley, Nepal, *Science of the Total Environment*, 575, pp. 779–790.
- Shrivastava, S. (2014) Water quality analysis of water bodies of Kantajhar Basti.
- Soltysiak, M., Dybrowska, D. and Nourani, V. (2018). A multi-method approach to groundwater risk assessment: A case study of a landfill in southern Poland, *Geological Quarterly*. 62(2), pp: 361–374.
- Srivastav, A., Krishna Kumar Yadav, K. K., Yadav, S., Gupta, N., Singh, J. K., Katiyar, R. and Kumar, V. (2018) Nano-phytoremediation of Pollutants from Contaminated Soil Environment: Current Scenario and Future Prospects, *Springer*, 6, pp. 383–401.
- Studies, R., Wada, T. and Studies, R. (2018) The role of geological structures on groundwater occurrence and flow in crystalline basement aquifers: a status

- review, *Bayero Journal of Pure and Applied Sciences*, 11(1), pp. 155–164.
- Szabolcs, I. (1964) The influence of irrigation water of high Sodium Carbonate content on soils, *Agrokemiaes talajtan*, 13(sup), pp. 237–246.
- Tadesse, N., Bairu, A., Bheemalingeswara, K., G/yohannes, T. (2011). Suitability of Groundwater Quality for Irrigation with Reference to Hand Dug Wells, Hantebet Catchment, Tigray, Northern Ethiopia. *Momona Ethiopian Journal of Science*. 3(2).
- Tarawneh, M. S. M., Janardhana, M. R. and Ahmed, M. M. (2019) Hydrochemical processes and groundwater quality assessment in North eastern region of Jordan valley, Jordan, *HydroResearch*, 2(2019), pp. 129–145.
- Tesfalem, N., Tesfamariam, A., Okbaslasie, A. and Tesfay, K (2019). Physico-chemical Analysis of Groundwater Around Mai- Bela, Asmara, Eritrea pp: 161–186.
- Todd, D. and Mays, L. (2004) *Groundwater hydrology*. (Accessed: 9 February 2021).
- United Nations International Children’s Emergency Fund, 2008. *Hand book on water quality*. (Accessed: 6 February 2021).
- United Nations Water Africa (2003) *The Africa Water Vision for 2025*, United Nations Water Africa, pp. 1–34.
- Villholth, K. G., Jeyakumar, P., Amerasinghe, P.H., Manamperi, A.S.P., Vithanage, M., Goswami, R.R. and Panabokke, C.R. (2010). Tsunami impacts and rehabilitation of groundwater supply: Lessons learned from eastern Sri Lanka, *Natural and Anthropogenic Disasters: Vulnerability, Preparedness and Mitigation*. pp. 82–99.
- Water, S. and Organization, W. H. (2006) *Guidelines for Drinking-water Quality First Addendum to Third Edition Volume 1 Recommendations*.
- Water, U. N. (2015) *Water for a sustainable world*, The United Nations World Water Development Report.
- Wegahita, N. K., Ma, L., Liu, J., Huang, T., Luo, Q. and Qian, J. (2020). Spatial assessment of groundwater quality and health risk of nitrogen pollution for shallow groundwater aquifer around fuyang city, china. *Water (Switzerland)*. 12(12),

pp.1– 20.

World Health organization (2009) Potassium in Drinking Water, Guidelines for Drinking-water Quality, World Health Organization, Geneva 4th Edition, pp. 1–5.

Wolock, M. and Jr, G. J. M. (1995) ‘Comparison of single and multiple flow direction algorithms for computing topographic parameters in TOPMODEL, 31(5), pp. 1315–1324.

World Health Organization (1996) Sodium in Drinking water Background, Health criteria and other supporting information, 2, p. 7.

Yadav, K. K., Gupta, N., Kumar, V., Sharma, S. and Arya, S. (2015). Water Quality Assessment of Pahuj River using Water Quality Index at Unnao Balaji, M. P., India, International Journal of Sciences: Basic and Applied Research. 19(1), pp: 241–250.

ANNEXES

Annex 1. Results of Physical Water Quality Parameters.

Triplicate									
Parameters	S1	S2	S3	S4	S5	S6	S7	S8	WHO
Temp (°C)	21.3	23.2	22.7	24.1	21.5	21.5	23.1	24.5	
	21.5	23.8	24.2	25.2	20.5	21.3	22.5	23.8	
	21.4	23.5	23.4	24.5	22.2	22	22.5	23.5	
mean	21.4	23.5	23.4	24.6	21.4	21.6	22.7	23.9	15
pH	7.3	6.55	7.2	7.3	7.4	6.85	7.35	6.82	
	7.5	6.6	6.8	7.5	7.35	6.80	7.34	6.80	
	7.55	6.65	7.1	7.8	7.4	6.75	7.36	6.81	
mean	7.45	6.60	7.03	7.53	7.38	6.80	7.35	6.81	6.65-8.5
EC(μs/cm)	193.5	360	140	1320	1252	450.8	1650	251.5	
	195.3	362	143	1321	1250	451.3	1652	252	
	195.5	360.5	142	1320	1251	451.5	1651	251.8	
mean	194.8	360.6	141.7	1320	1251	451.2	1651	251.8	250
TDS (mg/l)	776	230	320.5	890	520.5	217	1232	322.4	
	775	231.5	321	891	521.5	218	1231	322.6	
	777	232	322	891	520	217.5	1231	322.3	
Mean(mg/l)	776	231.2	321.2	890.7	520.7	217.5	1231	322.4	500
Turbidity (NTU)	19	15	12	36.6	29.5	42.1	4.5	11.2	
	18	14.5	11.5	37.1	28.4	42.9	4.45	11.1	
	18	14	11.2	36.8	28.8	42.3	4.52	11.1	
Mean	18.3	14.5	11.57	36.8	28.9	42.43	4.49	11.13	5

Triplicate									
Parameters	S9	S10	S11	S12	S13	S14	S15	S16	WHO
Temp (°C)	23.8	19.2	21.2	21.4	22.4	23.4	23.1	21.1	
	23.7	19.1	21.4	22.1	22.3	23.3	23.3	20.8	
	23.7	19.1	21.1	20.8	22.5	23.5	23.2	21.4	
Mean	23.73	19.13	21.23	21.4	22.4	23.4	23.2	23.1	15
pH	7.52	6.75	7.25	7.5	7.35	7.15	6.67	6.75	
	7.54	6.76	7.42	7.46	7.38	7.21	6.7	6.73	
	7.54	6.75	7.3	7.5	7.38	7.2	6.68	6.74	
mean	7.53	6.75	7.32	7.49	7.37	7.19	6.68	6.74	6.65-8.5
EC(µs/cm)	1325.2	250.1	959.2	515.2	365.6	752.5	720.4	652	
	1325	250.3	959.6	515	366	752.1	720.8	651.8	
	1325	250.2	959.4	515.1	366	752	720	652.1	
mean	1352.1	250.2	959.4	515.1	365.9	752.2	720.4	651.9	250
TDS (mg/l)	845.2	115.2	501.5	431.3	190.5	420.5	426	323.2	
	845.8	115	501.8	431.2	191	420.8	426.8	323.1	
	845.6	115.1	501.6	431.8	191.2	420.8	426.5	323.3	500
Mean (mg/l)	845.5	115.1	501.6	431.8	190.9	420.7	426.4	323.2	
Turbidity (NTU)	54.6	29.2	2.35	15.2	5.1	2.5	2.53	49.2	
	54.8	29.4	2.41	14.6	4.6	2.3	2.62	49.1	
	54.7	29.2	2.41	14.9	4.7	2.4	2.60	49.3	
Mean(NTU)	54.7	29.26	2.39	14.9	4.8	2.4	2.58	49.2	

Annex 2. Results of Chemical Water Quality Parameters.

Triplicate									
Parameters	S1	S2	S3	S4	S5	S6	S7	S8	WHO
TH (mg/l)	85.2	42.5	48.2	81.5	112.2	180	96.5	115.2	
	84.8	43.2	48.9	82	113.1	178	97.1	115.1	
	85.1	43.1	48.1	81	112.8	181	96.8	115.2	
Mean(mg/l)	85.02	42.9	48.4	81.5	112.7	179.7	96.8	115.2	300
TA (mg/l)	43.2	75.1	112.1	210	178.5	210	323.2	72.5	
	43.9	74.9	112.9	209.5	179	210.8	323	72.8	
	43.6	74.6	112.4	209.8	178.9	210.2	323.1	72.9	
Mean(mg/l)	43.57	74.9	112.5	209.8	178.8	210.3	323.1	72.63	200
Ca ²⁺ (mg/l)	36.4	21.2	17.25	11.1	12.1	44.2	29.5	16.2	
	37.1	21.5	16.95	10.3	12.9	43.5	29.8	16.4	
	37.3	21.3	16.9	10.7	12.4	44.2	29.7	16.6	
Mean(mg/l)	36.9	21.3	17.03	10.7	12.47	43.97	29.7	16.27	75
Mg ²⁺ (mg/l)	48.7	19.8	8.75	23.5	15.6	10.2	54.6	9.1	
	49.1	19.02	8.71	23.1	16.8	10.5	54.2	9.2	
	50.1	19	8.72	23.8	16.2	10.2	54.9	9.1	
Mean(mg/l)	49.3	19.27	8.73	23.5	16.2	10.3	54.57	9.13	50
Cl ⁻ (mg/l)	25.4	29.1	14.2	21.2	23.9	17.2	21.2	16.2	
	25.1	28.7	15.1	20.9	24.2	18.1	21.8	16.25	
	25.9	28	15.2	21.7	24	17.5	21.4	16.2	
Mean(mg/l)	25.5	28.6	14.8	21.3	24.03	17.6	21.47	16.22	250

Triplicate									
Parameters	S9	S10	S11	S12	S13	S14	S15	S16	WHO
TH (mg/l)	92.5	78.2	81.9	133.2	96.5	275.5	245.5	250.8	
	92.3	78.1	82.1	133.5	96.8	275.1	245.3	250.5	
	92.3	78.2	82.2	133.1	96.8	275.2	245.4	250.8	
Mean(mg/l)	92.37	78.2	82.06	133.3	96.7	275.3	245.4	250.7	300
TA(mg/l)	632.5	43.1	541.3	324.2	175.3	425.1	327	123.4	
	632.1	43.1	541.5	324.8	175.4	424.5	327.2	123.5	
	632.1	43.2	541.4	324.4	175.2	425	327.3	123.3	
Mean(mg/l)	632.2	43.13	541.4	324.5	175.3	424.8	327.2	123.4	200
Ca ²⁺ (mg/l)	19.2	5.25	85.5	48.5	18.4	120.7	153.4	65.2	
	19.5	5.3	85.2	48.6	18.2	121.1	153.6	65.35	
	19.3	5.29	85.2	48.6	18.3	121.2	153.5	65.3	
Mean(mg/l)	19.33	5.28	85.3	48.57	18.3	121	153.5	65.28	75
Mg ²⁺ (mg/l)	4.95	3.15	19.3	10.57	13.8	125.1	40.8	98.4	
	4.98	3.18	19.1	10.60	14.1	124.5	40.6	97.9	
	4.98	3.17	19.4	10.62	14.1	124.8	40.6	98.6	
Mean(mg/l)	4.97	3.17	19.27	10.59	13.97	124.8	40.67	98.3	50
Cl ⁻ (mg/l)	16.2	5.1	39.5	11.89	24.3	17.25	22.5	15.4	
	16	5.15	40.2	11.95	24.9	17.28	22.2	15.3	
	16.1	5.15	40.1	11.92	24.2	17.28	22.4	15.3	
Mean(mg/l)	16.1	5.13	39.93	11.92	24.47	17.27	22.5	15.33	250

TriPLICATE									
Parameters	S1	S2	S3	S4	S5	S6	S7	S8	WHO
SO ₄ ²⁻ (mg/l)	3.25	1.87	2.5	1.7	1.2	0.0	0.81	0.25	
	3.3	2.1	3.1	1.65	1.8	0.0	0.82	0.26	
	3.26	2.15	3.05	1.8	1.75	0.0	0.82	0.26	
Mean (mg/l)	3.27	2.04	2.88	1.72	1.58	0.0	0.82	0.26	250
CO ₃ ²⁻ (mg/l)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Mean (mg/l)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
HCO ₃ ⁻ (mg/l)	245.1	112.2	47.1	392.2	250.5	270	850.8	95.2	
	243.9	223.1	47.9	392.1	251.1	270.5	851.1	95	
	243.2	112.5	48.1	391.5	250.8	270	850.1	95.1	
Mean (mg/l)	244.1	112.6	47.7	391.9	250.8	270.2	850.6	95.1	300
F ⁻ (mg/l)	3.25	0.32	0.54	8.7	4.9	0.52	0.65	0.31	
	3.34	0.36	0.51	8.9	5.2	0.56	0.63	0.3	
	3.42	0.35	0.53	9.4	5.4	0.54	0.64	0.31	
Mean (mg/l)	3.34	0.34	0.53	9.0	5.2	0.54	0.64	0.31	1.5
Na ⁺ (mg/l)	201.5	18.2	28.7	322.5	250.8	154.6	452.3	26.2	
	202.1	18.9	29.2	323.1	251.2	153.9	452.8	26.3	
	202.2	18.6	28.9	322.8	251	153.2	452.7	26.3	
Mean (mg/l)	201.9	18.57	28.93	322.8	251	153.9	452.6	26.27	200

TriPLICATE									
Parameters	S9	S10	S11	S12	S13	S14	S15	S16	WHO
SO ₄ ²⁻ (mg/l)	13.5	0.0	0.0	15.2	4.35	6.52	0.0	21.8	
	13.80	0.0	0.0	15.3	4.38	6.54	0.0	22	
	13.80	0.0	0.0	15.1	4.4	6.6	0.0	21.9	
Mean (mg/l)	13.7	0.0	0.0	15.2	4.38	6.55	0.0	21.9	250
CO ₃ ⁻² (mg/l)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Mean (mg/l)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
HCO ₃ ⁻ (mg/l)	952.1	45.1	291.5	365.5	224.1	488.1	367.1	439.3	
	952.1	45.2	291.1	367.4	224.5	487.5	367.2	439.4	
	952.4	45.2	291.2	367.1	224.3	488.2	368.2	439.4	
Mean (mg/l)	952.2	45.16	291.3	366.7	224.3	487.9	367.5	439.4	300
F ⁻ (mg/l)	3.92	0.22	2.15	0.65	0.68	0.49	1.23	0.87	
	3.98	0.31	2.2	0.62	0.7	0.5	1.2	0.85	
	3.96	0.28	2.12	0.63	0.72	0.48	1.2	0.86	
Mean (mg/l)	3.95	0.27	2.16	0.63	0.7	0.49	1.21	0.86	1.5
Na ⁺ (mg/l)	353.2	11.20	176.1	68.5	49.5	25.2	14.52	33.5	
	353.1	10.90	176.2	69	49.1	25.4	14.5	34.2	
	353.4	11.0	176	68.8	49.4	25.4	14.51	33.9	
Mean(mg/l)	353.3	11.03	176.1	68.77	49.3	25.33	14.51	33.87	200

Triplicate									
Parameters	S1	S2	S3	S4	S5	S6	S7	S8	WHO
K ⁺ (mg/l)	8.85	5.25	6.5	14.5	11.20	13.8	8.65	6.25	
	8.97	5.30	6.18	15.2	11.80	13.2	8.72	6.30	
	8.90	5.30	6.15	14.9	11.60	13.1	8.71	6.25	
Mean (mg/l)	8.91	5.28	6.24	14.87	11.53	13.4	8.69	6.27	10
NO ₃ ⁻ (mg/l)	3.38	3.20	3.33	0.54	0.50	3.53	1.42	4.90	
	3.39	3.24	3.29	0.52	0.49	3.49	1.40	4.92	
	3.39	3.25	3.34	0.50	0.54	3.54	1.38	4.91	
Mean (mg/l)	3.39	3.23	3.32	0.52	0.51	3.52	1.40	4.91	10
Mn ²⁺ (mg/l)	0.25	0.04	0.03	0.15	0.25	0.11	0.018	0.25	
	0.21	0.02	0.05	0.20	0.30	0.18	0.02	0.24	
	0.21	0.03	0.02	0.18	0.28	0.16	0.03	0.23	
Mean(mg/l)	0.22	0.03	0.033	0.18	0.28	0.15	0.022	0.24	0.1
Fe ²⁺ (mg/l)	0.03	0.25	0.03	0.25	0.29	0.38	0.18	0.27	
	0.04	0.22	0.02	0.21	0.22	0.32	0.26	0.30	
	0.04	0.24	0.03	0.26	0.25	0.25	0.22	0.29	
Mean(mg/l)	0.04	0.23	0.03	0.24	0.26	0.32	0.22	0.29	0.3

Triplicate									
Parameters	S9	S10	S11	S12	S13	S14	S15	S16	WHO
K ⁺ (mg/l)	5.1	2.1	6.35	7.35	8.15	5.8	6.82	7.63	
	5.18	2.15	6.37	7.41	8.20	5.75	6.81	7.64	
	5.2	2.14	6.36	7.40	8.18	5.79	6.81	7.61	
Mean (mg/l)	5.16	2.13	6.36	7.39	8.18	5.78	6.82	7.63	10
NO ₃ ⁻ (mg/l)	0.88	3.00	0.29	3.28	3.11	3.45	2.83	2.93	
	0.89	3.02	0.30	3.22	3.10	3.44	2.86	2.94	
	0.89	3.01	0.30	3.22	3.11	3.45	2.81	2.97	
Mean (mg/l)	0.89	3.01	0.30	3.24	3.11	3.45	2.85	2.95	10
Mn ²⁺ (mg/l)	0.02	0.25	0.04	0.01	0.09	0.15	0.11	0.25	
	0.03	0.20	0.05	0.04	0.10	0.10	1.18	0.23	
	0.03	0.15	0.05	0.03	0.10	0.12	0.16	0.23	
Mean(mg/l)	0.02	0.20	0.05	0.027	0.10	0.12	0.15	0.24	0.1
Fe ²⁺ (mg/l)	0.06	0.01	0.16	0.00	0.00	0.08	0.35	0.15	
	0.05	0.05	0.18	0.00	0.00	0.03	0.31	0.19	
	0.06	0.02	0.17	0.00	0.00	0.04	0.29	0.18	
Mean(mg/l)	0.06	0.03	0.17	0.00	0.00	0.05	0.32	0.17	0.3

Annex 3. Results of Irrigation Water Quality Parameters.

Parameters	S1	S2	S3	S4	S5	S6	S7	S8
Na ⁺	8.78	0.81	1.60	14.03	10.91	6.69	19.68	1.14
K ⁺	0.23	0.14	0.16	0.38	0.30	0.34	0.22	0.16
Ca ²⁺	1.85	1.06	0.86	0.56	0.61	2.20	1.48	0.81
Mg ²⁺	4.11	1.60	0.72	1.96	1.36	0.86	4.55	0.76
CO ₃ ⁻²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCO ₃ ⁻	4.00	1.85	0.78	6.42	4.11	4.43	13.94	1.56
EC	194.8	360.6	141.7	1320	1251	451.2	1651	251.8
SAR	5.09	0.70	1.80	12.50	10.99	5.41	11.33	1.29
MH	68.96	60.15	45.57	77.78	69.04	28.10	75.46	48.41
RSC	-1.96	-0.81	-0.80	3.90	2.14	1.37	7.91	-0.01
KR	1.47	0.30	1.01	5.57	5.54	2.19	3.26	0.73

Parameters	S9	S10	S11	S12	S13	S14	S15	S16
Na ⁺	15.36	0.48	7.66	2.99	2.14	1.10	0.63	1.47
K ⁺	0.13	0.05	0.16	0.19	0.21	0.15	0.17	0.20
Ca ²⁺	0.97	0.26	4.26	2.43	1.16	6.05	7.68	3.26
Mg ²⁺	0.47	0.26	1.60	0.88	2.14	10.4	3.39	8.10
CO ₃ ⁻²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCO ₃ ⁻	15.61	0.74	4.78	6.01	3.68	8.00	6.02	7.20
EC	1352.10	250.20	959.4	515.10	365.9	752.2	720.40	651.90
SAR	18.00	0.94	4.48	2.32	1.67	0.38	0.27	0.61
MH	32.64	50.00	27.30	26.59	64.85	63.22	30.62	71.53
RSC	14.17	0.22	-1.08	2.70	0.38	-8.45	-5.05	-4.25
KR	10.67	0.92	1.31	0.90	0.65	0.07	0.06	0.13

Annex 4. Pollution Risk, Flow Direction Analysis Steps and Procedures

1. Open ARCGIS → Add DEM of study area → Add well point → select spatial analyst tools → Hydrology → Fill → Flow direction
2. Select data management tool → Raster → Raster processing → Resample
3. Select conversion tool → From raster → Raster to point → Right click on point raster → Properties → Symbology → Click on unique value → Grid code → Double click 1st grid code → Click on drawdown button → Write the word cutting on the box → Under dimension click on arrow → Adjust font, color and angle fit with grid code.

Annex 5. Sample Pictures Taken During Laboratory Experiment.

