ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

COLLEGE OF SOCIAL SCIENCE

DEPARTMENT OF GEOGRAPHY AND ENVIRONMETAL STUDIES

ASSESSING GROUND WATER QUALITY OF ADDIS ABABA CITY BY USING GEOGRAPHICAL INFORMATION SYSTEM

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ADERAW TSEGAYE

A PROJECT SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILMENTS OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS IN GEOGRAPHY AND ENVIRONMENTAL STUDIES (SPECIALIZATION: GEOGRAPHIC INFORMATION SYSTEM, REMOTE SENSING AND DIGITAL CARTOGRAPHY)

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This is to certify that project presented by Aderaw Tsegaye entitled: *Asssessing ground water quality of Addis Ababa city by using Geographical Information System* and submitted in partial fulfillments of the requirements for the degree of master of arts in Geography and Environmental Studies with specialization in Geographic Information System, Remote sensing and Digital Cartography complies with the regulation of the university and meets the accepted standards with respect to originality and quality.

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Abstract

Groundwater is one of the most important natural resources. It becomes a necessary resource over the past years due to the increase in its usage for drinking, irrigation and industrial uses etc. Groundwater quality assessment is necessary to guarantee sustainable safe use of water. Mapping of spatial variability of groundwater quality is of vital importance and it is particularly significant where groundwater is primary source of potable water. The present study has been undertaken to analyze the spatial variability of groundwater quality for Addis Ababa city, capital of Ethiopia. Ground water pollution is a global issue. However, the extent and degree of severity of water pollution is more prominent in developing countries. The aim of this research is to provide an overview of present groundwater quality spatial distribution over the city of Addis Ababa. Geographical Information System (GIS) is used for the spatial analysis and it is a powerful tool for representation and analysis of spatial information related to water resources. Geostatistics was used to determine the spatial distribution of groundwater quality parameters in the study area using GIS and geostatistical techniques. Ordinary kriging interpolation techniques was applied to generate water quality maps. The major water quality parameters such as Total Dissolved Solids, Total hardness, Chloride, Nitrate, Sulphates, Magnesium and Calcium have been analysed. The spatial variation maps of these groundwater quality parameters shows that mostly in the central part of the city there is high concentration of nitrate, TDS, total hardness. But from those parameters chloride, Magnesium, calcium and sulphate have low concentration below the world health Organization standard. The final integrated map shows four priority classes such as Excellent, Good, Poor and Very poor groundwater quality zones of the study area and provides a guideline for the suitability of groundwater for domestic purposes. Water quality index (WQI) was used to assess the suitability of groundwater from the study area for drinking purpose. From the WQI assessment The map showed that 78.18 % (422.17 km^2) of the groundwater of the city were found to be in the excellent water class, 20.86 % (112.62 km^2) good, 0.9 % (4.87 km^2) poor and the remaining 0.06 % (0.34 km^2) was classified under very poor water class based on the computed WQI classification results.

Key words: Geostatistics, GIS , Ground water, Interpolation, water quality

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AAWSA	Addis Ababa water and sanitation authority
a.m.s.l	Above mean sea level
ASR	Average standard error
BGS	British Geological Survey
CAWST	Center for Affordable water and sanitation Technology
CGWB	Central Ground Water Board
ESRI	Environmental system and research institute
GIS	Geographical information system
GVM	Groundwater Vulnerability Mapping
i.e	That is
ME	Mean error
MSE	Mean square error
QQ plots	The quantile quantile plot
RMSE	Root mean error
RMSSE	Root mean square standardized error
TDS	Total dissolved solids
UNEP	United Nations Environment Programme’s
UNESCO	United Nation Educational Science and Cultural Organization
UNICEF	United Nations Children’s Fund
WHO	World health organization
WQI	Water quality index

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Water is needed in all aspects of life. Water obtained from rivers, lakes, springs and wells has been used for drinking, washing, agriculture, and manufacturing. Most of the Earth's liquid freshwater is found, not in lakes and rivers, but is stored underground in aquifers (UNEP, 2003). So groundwater is one of earth's most vital renewable and widely distributed resources as well as an important source of water supply throughout the world (Khadri et al, 2013). At least two billion people around the world rely on ground water as their only source of drinking water (UNEP, 2003). Where surface water is absent, the supply of good quality ground water is essential for the health and development of nations. The quality of water is a vital concern for mankind since it is directly linked with human welfare. The issues of groundwater use and quality have until recently received far less consideration than surface water, and data on groundwater stocks and flows are even less reliable. The world health organization has repeatedly insisted that the single major factor adversely influencing the general health and life expectancy of a population in many countries of the developing world is the access of clean drinking water. Water quality problems can often be as severe as those of water availability but less attention has been paid to them, particularly in developing regions (UNEP, 2003).

Ground water pollution is a global issue. It is vulnerable to a variety of threats, including overuse and contamination. Ethiopia is also facing the problem of water quality degradation (Tamiru, 2006). However, the extent and degree of severity of water pollution is more prominent in major cities, like Addis Ababa where the problem is at its peak in this century (Tamiru , 2006).

In groundwater studies, GIS is commonly used for site suitability analyses, managing site inventory data, estimation of groundwater vulnerability to contamination, groundwater flow modeling, modeling solute transport and leaching, and integrating groundwater quality assessment models with spatial data to create spatial decision support systems (Balakrishnan et al, 2013). Therefore it is suggested that the use of GIS techniques is vital in testing and improving the groundwater contamination risk assessment methods. For any city, a ground water quality map is important to evaluate the water safeness for drinking and irrigation purposes and also as a preventive indication of potential environmental health problems.

The groundwater quality is equally important as that of quantity. Mapping of spatial variability of groundwater quality is of vital importance and it is particularly significant where groundwater is primary source of potable water. Considering the above aspects of groundwater contamination and use of GIS in groundwater quality mapping, this study demonstrates to map the groundwater quality in Addis Ababa city, Ethiopia.

1.2 Statement of the problem

Safe water is a precondition for health and development and a basic human right, yet it is still denied to hundreds of millions of people throughout the developing world (UNICEF, 2008). Water quality degradation is one of the major environmental problems of these days. Contamination of surface and groundwater is the most serious problems affecting the health of the population. Many major cities in Africa use groundwater for different purpose (UNEP, 2005). Rapid urbanization in most of these cities has led to unprecedented population growth, resulting in the development of large areas of unplanned and sub-standard housing. The lack of services in such informal settlements poses serious threats to groundwater through sewerage and effluent leakages, the dumping of domestic waste, and uncontrolled industrial and commercial activities. As many of these settlements rely on groundwater as their main source of potable water, such pollution poses major health risks to a large proportion of their population (UNEP, 2005). Water related diseases caused by insufficient safe water supplies coupled with poor sanitation and hygiene cause 3.4 million deaths a year, mostly among children (UNICEF, 2008). Despite continuing efforts by governments, civil society and the international community, over a billion people still do not have access to improved water sources (UNICEF, 2008).

In developing countries sources of pollution from domestic, agricultural, industrial activities are unregulated (UNEP, 2005). Likewise in Addis Ababa, where there is no as such environmental protection practice there are a number of pollutant sources that continuously deteriorate the quality of surface and ground water (Tamru, 2004).

The issue of ground water pollution has not been considered as a major problem in Ethiopia until recent times (Ketema, 2009). However, currently there is an ever increasing demand for application of fertilizers and pesticides to enhance food production. At the same time there is expansion of settlements and industries in most cases happens without the proper installation of sewer and drainage systems and poor practices of waste disposal management. So these practices polluted the ground water of Addis Ababa (Ketema, 2009).

Shallow groundwater of some urban areas contains high nitrates content, up to 300 to 950 mg/L.

In Addis Ababa and its surrounding areas, groundwater resources have been investigated in terms of potential, flow models, water quality assessment and vulnerability by different researchers. For instance Girma Hailu (2011) studies assessment of the status of nitrate pollution in selected water sources in Addis Ababa, Shilima Abebe (2011) conduct on Ground water quality problems in summit-Bole and Kotebe area. However, the scopes of these studies have been limited, because, Girma studied only the nitrate spatial distribution of Addis Ababa city. Shilma also studied ground water quality problems, but his boundary is focused only the summit bole and yeka kotebe part of Addis Ababa. In terms of ground water quality mapping using GIS there is no full documented work that incorporates all parameters (such as the distribution of chloride, Total hardness, Sulphate, Ca, Mg, TDS and NO_3, etc) set by WHO for the whole part of Addis Ababa city. According to Negash (2011) in Ethiopia there is capacity problem for water resource management to deploy modern technology such as analytical capacity, remote sensing and GIS, contract management, negotiation skills, standardization etc. Cannata (2006) recommended that GIS is a very powerful and promising tool in water resource assessment and management, because of its advantages of data collection, storage, management, analysis, format conversion, and display.

1.3 Objectives of the study

1.3.1 General objective

The main objective of the research work is to develop a groundwater quality assessment mapping approach using GIS, based on the available physico-chemical data from wells location in Addis Ababa city.

1.3.2 Specific objective

- To determine spatial distribution of groundwater quality parameters such as Hardness, TDS, Ca, Mg, NO_3-, Cl and Sulphate.
- To generate groundwater quality zone map for the Addis Ababa city.

- To create Water Quality Index (WQI).

1.4 Significance of the study

Ethiopia in general and Addis Ababa in particular uses groundwater for domestic purposes at large. The output of the intrinsic vulnerability and hazard maps are simplified forms of maps, which can be easily understood even by non professionals. The degree of spatial distribution different Physico_ Chemicals in the ground water of the study area is presented with different color legends. This helps to understand and implement by the local authorities and land planners easily. They represent an important preliminary tool in decision making pertaining to the management of groundwater quality. Generally, the maps are practical tools which can help as a road map towards the sustainable use and management of the groundwater quality in the area.

1.5 Scope and limitation of the study

Describing the overall water quality condition is difficult due to the spatial variability of multiple contaminants and the wide range of indicators that can be measured. So this study has shown seven parameters (Nitrate,calcium,Magnisum,Sulphate,TDS,Hardness and Chloride) distributions. Because of the data is not available, the spatial temporal variation of water quality map is not addressed in this research.

There were limitations or challenges faced to the researcher to accomplish this research finding. Some of the challenges were:

1. There was no enough water quality data on Addis Ababa bore holes (both during dry and rainy seasons). In general, there is no Suffient and reliable data which enable to make necessary analysis.
2. Lack of completeness: some water and waste water sampling and testing programmes have been done by AAWSA only on very limited parameters leaving the rest known.

CHAPTER TWO

Literature Review

2.1 Ground water Resource

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

2.2 Ground water quality and sources of Pollution

Groundwater quality is a hidden issue inside a hidden resource, and as a result far too little attention is given to it. Once groundwater has become polluted, it is usually a very long, complex and expensive task to restore the water quality. For these reasons that monitoring, prevention and remediation of groundwater pollution is a vital management issue (UNEP, 2003).

The quality of water either it is surface water or ground water affected by both natural influences and human activities (Chilton, 1996). Similarly (CAWST, 2013) stated that while water contains natural contaminants, it is becoming more and more polluted by human activities such as, inadequate wastewater management, dumping of garbage, poor agricultural practices, and chemical spills at industrial sites. Even though water may be clear, it does not necessarily mean that it is safe for us to drink. It is important to judge the safety of water by taking the following three types of parameters into consideration (CAWST, 2013).

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

The World Health Organization WHO (2011) divides the sources of chemicals into the following five groups.

1. Naturally occurring
2. Agricultural activities

3. Industrial sources and human dwellings

4. Water treatment

5. Pesticides used in water for public Health

Table 1: Sources of Chemical Contamination (source WHO, 2011)

Source of Chemicals	Examples	Common Chemicals
Naturally occurring	Rocks and soils	Arsenic, chromium, fluoride, iron, manganese, sodium, sulfate, uranium
Agricultural activities	Manure, fertilizer, intensive animal practices, pesticides	Ammonia, nitrate, nitrite
Industrial sources and human dwellings	Mining, manufacturing and processing industries, sewage solid waste, urban runoff, fuel leakages	Nitrate, ammonia, cadmium, cyanide, copper, lead, nickel, mercury
Water treatment	Water treatment chemicals, piping materials	Aluminium, chlorine, iodine, silver
Pesticides used in water for public Health	Larvicides used to control insect vectors of disease	Organophosphorus compounds (e.g., chlorpyrifos, diazinon, malathion) and carbamates (e.g., aldicarb, carbaryl, carbofuran, oxamyl)

2.2.1 Groundwater Quality of Ethiopia

Even though there is few data exist for the general state of groundwater quality across Ethiopia, but from those available, the quality is shown to be highly variable, ranging from fresh waters in many of the springs to more saline waters in parts of the Rift valleys (BGS, 2001). The groundwater quality of Ethiopia is both anthropogenically and naturally affected (Tamru, 2006). The main quality controls (Tamru, 2006) are: Geomorphological and geographical conditions, Climate, Geology (geological structures, rock composition, weathering, magmatism, geothermal activities,), Physico_chemical factors (temperature, pressure, chemical properties of elements, solubility of chemical compounds, pH, Eh, etc.), Biological factors (effects of micro-organisms, plants and animals) and anthropogenic influences.

Most of the accessible published information is for water quality within the Rift valley regions. From this, it is evident that groundwater in the Rift zone is influenced by geothermal waters with abnormally high concentrations of fluoride and total dissolved salts. Fluoride is a recognized major problem, especially for the communities living within the Rift. In the south, southeast and northeastern parts of the country, there is high salinity content in ground water (BGS, 2001).

2.2.2 Ground water quality of Addis Ababa

According to Girmay (2010) suggest that aquifers in and around the city of Addis Ababa are showing signs of increasing contamination by chemicals including nitrate. The level of nitrate contamination in some areas, particularly the minor aquifers is observed to be above permissible limits as defined by local and international standards. Girmay stated that at the minor aquifer nitrate values as high as 112 mg/L have been observed. This is more than twice the WHO recommended maximum limit of 50 mg/L. At the major aquifers (located in the south of the city around Akaki-Kaliti areas) values as high as 24 mg/L have been observed. This is considered to be lower than the maximum permissible value, but a steady rise has been observed (Girmay, 2010).

The ministry of water (2011) report shows that, shallow aquifers to the south of Addis Ababa are most prone to contamination .Whereas the pollution risk for the very shallow aquifer to the north of the city is less. For the deep and very deep aquifers the reverse is true. At present the highest pollution is measured around the Merkato area. The high nitrate and chloride observed at Merkato area corresponds to the maximum population density within Addis Ababa.

2.3 Sources of Ground water pollution in Addis Ababa

Water Pollution is a global problem. It occurred when humans began to farm the land and settle in villages and towns many thousands of years ago (UNEP, 2003). There are numerous sources of pollutants that could deteriorate the quality of water resources. In developing countries sources of pollution from domestic, agricultural, industrial activities are unregulated (Tamru et al, 2003). Similarly in Addis Ababa, where there is no as such environmental protection practice there are a number of pollutant sources that continuously deteriorate the quality of surface and ground water (Tamru et al, 2003). According to Tamru (2004), in the city of Addis Ababa the impact of human population on surface and groundwater is increasing. The major sources of pollutants in the study area are: industrial establishment, agricultural activities, municipal wastes, fuel stations, garages and health centers (Tamru et al, 2003). In the same way AAWSA (2000) reports shows that the sources of pollution of ground water in Addis Ababa are categorized as: Industries & Factories, Government & Private institutions, Pit-latrines & Septic Tanks, Poor Solid Waste Management, Domestic animals, Sewerage lines, Wastewater treatment Plant effluent and Surface Run-off. Generally the major sources of water pollution in Addis Ababa are explained below.

I. Impact of Industry on Degradation of Water Quality: Both in quantity and quality, industries are identified to be the first in causing sever pollution problems in Addis Ababa urban streams (AAWSA, 2000). According to UNESCO national water development report for Ethiopia (2004), about 90% of industries in Addis Ababa are simply discharging their sewage into nearby water bodies, streams and open land without any form of treatment. Most of the high water consuming industries in the Awash basin in particular in the city of Addis Ababa and in the Akaki area draw water for production purposes from water supply sources and discharge their by-product wastes in to streams and rivers without any kind of treatment (UNESCO, 2004). Besides this, there is no restriction on industrial plants discharging their wastewater into the rivers and watercourses. As cited by (UNESCO, 2004) in 1996 report of ministry of health on the study of liquid waste management, out of 118 industrial establishments assessed in the city of Addis Ababa, 40 have solid waste discharges, 61 generate air pollutant discharges while 62 generate liquid wastes that are discharged to the surrounding. Only 6 out of the investigated factories are found to have some form of wastewater treatment plants while the rest discharge their wastes without any form of treatment.

II. Government & private Institutions: Most governmental hospitals in Addis Ababa are located far from existing sewerage lines. In addition to this other institutions such as; Government offices, schools and academic institutions large number of hotels, bars, restaurants , Garages, fuel and service stations in Addis Ababa can pollute the both ground and surface water quality (AAWSA, 2000).

III. Poor solid waste management: Industrial, commercial and domestic solid waste, piled open grounds, waste-bins, stream banks, under bridges, etc are causing sever pollution problems. Uncollected solid waste is piled and littered in many parts of the city, which is often transported by storm run-off into urban streams (AAWSA, 2000).

IV. Agricultural pollution: In the urban centers of Addis Ababa agricultural pollution is dominantly associated with animal husbandry. Due to high density of cattle, large amounts of wastes are accumulated in a restricted area. As a result it contaminates the ground water (Tamru *et al*, 2003).

2.4 Ground water Vulnerability Mapping

Groundwater is vulnerable to contamination by anthropological activities and it is very difficult to remediate once contaminated. To properly manage and protect the resource, it is important to determine areas with more aspects of vulnerable to contamination (Jamil *et al*, 2011). Different models found in the literature can be applied to mapping of groundwater vulnerability. Those models are:

1. Overlay and index methods (Example, DRASTIC)
2. Process-based simulation models (Example, Numerical model)
3. Statistical methods (Example, Kriging, Logistic Regression)

Development of the vulnerability maps is useful for many aspects of water management, including prioritizing areas for monitoring, protection, and further investigation and the development of risk assessments, resource characterization, and education (Ohio EPA, 2009).

2.5 Statistical Methods of Modeling for ground water mapping

In the case of statistical models, the model parameters are commonly estimated in an objective way, following the probability theory (Hengl, 2007). The predictions are accompanied with the estimate of the prediction error. In statistical method the drawback is the input dataset usually need to satisfy strict statistical assumptions. There are at least four groups of statistical models (Hengl, 2007).

- kriging (plain geostatistics).
- environmental correlation (e.g. regression-based).
- Bayesian-based models (e.g. Bayesian Maximum Entropy).
- mixed models (regression-kriging).

2.5.1 Basic Kriging (ordinary, Universal)

kriging is based on statistical models that include the statistical relationship among the measured points. It is the best unbiased predictor whether or not the data is normally distributed. However if the data is normally distributed, kriging is the best predictor among all unbiased predictors (ESRI, 2001). Kriging method involves three steps (Kumar et al, 2013).

1.Exploratory data analysis: Exploratory data analysis has been performed to explore data consistency, removing outliers and identifying statistical distribution where data came from Kriging methods work best for normal distribution data (ESRI, 2003). Using measured sample points from a study area, Geostatistical analyst can create accurate predictions for other unmeasured locations within the same area. Exploratory spatial data analysis tools included with Geo statistical analyst are used to assess the statistical properties of data such as spatial data variability, spatial data dependence, and global trends (ESRI, 2003).

2. Structural analysis of data: Spatial correlation or dependence can be quantified with semivariograms (or variograms). Kriging relates the semivariogram, half the expected squared difference between paired data values z(x) and z(x + h) to the distance lag h, by which locations are separated.

3. Prediction: Semivariogram models (Circular, Spherical, Exponential, and Gaussian,) used to test for each water quality parameters. Predictive performances of the fitted models were checked on the basis of cross validation tests. The values of mean error (ME), mean square error (MSE), root mean error (RMSE), average standard error (ASR) and root mean square standardized error (RMSSE) were estimated to ascertain the performance of the developed models (Kumar et al, 2013).

Advantages of kriging

Though, there are many interpolation techniques available but Kriging is most suitable and having many advantages over others (Kumar, 2013). Because of:

-Helps to compensate for the effects of data clustering, assigning individual points within a cluster less weight than isolated data points (or, treating clusters more like single points).

- Gives estimate of estimation error (kriging variance), along with estimate of the variable, *Z*, itself (but error map is basically a scaled version of a map of distance to nearest data point, so not that unique).
- Availability of estimation error provides basis for stochastic simulation of possible realizations of *Z*(u) (Bohling, 2005).

Disadvantage of kriging

In kriging method, searching for semivariograms and determining the best fitted semivariogram model and preparing the required statistical assumptions is a time consuming and trial and error procedure (Mashagbah *et al*, 2012).

2.5.2 Spline Method

spline estimates values using a mathematical function that minimizes overall surface curvanture, resulting in a smooth surface that passes exactly through the input points (ESRI, 2001).

2.5.3 Inverse Distance Weighted

IDW estimates cell values by averaging the values of sample data points in the vicinity of each cell. The closer a point is to the center of the cell being estimated, the more influenced, or weight, it has in the averaging process. This method assumes that the variable being mapped decreases in influence with distance from its sample location (ESRI, 2001). The disadvantage of IDW is that the quality of interpolation result can decrease, if the distribution of each sample data points is uneven, and also maximum and minimum values in the interpolated surface can occur at sample data points (Ishaku *et al*, 2011).

2.6 Geo statistical Methods in Water Quality Analyses

2.6.1 Arc GIS spatial Analyst

There are a number of strengths that GIS technologies bring to water resources research. GIS allows for improved database organization and storage (John, 2003). Spatial Analyst is an optional extension (separately purchased add-on program) for ESRI’s ArcView and ArcGIS software packages. The Spatial Analyst Extension adds raster GIS capability to the ArcView and

ArcGIS vector GIS software. Spatial Analyst allows for use of raster and vector data in an integrated environment and enables desktop GIS users to create, query, and analyze cell based raster maps, derive new information from existing data, query information across multiple data layers, and integrate cell-based raster data with vector data sources (Shamsi, 2005).

2.6.2 GIS Interpolation

Interpolation is the process by which a surface is created, usually a raster dataset, through the input of data collected at a number of sample points. There are several forms of interpolation, each which treats the data differently, depending on the properties of the data set (ESRI, 2003). All interpolation algorithms (inverse distance squared, splines, radial basis functions, triangulation, *etc.*) estimate the value at a given location as a weighted sum of data values at surrounding locations.

2.7 The principles of Geo statistical analysis

Geostatistical Analyst uses sample points taken at different locations in a landscape and creates (interpolates) a continuous surface. Geostatistical analyst provides two groups of interpolation techniques: deterministic and geostatistical. All methods rely on the similarity of nearby sample points to create the surface. Deterministic techniques use mathematical functions for interpolation. Geostatistics relies on both statistical and mathematical methods, which can be used to create surfaces and assess the uncertainty of the predictions (ESRI, 2003).

2.8 Estimation of ground water quality index (GWQI)

WQI is computed to reduce the large amount of water quality data to a single numerical value. It reflects the composite influence of different water quality parameters on the overall quality of water. It is a very useful tool for communicating the information on the overall quality of water. The standards for purposes of drinking should have been considered for the calculation of WQI as recommended by World Health Organization (WHO). The formula used to determine the aggregated water quality index is given below equation (Kumar et al, 2013).

$$\mathrm{WQI} = \sum_{i=1}^{n} \mathrm{WiIi}$$

Where,

I_i is the sub-index of i^{th} water quality parameter

WQI is water quality index and ‘n’ is the number of water quality parameters considered.

W_i is the weightage of the i^{th} water quality parameter.

2.9 Spatial distribution of ground water quality

Unlike microbiological contamination, most chemicals in drinking water pose a health concern only after years of exposure. Often chemical contamination goes unnoticed until disease occurs due to chronic exposure (CAWST, 2013). The severity of health effects depends upon the chemical and its concentration, as well as the length of exposure. There are only a few chemicals that can lead to health problems after short term exposure, such as nitrate, unless there is a massive contamination of a drinking water supply (WHO, 2011). It is not possible to test water for all of the chemicals that could cause health problems. Most chemicals occur rarely, and many result from human contamination of a small area, affecting only a few water sources. However, three chemicals have the potential to cause serious health problems and occur over widespread areas. These are arsenic and fluoride, which can occur naturally, and nitrate, which is commonly used in fertilizer for agriculture. These three contaminants are more often found in groundwater, though surface water can also be impacted (CAWST, 2013).

Nitrate (NO_3-)

The main source of nitrate in water is from atmosphere, legumes, plant remains and animal excreta (WHO, 2011). It also originates from sewage effluents, septic tanks and natural drains carrying municipal wastes. NH_{4+} from organic sources is converted to NO_3^- by oxidation. Because of this and its anionic form NO_3^- is very mobile in groundwater (Balakrishnan et al, 2011). The concentration of nitrate in natural water is less than 10 mg/L. Water containing more than 100 mg/L is bitter to taste and causes physiological distress.

The ground water nitrate distribution in Addis Ababa was shown by Girma Hailu (2011) in figure 1 below. The study result shows that high and very high nitrate concentration is found in the central part of the city. Other localities of the study area were seen to have from low to moderate concentrations of nitrate.

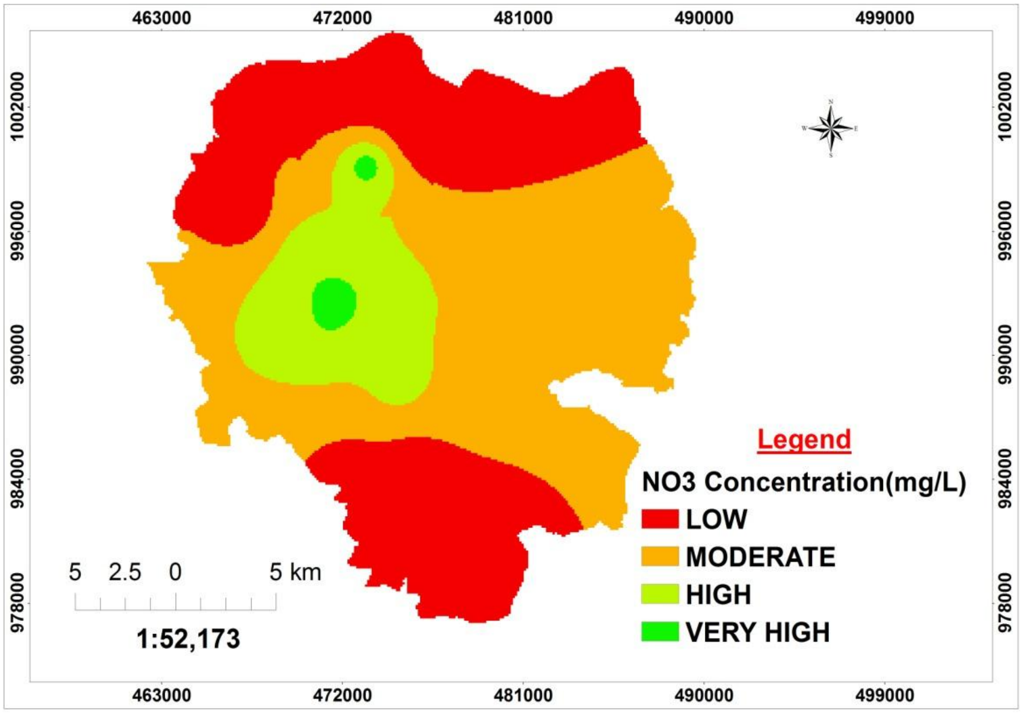


Fig.1: Nitrate distribution map from wells (Source: Girma Hailu, 2011)

Chloride (Cl^-)

Chloride is minor constituent of the earth's crust. Chloride in drinking water originates from natural sources, sewage and industrial effluents, urban runoff containing salt, and saline intrusion (WHO, 2011). High concentration of chloride gives a salty taste to water and beverages and may cause physiological damages. Water with high chloride content usually has an unpleasant taste and may be objectionable for some agricultural purposes. The value of chloride was below WHO recommended unit for most of the water sample from Yaka-Kotebe and Summit-Bole area parts of Addis Ababa. However, the value is higher for water sample from central part of the study area due to anthropogenic impact (Shilima, 2011**).**

2.10 Guidelines for water quality parameters

Safe drinking water is required for all usual domestic purposes, including drinking, food preparation and personal hygiene. Every effort should be made to achieve drinking water that is as safe as practicable (WHO, 2011).

The nature and form of drinking water standards may vary among countries and regions. There is no single approach that is universally applicable. It is essential in the development and implementation of standards that the current or planned legislation relating to water, health and local government is taken into account and that the capacity of regulators in the country is assessed. Approaches that may work in one country or region will not necessarily transfer to other countries or regions. It is essential that each country review its needs and capacities in developing a regulatory framework (WHO, 2011). Based on the water quality standards stipulated by the WHO ranks were assigned for each parameter depending on the respective tested values, as given in the Table 2.

Table 2: Drinking Water Quality Standards of Ethiopia and WHO (sources: from Ethiopian standard guidelines ES 261:2001 and WHO, 2011)

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

CHAPTER THREE

3. Materials and methods

3.1 Description of the study area

3.1.1 Location

Addis Ababa is located in the central highlands of Ethiopia, which covers an area of about 540 km^2. Its geographic location is between 38.638° and 38.906° east and 8.832° and 9.09° north. The administration of the city is divided in to ten sub-cities: Bole, Arada, Cherkos, Kolfe Keraniyo,Addis ketema, Lidata, Akaki-Kaliti, Gullele, Nefas-Silk Lafto and Yeka.

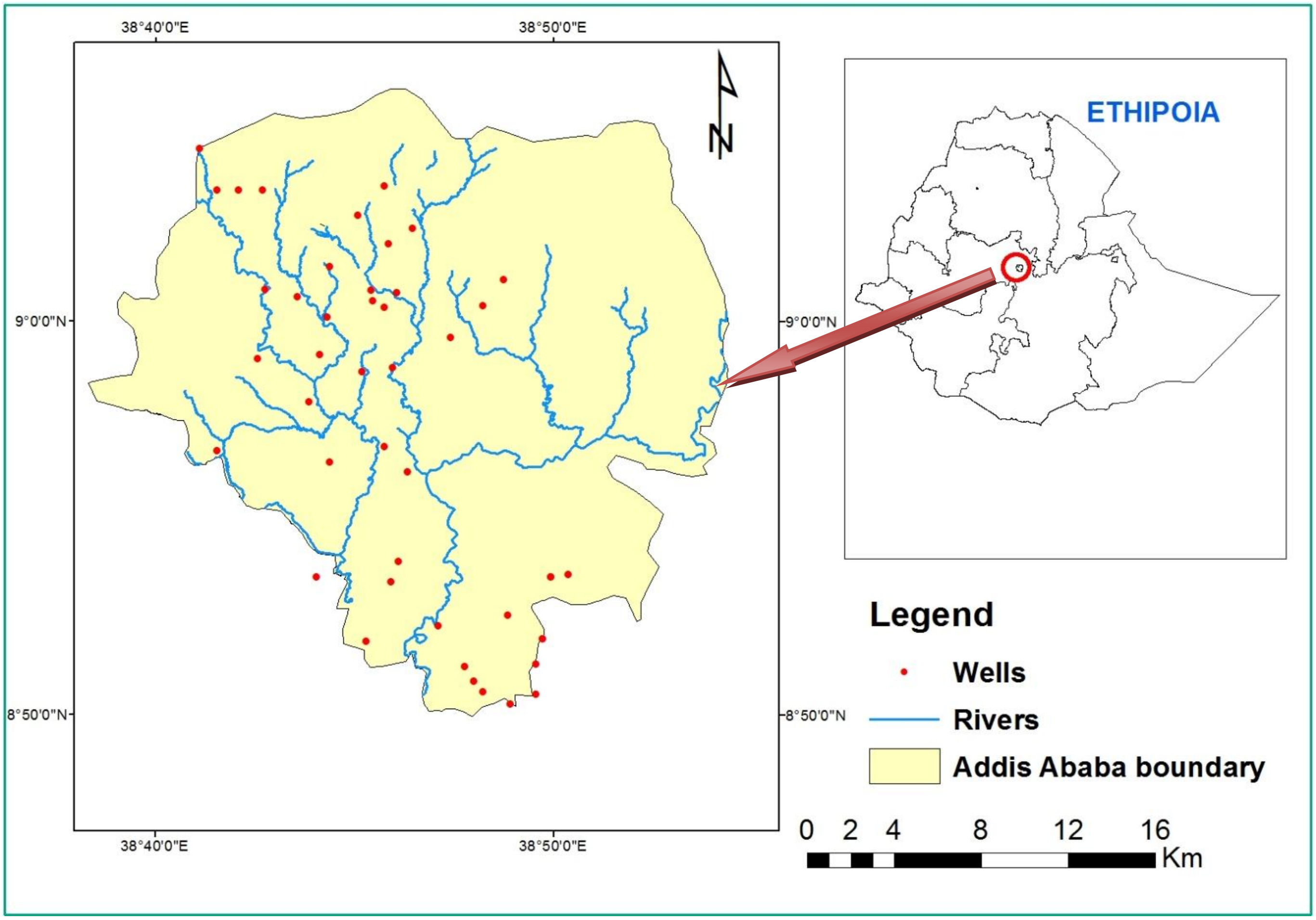


Figure .2: Map of the Study Area

3.1.2 Population size

According to city government of Addis Ababa 2011/2012 report, the total population of Addis Ababa was estimated to 3,048,631 of whom 1,595,968 were females and the rest 1,452,663 were males. This is 3.71 percent of Ethiopian population of 84.3 million and 22.42 percent of urban population (14 million). The population size of sub-Cities varies in space. As a result Kolfe Keranyo (15.66%), Yeka (12.65%), Nefas Silk (11.55%) and Bole (11.28%) have the largest share of population of the city respectively. On the other hand, Lideta (7.36) Sub-city has the smallest share of the city's population.

3.1.3. Climate

Addis Ababa has a Subtropical highland climate. The city has a complex mix of highland climate zones, with temperature differences of up to 10 °C (18 °F), depending on elevation and prevailing wind patterns (Tamru et al, 2003). The high elevation moderates temperatures year round, and the city's position near the equator as a result temperatures are very constant from month to month. Addis Ababa was voted as the city with the best and the most stable weather in the world. It has 9.9 to 22.7$^{o}{}_{C}$ average monthly minimum and maximum temperature respectively. It has also 1205.2 mm annual precipitation. The climate of the city ranges from temperate to cool temperate (Weina-Dega to Dega). Maximum temperature, minimum temperature and annual rainfall of the city are shown in the following two figures.

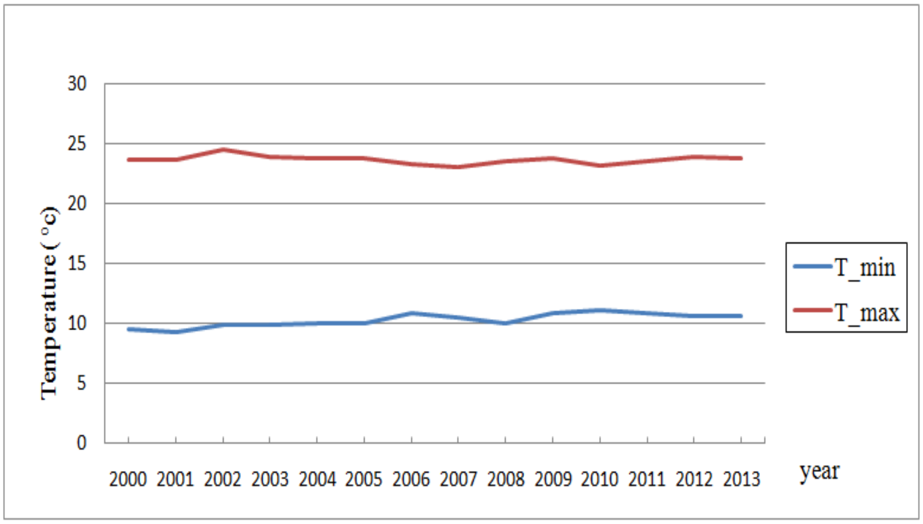


Fig .3: Maximum and minimum temperature of Addis Ababa from 2000 to 2013 (Source: metrology agency, 2014)

Fig. 4: Annual rainfall of Addis Ababa from 2000 to 2013 (Source: metrology agency, 2014)

3.1.4 Water resources and supply

Water access and adequacy is one of the conditions that make an urban centre comfortable place to live in. The city administration provided water for its residents from underground (70,152,807 m^3) and surface water sources (42,062,760 m^3) (AAWSA, 2000).

Available potential water resources in and around Addis Ababa are generally classified in to two major groups.

1. Surface water resources (rivers, streams, lakes and artificial dams)
2. Ground water resources (shallow and deep wells and springs)

Available ground water potential in and around Addis Ababa is further classified as:

- ✓ Deep aquifer system, exploited through drilling of deep bore holes
- ✓ Shallow aquifer system –through hand dug wells
- ✓ Confined aquifer –through artesian wells and
- ✓ Gravity springs.

3.2 Physiography

Addis Ababa is located on the shoulder of the Western Main Ethiopian Rift escarpment. It's elevation ranges generally between 1780 m and 3380 meter a.m.s.l. However, the portion of the area with elevation greater than 3200 meter a.m.s.l is negligibly small. The Northern part is within the elevation range of 2670 meter and 3000 meter a.m.s.l. This area is very sloppy, however, both elevation and slope decreases progressively towards the South. A large portion of the central part of the project area falls in a narrow elevation range of 2313 and 2491 meter a.m.s.l. As shown digital elevation model map below Proceeding further South wards, the topography becomes very gentle and a very wide area falls under a smaller elevation range of 2053 meter and 2192 meter a.m.s.l.

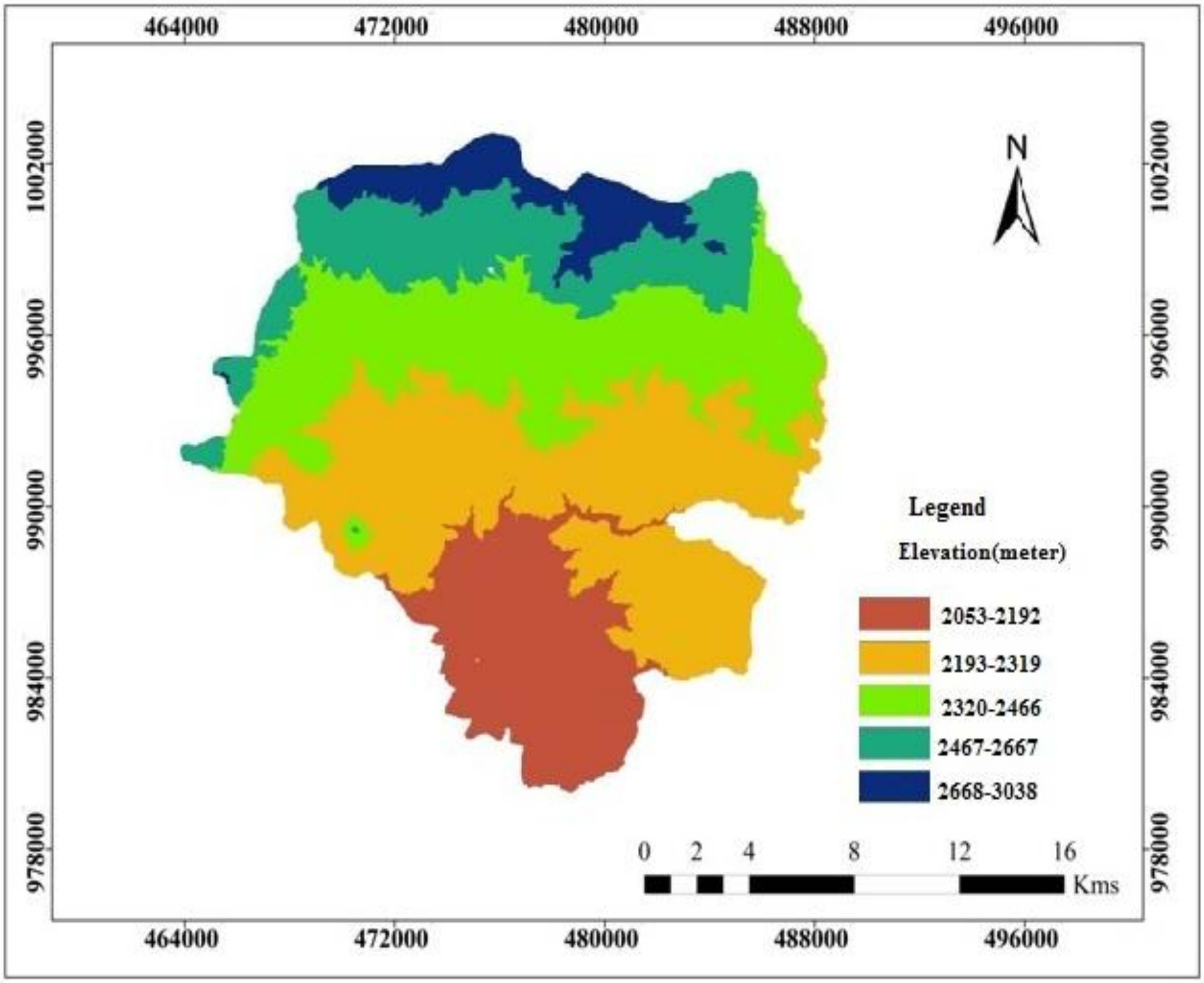


Fig. 5: Topographic map of Addis Ababa

3.3 Land use

Land use activities have direct impacts on water quality, while water quality greatly influences the sitting of land use activities. Inappropriate land use, particularly poor land management, causes chronic groundwater quality problems. Acute groundwater quality problems are common and arise from unsuitable land use (Omran, 2012).

For effective urbanization and organized urban development, a well thought urban planning exercise is a prerequisite. Even though land is the largest economic resource of Addis Ababa, the land use pattern is characterized by haphazard development which mainly geared towards horizontal expansion (Finance and economic development office report, 2010). Particularly, most of the riverside areas in the city are not well kept and utilized as per the acceptable standard. For this research the city of Addis Ababa is classified in to five generalized land use land cover categories. As it shows in Figure 6 below the land use class are Commercial, plantation area, Field crop, residential and under construction.

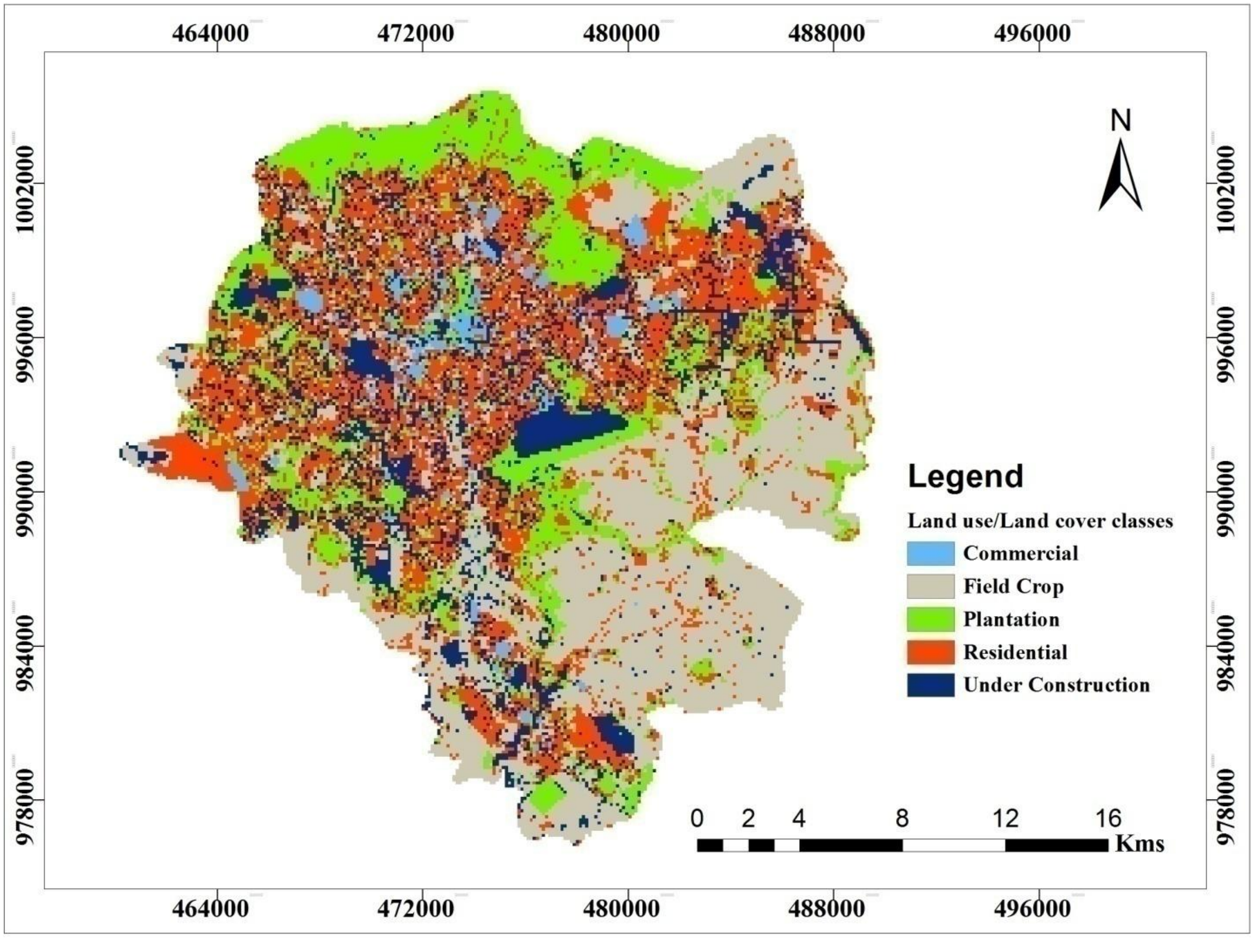


Fig .6: Land use land cover map of Addis Ababa

3.4 Methodology

3.4.1 Sources of data

Water quality data for a number of 564 wells were collected from Addis Ababa water and sewerage Authority. This data set were obtained in the year 2012 of average data both dry and wet season. The data set includes measurements of several physical and chemical parameters of ground water obtained by Laboratory analytical techniques done by AAWSA. Out of 564 wells 181 are located outside city's administrative boundary .i.e. the project area which includes AAWSA water supply sources, geographically extends far beyond the current limit of the city's administration. So that the wells which are found surrounding of the city border are used for as data sources to interpolation purpose. Furthermore, in order to generate the environmental pollution research, it is difficult to follow man made administrative boundary.

3.4.2 Preparation of well location point feature

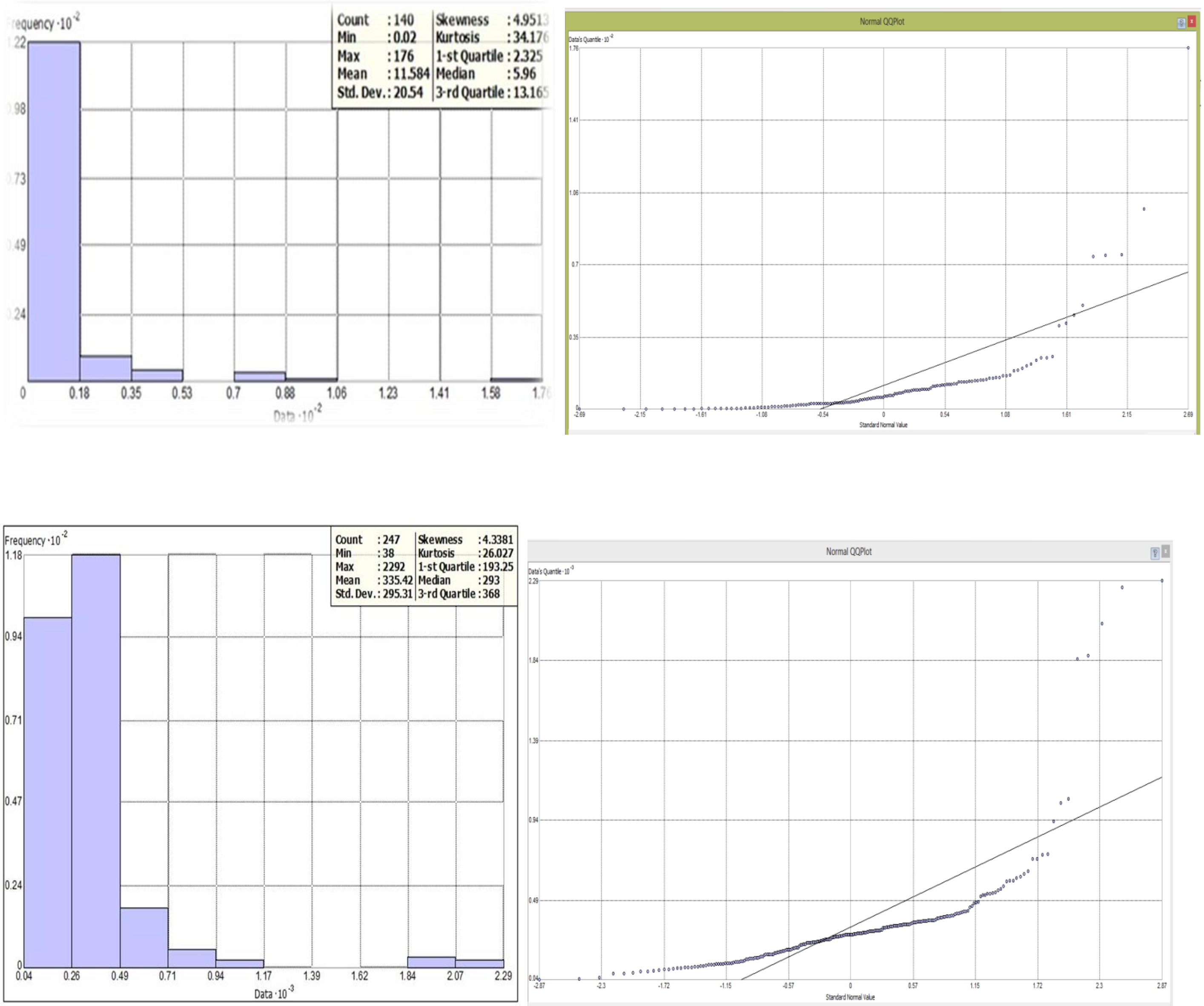
Based on the location data obtained, point feature showing the position of wells was prepared. The water quality data thus obtained forms the non-spatial database. Water quality data stored in excel format and linked with the spatial data by join option in Arc Map and then changed in to shape file. The spatial and the non-spatial database formed are integrated for the generation of spatial distribution maps of the water quality parameters.

3.4.3 Kriging interpolation Techniques

The dataset of water quality parameters were imported into Arc Map software. The ESRI Geographic information system (GIS) was used for the construction of the interpolation surfaces through applying the 'Geostatistical Analyst' extensions of ArcGIS 10 software package. Arc Map is very powerful for visualization and processing with user intervention. In this study Kriging method was applied because, it is recognized that the statistical approach (geostatistical methods), has several advantages over the deterministic techniques. The fact of giving unbiased predictions with minimum variance and taking into account the spatial correlation between the data recorded at different locations is an important advantage of Kriging. Moreover, besides interpolation, Kriging provides information on interpolation errors. Such values can be mapped to generate error surfaces which inform about the reliability of estimates. Out of different Kriging techniques, the ordinary Kriging (OK) method was used because of according to Kumar (2013) states that using ordinary kriging is better than other kriging methods because of its prediction accuracy. Kriging is an advanced interpolation procedure that generates an estimated surface from an x-y scattered set of points with z values.

3.4.4 Examining the distribution of the data

In the Arc GIS Geostatistical analyst, the histogram and normal QQ Plots were used to see the distribution of data. The quantile-quantile (QQ) plot is used to compare the distribution of the data to a standard normal distribution, providing another measure of the normality of the data. Normal QQ Plots provide an indication of univariate normality. If the data is asymmetric (i.e. far from normal), the points were deviate from the line. The histogram tool provides a univariate (one variable) description of the data. The tool displays the frequency distribution for the data set and calculates summary statistics. If the data is not normally distributed, it should be transformed by using log transform application. The histograms and normal QQ plots were plotted as shown in Figure belows to check the normality of the observed data. Histogram and QQ Plot analyses were carried out for each water quality parameter and it was found that all the analyzed parameters Nitrate, TDS, Chloride, Ca, Mg, Hardness and Sulphate showed skewed distribution.


Count : 140
Min : 0.02
Max : 176
Mean : 11.584
Std. Dev. : 20.54
Skewness : 4.9513
Kurtosis : 34.176
1-st Quartile : 2.325
Median : 5.96
3-rd Quartile : 13.165

Count : 247
Min : 38
Max : 2292
Mean : 335.42
Std. Dev. : 295.31
Skewness : 4.3381
Kurtosis : 26.027
1-st Quartile : 193.25
Median : 293
3-rd Quartile : 368

Fig .7: Histogram and QQ plot of Nitrate and TDS respectively

From the above Histogram and QQ plot of Nitrate and TDS shows that, the distribution of water quality data set are highly skewed and asymmetrical. The skewed amount of Nitrate and TDS are 4.95 and 4.33 respectively. So it has been log transformed to be closer from a normal distribution. Histogram and QQ plot of log transformed data presented in appendix 1.

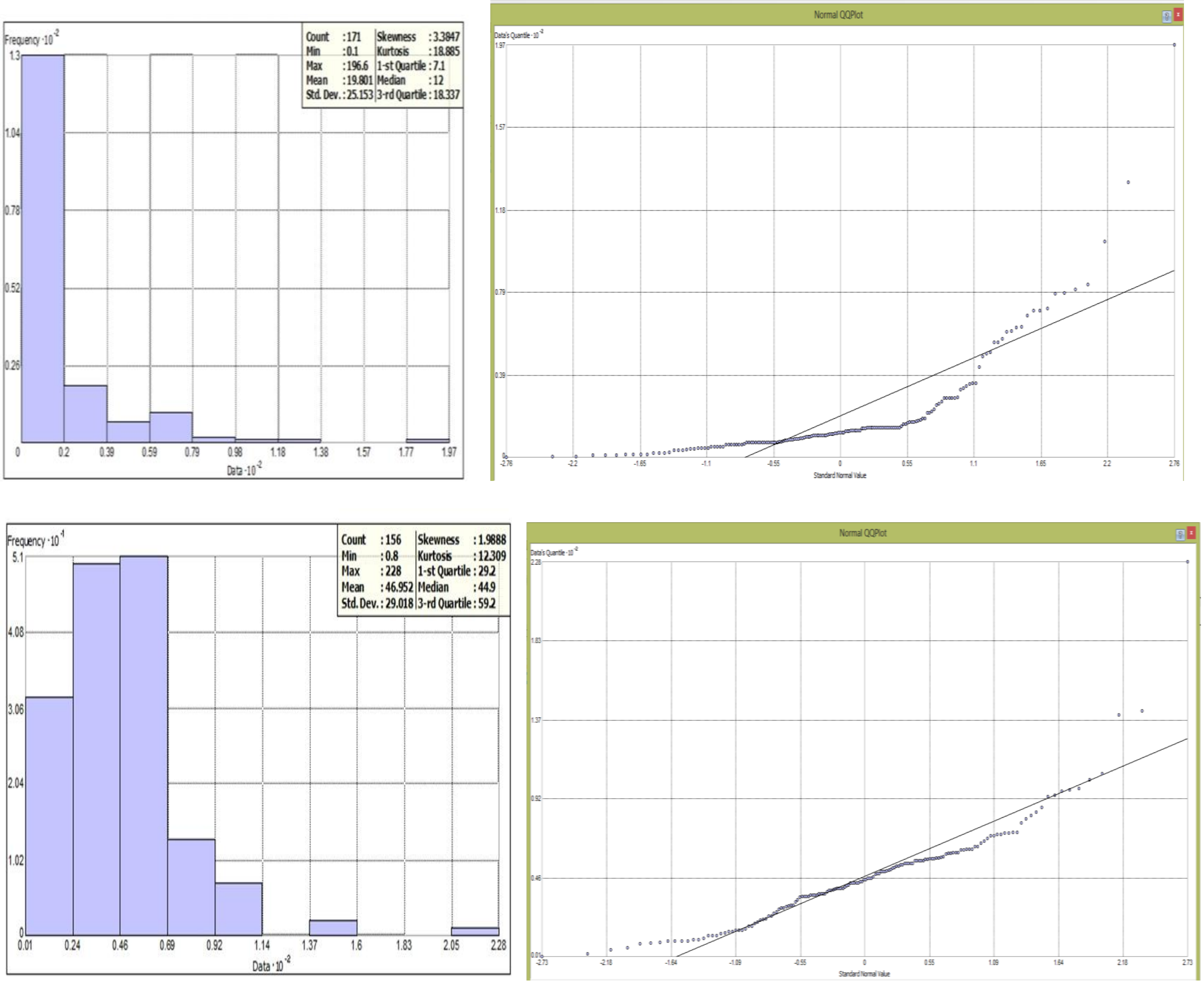


Fig.8: Histogram and QQ plot of Chloride and Calcium respectively

From the above Histogram and QQ plot of Chloride and Calcium shows that, the distribution of water quality data is skewed and asymmetrical. The skewed amount of Chloride and Calcium are 3.38 and 1.98 respectively. So it is not normal distribution, therefore, the log transformation of data was applied to be closer from a normal distribution. Histogram of log transformed data is presented in appendix 1. After the log transformation, the Chloride and Calcium concentrations are approximately normally distributed.

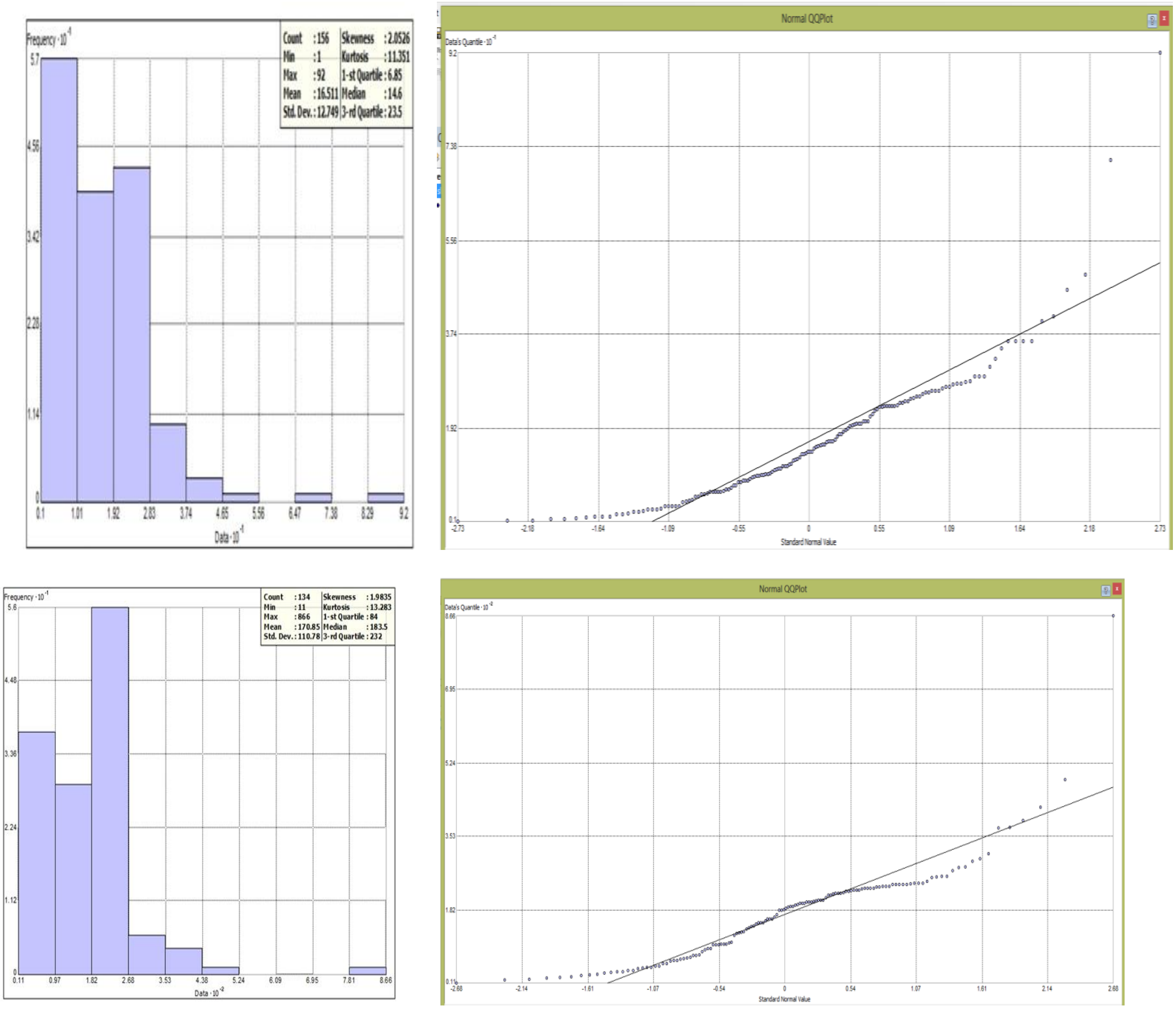


Fig .9: Histogram and QQ plot of Magnesium and hardness respectively

From the above Histogram and QQ plot of Magnesium and hardness shows that, the distribution of water quality data is skewed and asymmetrical. The skewed amount of Magnesium and hardness are 2.05 and 1.98 respectively. So it is not normal distribution, therefore, the log transformation of data was applied to be closer from a normal distribution. Histogram of log transformed data is presented in appendix 1. After the log transformation, the Magnesium and hardness concentrations are approximately normally distributed.

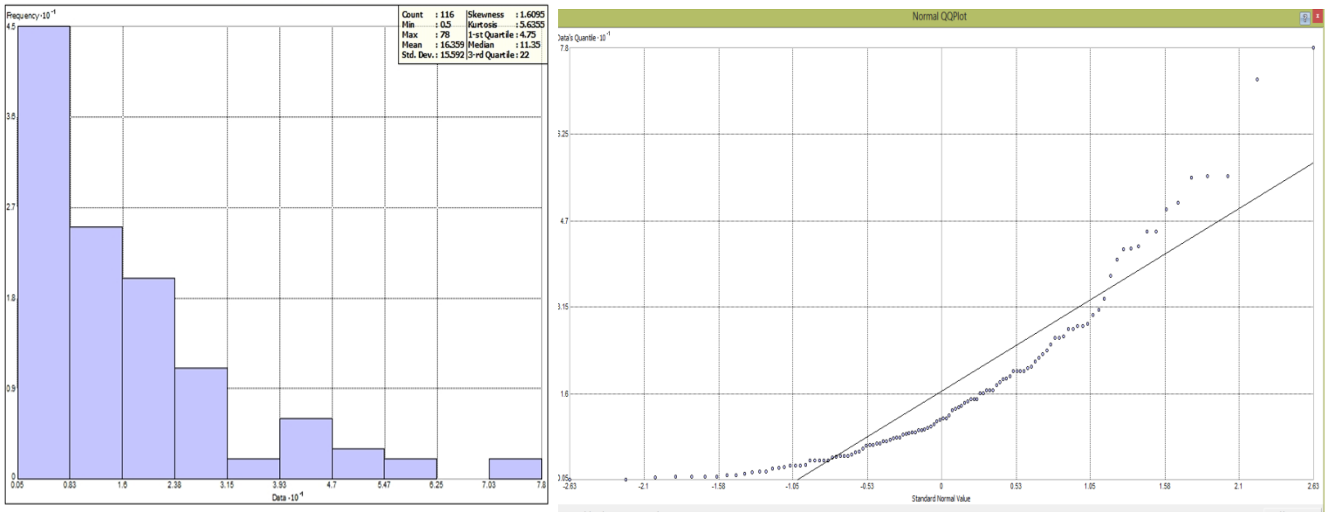


Fig. 10: Histogram and QQ plot of sulphate

From the above Histogram and QQ plot of Sulphate shows that, the distribution of water quality data is skewed by 1.6 and asymmetrical. So it is not normal distribution, therefore, the log transformation of data was applied to be closer from a normal distribution. Histogram of log-transformed data is presented in appendix 1. After the log transformation, the Sulphate concentrations are approximately normally distributed.

3.4.5 Log transformation

Log transformation is one of the widely used methods for data normalization. Kriging methods work best if the data are approximately normally distributed. The application of any interpolation method for the spatial interpolation of data assumes a normal distribution. It is a pre-requisite to transform skewed data into a normal distribution before applying to any geostatistical analysis. So in this study the water quality parameters such as Hardness, TDS, Ca, Mg, NO3, Cl and Sulphate are highly skewed in their distribution. So in order to minimize the error for those parameters, a log transformation has been applied to make the distribution closer to normal.

3.4.6 Semivariogram models

In this study, the semivariogram models (Spherical, Stable, Exponential and Gaussian) were tested for each parameter data set. Prediction performances were assessed by cross validation.

Cross validation allows determination of which model provides the best predictions. According to Berktay and Nas (2008), for a model that provides accurate predictions, the standardized mean error should be close to 0, the root mean square error and average standard error should be as small as possible (this is useful when comparing models), and the root mean square standardized error should be close to 1.

3.4.7 Cross validation results

According to the cross-validation results presented in table 3 below all models proved robust and can thus be used to predict values and create surfaces.

Table 3: Cross_validation results for ordinary kriging

Parameters	Best fitted Models	Number of samples	Prediction errors				
			Mean	Root-mean square	Average standard error	Mean standardized	Root-mean-square standardized
Ca^{2+}	Gaussian	156	-0.30097	27.74338	31.0446	-0.0052258	0.9198172
Mg^{2+}	Gaussian	156	0.002169748	11.82397	11.8782	-0.0001535	1.018596
Cl^{-}	Exponential	171	0.1501	24.8545	31.7748	0.00308	0.8064344
No^{-}_{3}	Stable	140	0.09289	15.3728	11.8127	0.010297	1.27816
TDS	Spherical	247	1.318391	229.35520	314.5023	0.00202	0.77038446
So_4^{--}	Gaussian	116	-0.24710	14.12892	14.004	-0.0163	0.9782
Hardness	Stable	134	-1.4692	101.4403	115.8076	-0.00477	0.8895

3.4.8 Procedures to generate water quality index (WQI)

To generate the ground water quality index (WQI) map, nine parameters such as TDS, hardness, nitrate, Chloride, Sulphate, Magnesium, calcium, fluoride and PH were selected from the data set. Standards for drinking water were chosen since human health is taken as priority besides the high quality of water makes it suitable for drinking purposes. Those nine parameters fall under the category of chemically derived contaminants that could alter the water taste, odor or appearance and affect its acceptability by consumers (WHO, 2011). Ethiopian standards and

WHO (2011) standards for drinking purposes have been considered for the calculation of WQI. To compute WQI four steps were followed.

First step:

Each of nine parameters has been assigned a weight (Wi) according to its relative importance in the overall quality of water for drinking purposes (Table 4). The maximum weight of 5 has been assigned to parameters such as nitrate due to their major importance in water quality assessment (Srinivasamoorthy *et al*, 2008). Other parameters like calcium, magnesium and sodium were assigned a weight between 1 and 5 depending on their importance in the overall quality of water for drinking purposes.

Table 4: Ethiopian standards weight (wi) and calculated relative weight (Wi) for each parameter (*source, Srinivasamoorthy et al, 2008*)

Drinking Water Quality Parameter	Ethiopian Standard (mg/L)	Weight (Wi)	Relative Weight (WI)	Relative Weight (%)
Nitrate	50	5	0.17	17
Fluoride	1.5	4	0.13	13
Magnesium	50	2	0.07	7
Chloride	250	3	0.10	10
Calcium	75	2	0.07	7
Hardness	300	2	0.07	7
Sulphate	250	4	0.13	13
TDS	1000	4	0.13	13
PH	6.5 to 8.5	4	0.13	13
Total		30	1	100

Second step

The relative weight (WI) is computed using a weighted arithmetic index method given below (Panwar *et al*, 2012) in the following steps.

$$\mathrm{WI}= \frac{Wi}{\sum_{i=1}^{n} Wi}$$

Where, WI is the relative weight, wi is the weight of each parameter and n is the number of parameter.

Third step:

A quality rating scale (Qi) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines of WHO (2011) and then multiplied by 100.

$Qi = (Ci / Si) \times 100$

Where Qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/L, and Si is the WHO drinking water standard for each chemical parameter in mg/L according to the guidelines of WHO (2011)…………….. (See appendix 2)

Fourth step:

The SIi is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation:

$SI_i = W_i \times Q_i$

Where SI_i is the sub index of i^{th} parameter and Q_i is the rating based on concentration of i^{th} parameter. The overall water quality index (WQI) was calculated by adding together each sub index values of each groundwater samples as follows:

$$\mathbf{WQI = \sum SI_i}$$

Water quality types, were determined on the basis of WQI. The last result of WQI off the study area is ranged between 17 and 233. (See appendix 2)

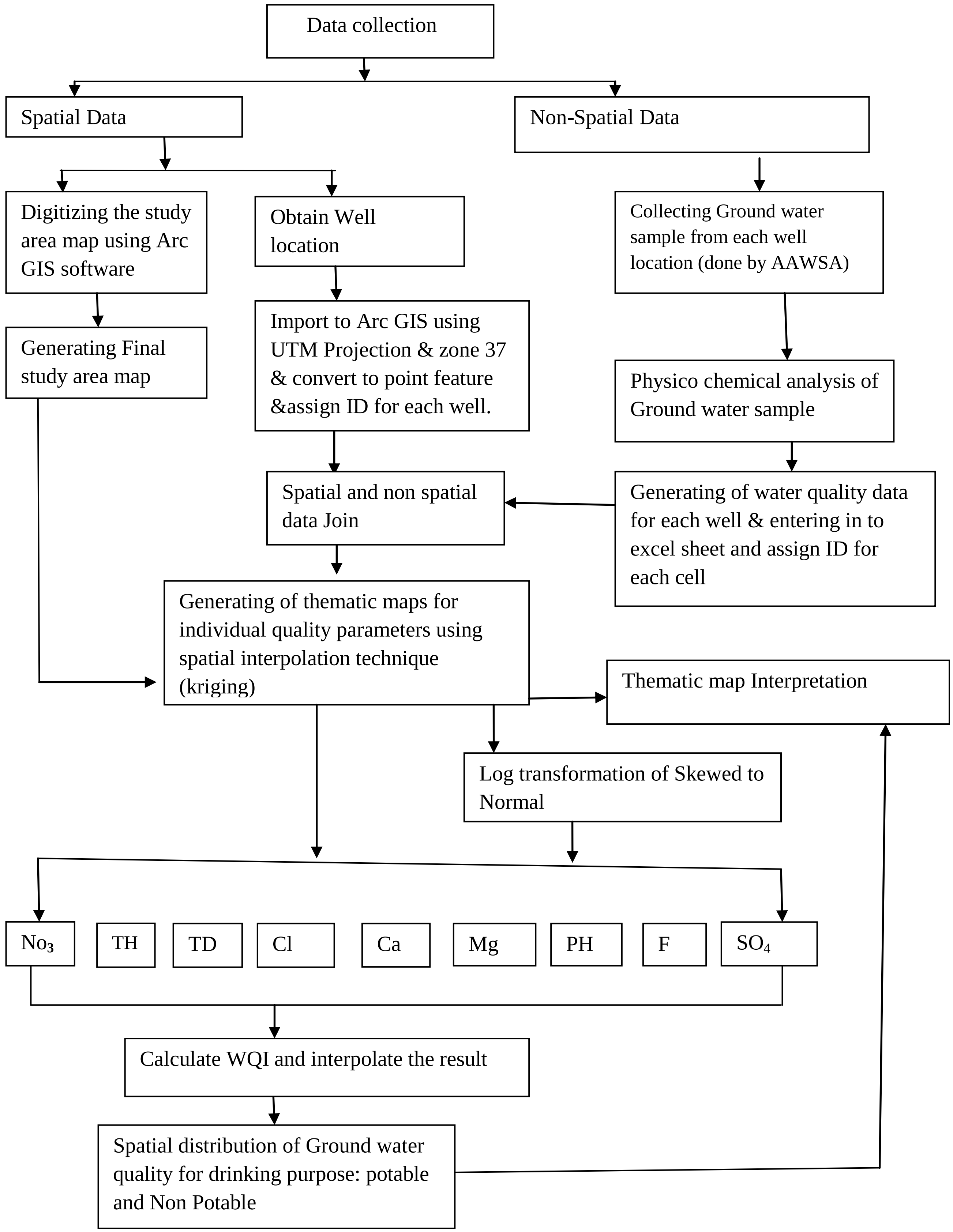


Fig .11: Flow chart of the method

CHAPTER FOUR

4. Results and Discussion

4.1 Spatial distribution of ground water

Groundwater quality maps are useful in assessing the usability of the water for different purposes. The spatial and attribute data are integrated for the generation of spatial variation maps of major water quality parameters like, Nitrate, Total Dissolved Solids (TDS), Total hardness, Sulphates, Calcium, and magnesium. Based on these spatial variation maps of major water quality parameters, an Integrated Groundwater quality map of the study area was prepared using GIS. This integrated groundwater quality map helps us to know the existing groundwater condition of the study area.

4.1.1 Nitrate

Nitrate is very mobile in water, and groundwater typically contains higher levels than surface water. Nitrate concentrations in the well samples of study area showed high spatial variations and ranged from 0.02 to 176 mg/L with a mean and standard deviation as 11.58 and 20.54 respectively. As seen from the analyzed data (Table 5) and Figure 12 below, concentration of nitrate was seen highly polluted in the central western sides of the study area. The nitrate concentrations at this part is higher than the guideline or standard value of 50 mg/L set by WHO and Ethiopian standard for drinking water specifications.

Table 5: Statistical evaluation of groundwater quality parameters

No	Hydrochemicla parameter	Number of data	Min	Max	Mean	Median	Std	Skewness	Kurtosis	Model Type
1	Ca^{2+}	156	0.8	228	46.95	44.9	29.018	1.9888	12.309	Gaussian
	Ca^{2+a}	156	-0.22	5.42	3.629	3.8044	0.7672	-1.5225	7.16	
2	Mg^{2+}	156	1	92	16.511	14.6	12.746	2.0526	11.351	Gaussian
	$Mg^{2+\ a}$	156	0	4.521	2.47	2.681	0.9004	-0.7223	3.0489	
3	Cl^{-}	171	0.1	196.6	19.801	12	25.153	3.3847	18.885	Exponential
	$Cl^{-\ a}$	171	-2.30	5.28	2.44	2.4849	1.0929	-0.5847	5.1074	
4	No^{-}_{3}	140	0.02	176	11.58	5.96	20.54	4.9513	34.176	Stable
	$No^{-}_{3}\ ^{a}$	140	3.91	5.17	1.48	1.7843	1.6544	-0.9749	4.2997	
5	TDS	247	38	2292	335.4	293	295.31	4.3381	26.027	Spherical
	TDS ^{a}	247	3.63	7.73	5.60	5.6802	0.61	0.17503	4.7665	
6	So_4^{--}	116	0.5	78	16.359	11.35	15.592	1.6095	5.6355	Gaussian
	$So_4^{--\ a}$	116	0.693	4.35	2.29	2.429	1.1213	-0.565	2.86	
7	Hardness	134	11	866	170.85	183.5	110.78	1.9835	13.283	Stable
	Hardness ^{a}	134	2.39	6.76	4.8979	5.2122	0.7809	-0.8858	3.3151	

^{a} = Transformed using logarithm.

The above table represents the summary of the statistical evaluation of hydrochemical parameters analyses conducted on the samples. It also shows characteristics parameters of best fitted semivariogram models of groundwater quality parameters in the study area. The results shows that the best fit model for the prediction of Ca, Mg, Cl, NO_3 , TDS, SO_4, and Total Hardness(TH) were gaussian, gaussian, exponential, Stable, spherical, gaussian and Stable respectively.

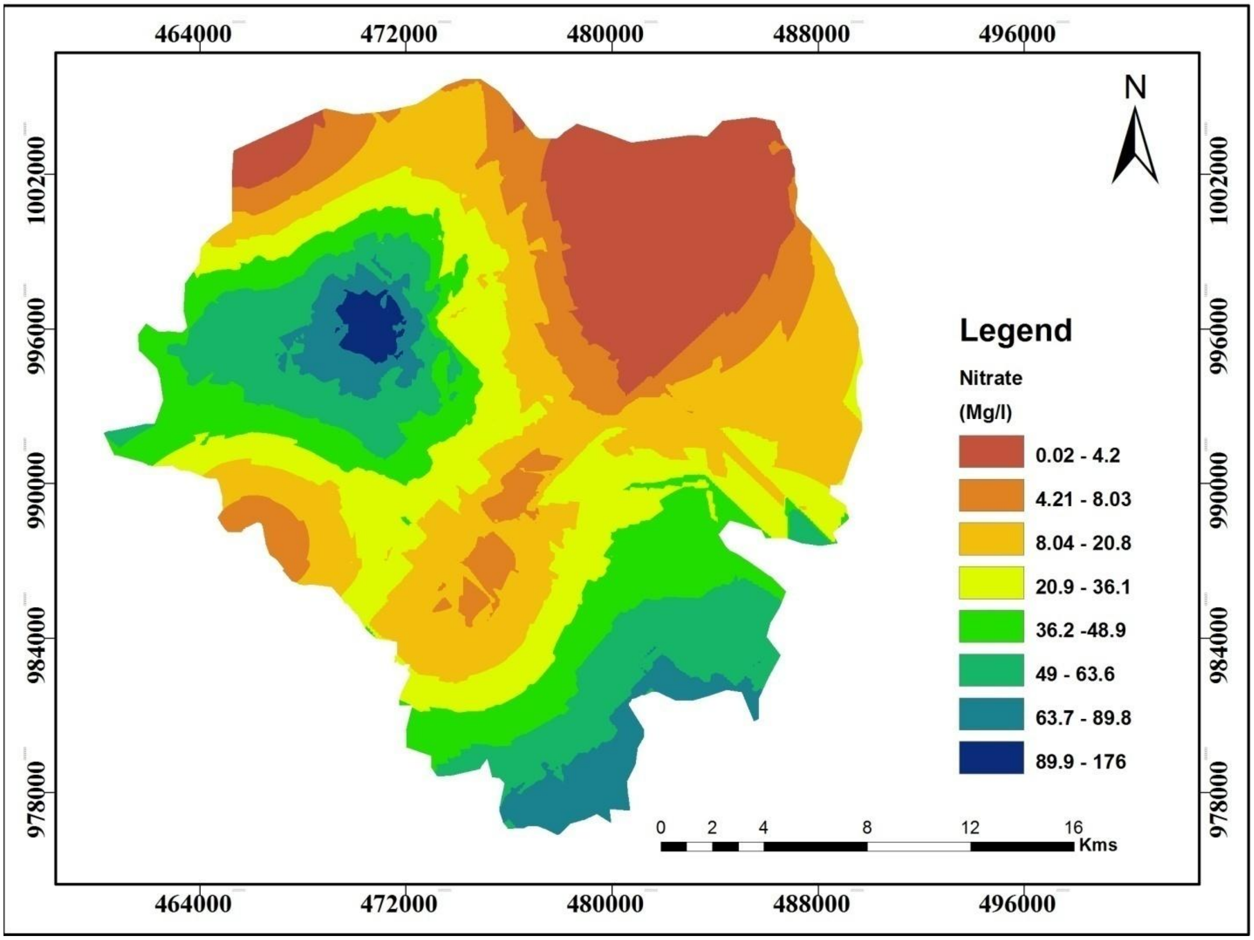


Fig.12: **Prediction map of Nitrate on the study area**

The ministry of water (2011) report shows that at present, the high nitrate and chloride observed at Merkato area corresponds to the maximum population density within Addis Ababa. The same is true in this study the central part of the city specifically in the border line of Lideta, Arada and Addis kifle ketema (around Mercato) there is higher concentration of nitrate as compare from the rest part of the city. Even if there is the maximum recommended values of nitrate in mg/L set by WHO, but different countries classified the amount of nitrate in varies class from very low up to very high ranges. In the case of Addis Ababa nitrate concentrations range and rating value are given as follows cited by Girma (2011) from (Tamiru *et al*, 2005).

Table 6: Rating value for nitrate concentration. Sources (Girma, 2011) as cited from (Tamiru Alemayehu *et al*, 2005).

NO_3 (mg/L)	Rating value
<25	Low
25-50	Moderate
50-100	High
>100	Very High

The nitrate pollution from water sources that are given low, moderate, high and very high priority rating values are characterized to assess the risk of potential contamination load of nitrate to groundwater spatially distribution in the study area .

Based on above table, the reclassified map of nitrate distribution (Figure.13) below showed that high (50_100 mg/L) and very high nitrate pollution (>100 mg/L) in the central western part of the study area. Whereas majority part of the city is categorized as low and a little part has moderate nitrate distribution.

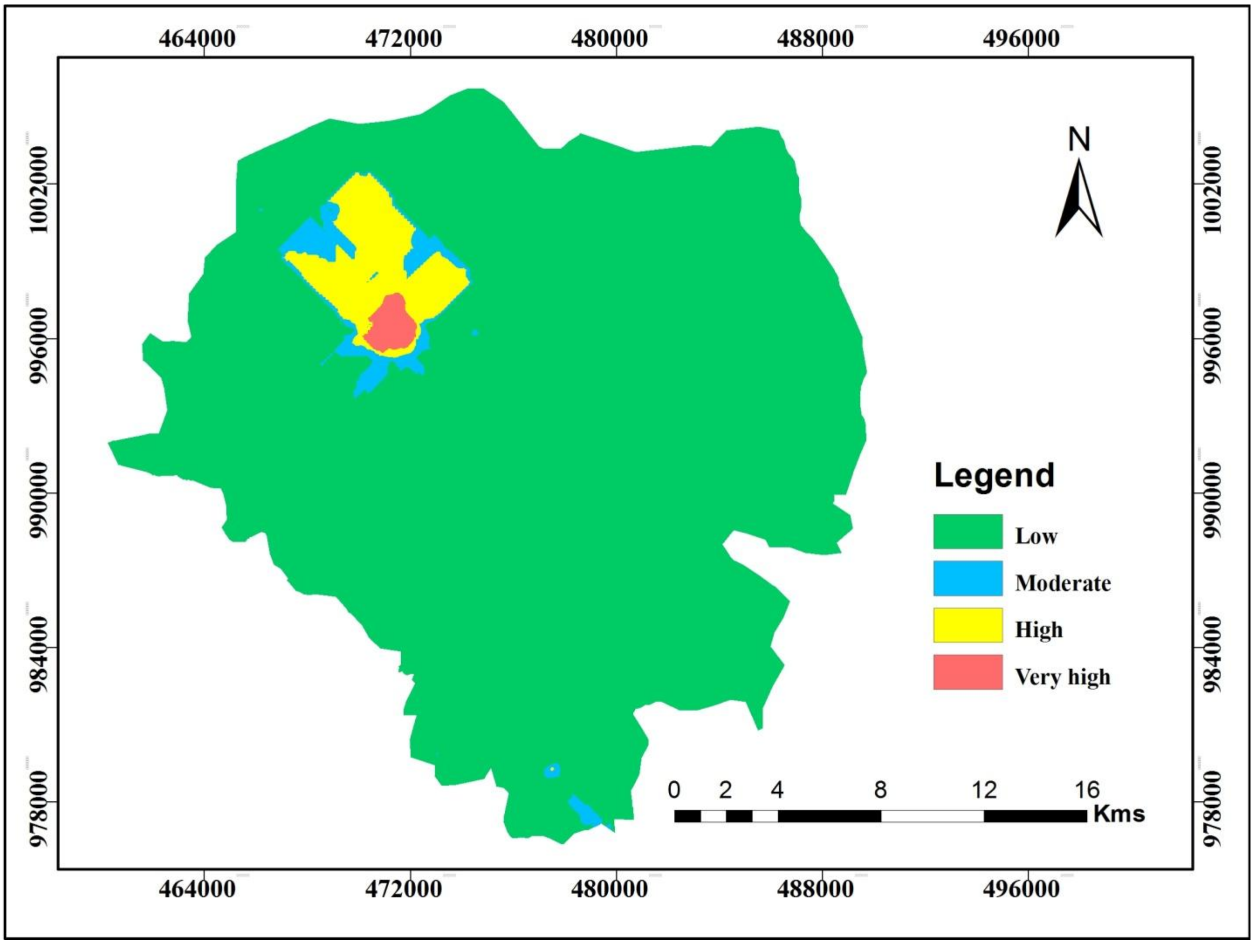


Fig.13: Reclassified map of Nitrate distribution

4.1.2Total Dissolved Solids (TDS)

TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, Sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions (UNICEF, 2008). The total concentration of dissolved minerals in water is a general indication of the overall suitability of water for many types of uses (Karthikeyan *et al*, 2013). Different researchers (such as, Karthikeyan *et al*, 2013 and Subramani et al, 2012) Classified the TDS value in to different ranges. For instance according to Karthikeyan et al (2013) the Total Dissolved Solids (TDS) was classified in to three ranges (0-500 mg/L, 500-1000 mg/L and >1000 mg/L). Water contains less than 500 mg/L of dissolved Solids; it is generally satisfactory for domestic use and for many industrial purposes. If the Water with more than 1000mg/L of dissolved solids usually gives disagreeable taste or makes the water unsuitable. Water with high TDS often has a bad taste and high water hardness, and could result in a laxative effect. High concentrations of TDS may also reduce water clarity.

TDS concentration in the ground water of study area is ranged from 38 to 2292 mg/L with mean and standard deviation as 335.4 and 295.31 respectively. The spatial variation map for TDS for this study was prepared in to nine class ranges and presented in figure 14. From the spatial variation map it was observed that, the larger portion of the study area has under the good range (0-500 mg/L). But the small portion of central part of the city there is high concentration of TDS (1000 up to 2292 mg/L).

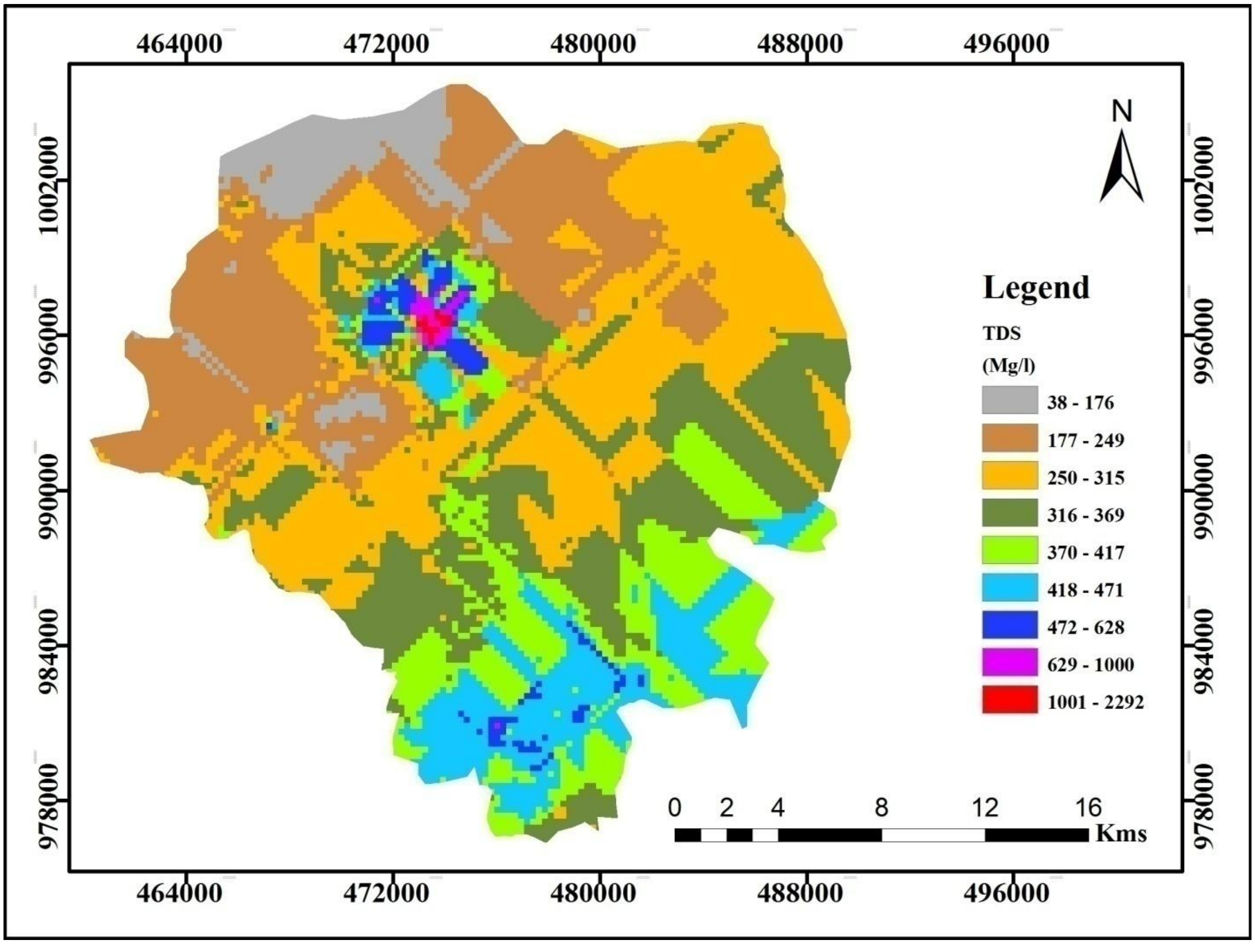


Fig. 14: Prediction map of TDS distribution on the study area

4.1.3 Total Hardness

Hardness in water is caused primarily by the presence of carbonates and bicarbonates of calcium and magnesium, Sulphates, chlorides and nitrates. The total hardness of water classified in to three ranges (0-300 mg/l, 300-600 mg/l and >600 mg/l) low, medium and high respectively

(Karthikeyan *et al*, 2013). To evaluate hardness distribution based on these ranges the spatial variation map for total hardness of Addis Ababa city has been presented in figure 15 below. Hardness concentration in the ground water of study area is ranged from 11 to 866 mg/L with mean and standard deviation as 170.85 and 110.78 respectively. From the map it was observed that for most part of the city areas, the total hardness value is less than 300 mg/L was observed, except the central part of Addis Ababa, which has 308 up to 866 mg/L.

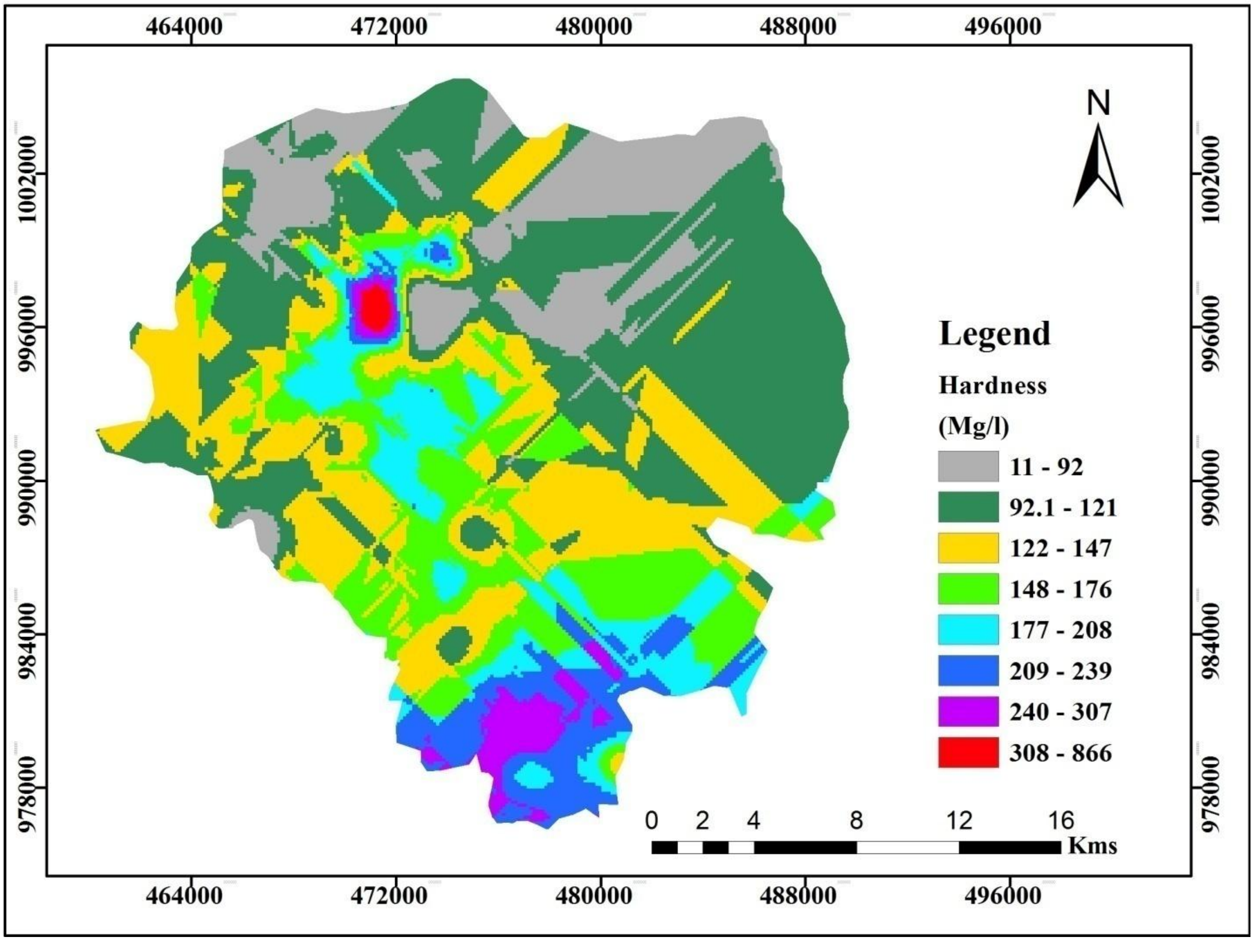


Fig.15: Prediction map of hardness on the study area

The most common problem associated with groundwater may be hardness, caused by an abundance of calcium or magnesium. Calcium and magnesium are found in groundwater because of the dissolving of limestone. Calcium and magnesium ions also can be released when water reacts with gypsum. Hard water causes no health problems, but can be a nuisance as it may cause soap curds to form on pipes and other plumbing fixtures (UNICEF, 2008). The total hardness of water may be divided in to two types, carbonate or temporary and bi-carbonate or permanent hardness. The hardness produced by the bi-carbonates of calcium and magnesium can be virtually removed by boiling the water and is called temporary hardness. The hardness caused mainly by Sulphates and chlorates of calcium and magnesium cannot be removed by boiling and is called permanent hardness (Karthikeyan et al, 2013).

4.1.4 Chloride

Chloride is present in all natural waters, mostly at low concentrations. It is highly soluble in water and moves freely with water through soil and rock (CGWB, 2010). High concentrations of Chloride can make water unpalatable and, therefore, unfit for drinking or livestock watering (UNICEF, 2008). According to CGWB (2010) in ground water the chloride content is mostly below 250 mg/L except in cases where inland salinity is prevalent and in coastal areas. The same is true in Addis Ababa, the ground water chloride ion concentration is below 250 mg/L. It various between 0.1 to 196 mg/L with mean and standard deviation as 19.8 and 25.15 respectively. The spatial distribution of chloride concentration is illustrated in figure 16 below. Even though the amount of chloride distribution in the whole study area is less than WHO and Ethiopian standard, but relatively higher concentration of chloride is observed in the northwestern and south western part of the Addis Ababa. Similarly Bereket and Mihret (2011) states that in the north western, around south western part of Addis Ababa there is relatively higher values of chloride concentration.

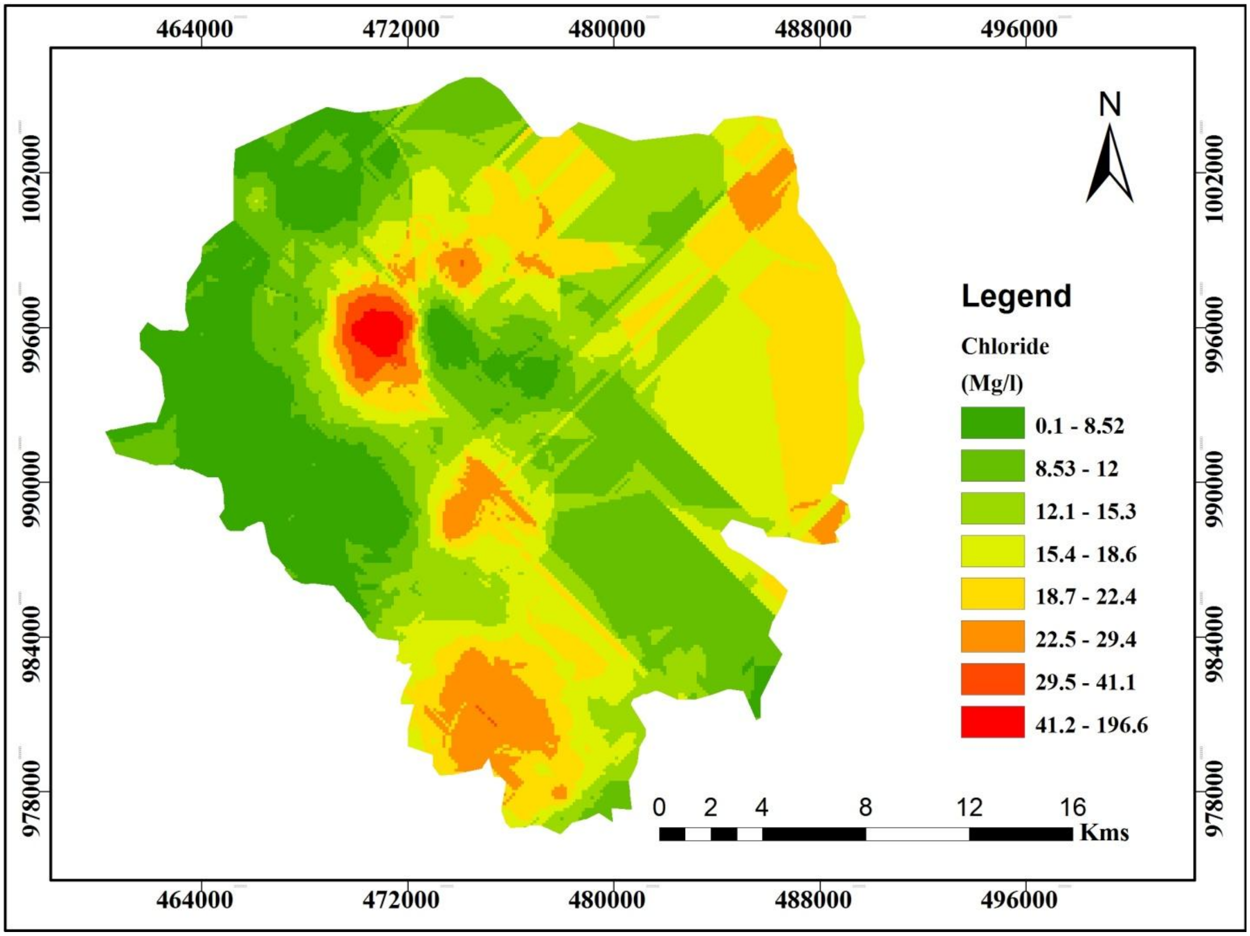


Fig.16: Prediction map of chloride on the study area

4.1.5 Calcium

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

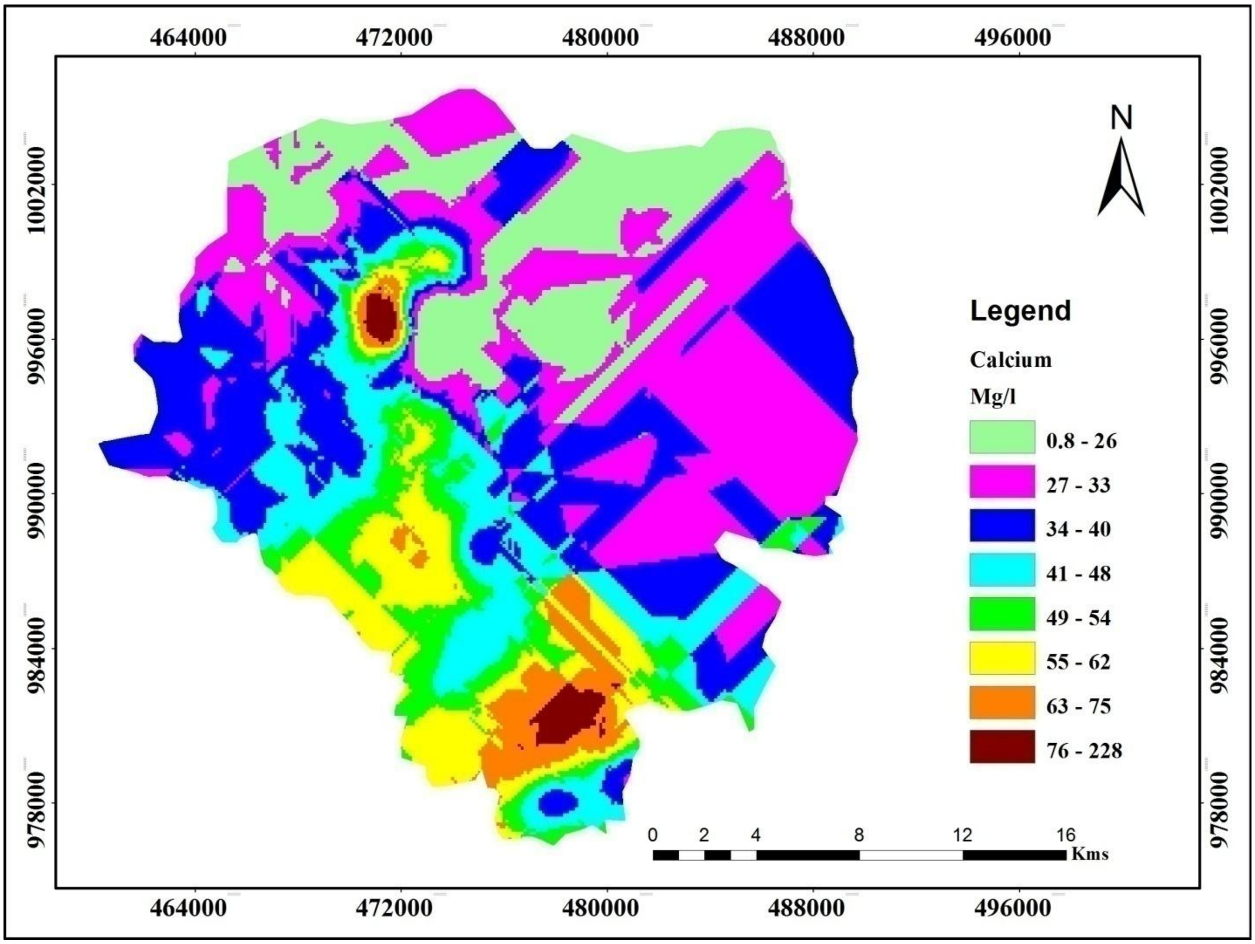


Fig.17: Prediction map of Calcium on the study area

According to Karthikeyan et al (2013) the amount of Calcium in water was classified in to three ranges (0-75 mg/L, 75-200 mg/L and >200 mg/L) low, moderate and poor respectively. Based on these ranges the spatial variation of Calcium in Addis Ababa, except the little parts of the city (central and southern) almost all area has low concentration. From the figure 17 it is evident that the distribution of calcium is ranged from 0.8 to 228 mg/L with mean and standard deviation as 46.95 and 29.01 respectively.

The salts of calcium, together with those of magnesium, are responsible for hardness of water. Calcium is an essential element for all organisms and is incorporated into the shells of many aquatic invertebrates, as well as the bones of vertebrates (UNICEF, 2008).

4.1.6 Magnesium

Magnesium occurs typically in dark colored minerals present in igneous rocks such as plagioclase, pyroxenes, amphiboles, and the dark colored micas. It also occurs in metamorphous rocks, as a constituent of chlorite and serpentine (Perk, 2006). Magnesium is common in natural waters as Mg2+, and along with calcium, is a main contributor to water hardness. Natural concentrations of magnesium in fresh waters may range from 1 to 100 mg/L (UNICEF, 2008). Magnesium is usually less abundant in waters than calcium, because magnesium is found in the earth’s crust in much lower amounts as compared with calcium (Kozisek, 2003). Similarly to this idea as it shown in the figure 18 in the ground water of Addis Ababa the distribution of magnesium (which is 1 to 92 mg/L) is less than calcium (which is 0.8 to 228 mg/L).

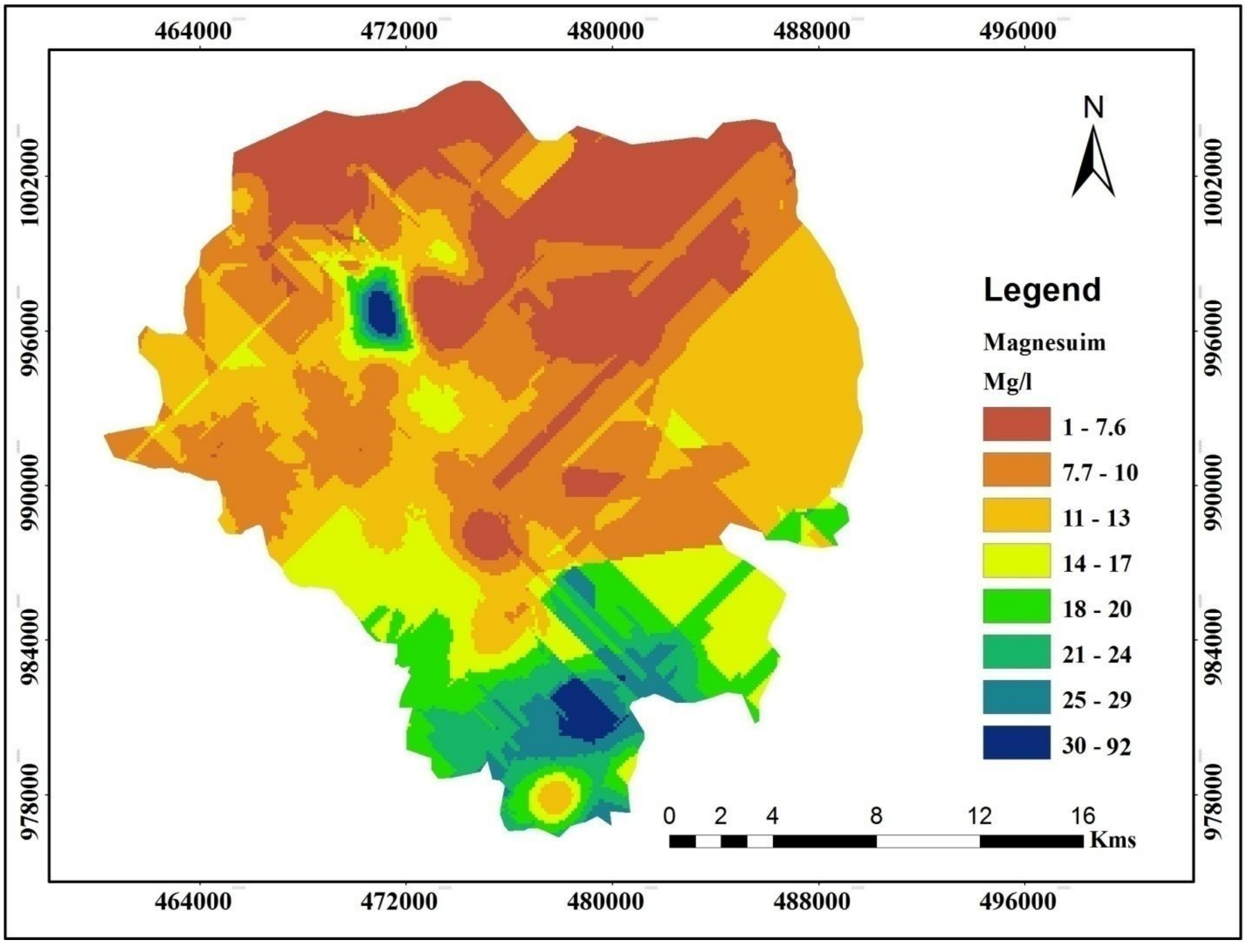


Fig. 18: Prediction map of Magnesium on the study area

From the map shown above, Magnesium concentration in the ground water of study area is ranged from 1 to 92 mg/L with mean and standard deviation as 16.51 and 12.74 respectively.

4.1.7 Sulphate

Sulphate (SO_4^{2-}) is a combination of sulphur (S) and oxygen (O). It occurs naturally in many soil and rock formations. In groundwater, most sulphates are generated from the dissolution of minerals, such as gypsum and anhydrite. Saltwater intrusion and acid rock drainage are also sources of Sulphates in drinking water. Man made sources include industrial discharge and deposition from burning of fossil fuels (WHO, 2011). Sulphate concentrations in natural waters are usually between 2 and 80 mg/L. High concentrations greater than 400 mg/L may make water unpleasant to drink (UNICEF, 2008).

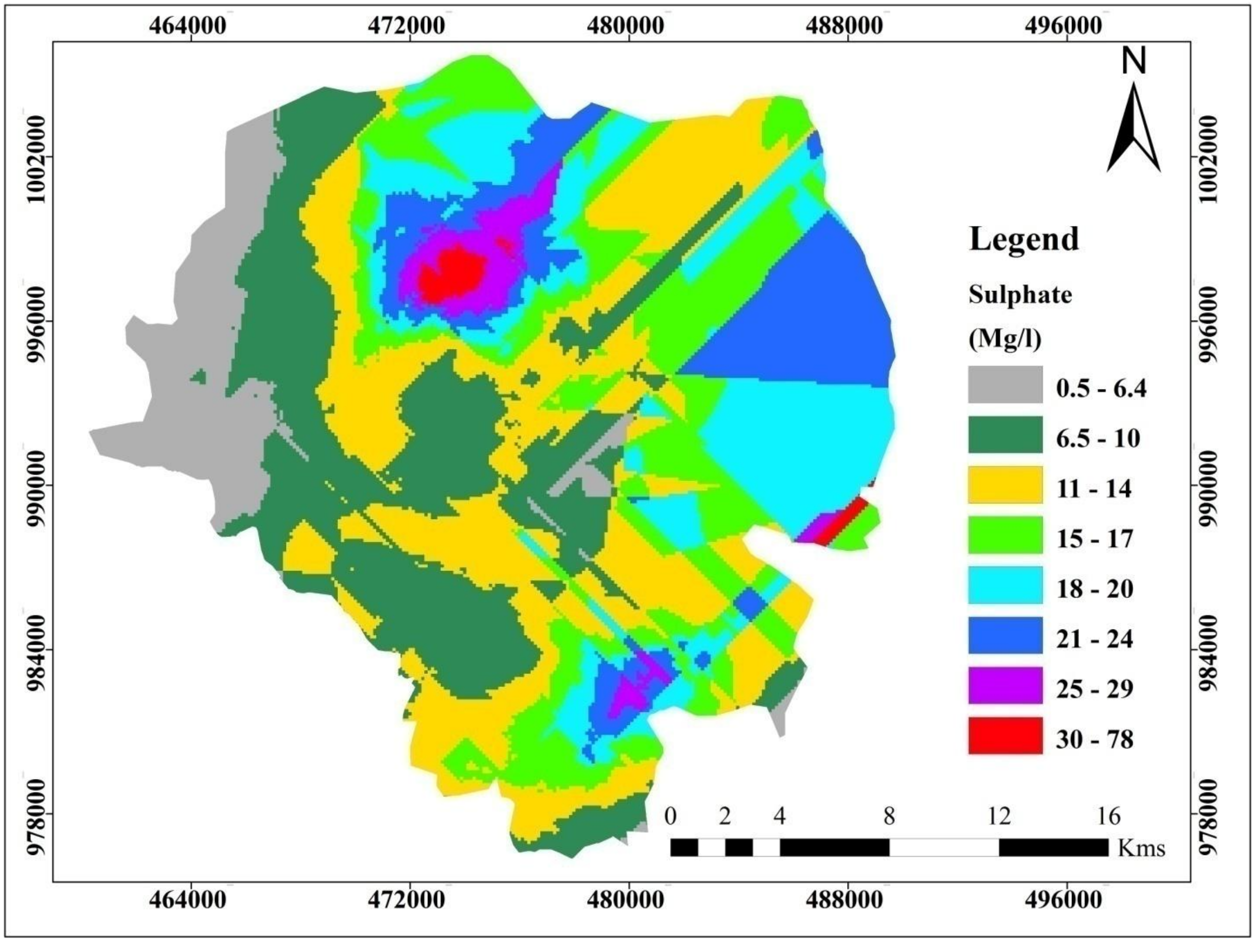


Fig. 19: Prediction map of Sulphate on the study area

Sulphate concentration in the ground water of study area is ranged from 0.5 to 78 mg/L with mean and standard deviation as 16.35 and 15.59 respectively. The concentrations of all the groundwater samples analyzed were found to be below within the desirable limit (250 mg/L). But as shown in the above figure the concentration of Sulphate is not evenly distributed. In central part of the city there is more concentration of Sulphate (30 up to 78 mg/L) than other areas.

Sulphate present above 500 mg/L in water may affect the taste of water. At levels above 1000 mg/L, Sulphate in drinking water can have a laxative effect, although these levels are not normally found in drinking water (WHO, 2011). Sulphate minerals in drinking water can increase corrosion of plumbing and well materials. Sulphur bacteria may produce a dark slime or deposits of metal oxides that develop as a result of the corrosion of metal pipes. The slime or deposits can clog plumbing and stain clothing (perk, 2006).

4.2 Water quality index (WQI)

Water quality assessment of the study area was done by calculated Water Quality Index (WQI). The WQI was calculated by using water quality parameters, drinking water standard of WHO (2011) and Ethiopian standards. Nine parameters such as: pH, TDS, Total Hardness, Calcium, Magnesium, Sulphates, Chlorides, Fluorides and Nitrates have been used to produce water quality index. The final result shows that the water quality index value is ranged from 17.32 to 233.09. According to Vasanthavigar et al (2009) water quality index value have been classified in to five classes. WQI is less than 50, 50 to 100, 101 to 200, 201 to 300 and greater than 300 have the value Excellent, good, poor, very poor and unsuitable for drinking respectively.

Table 7. The WQI range and type of water (source Vasanthavigar et al, 2009)

Range	Type of water
<50	Excellent water
50_100	Good water
101_200	Poor water
201_300	Very poor water
>300	Water unsuitable for drinking purposes

Based on this range shown by above table water quality of study area is categorized excellent to very poor.

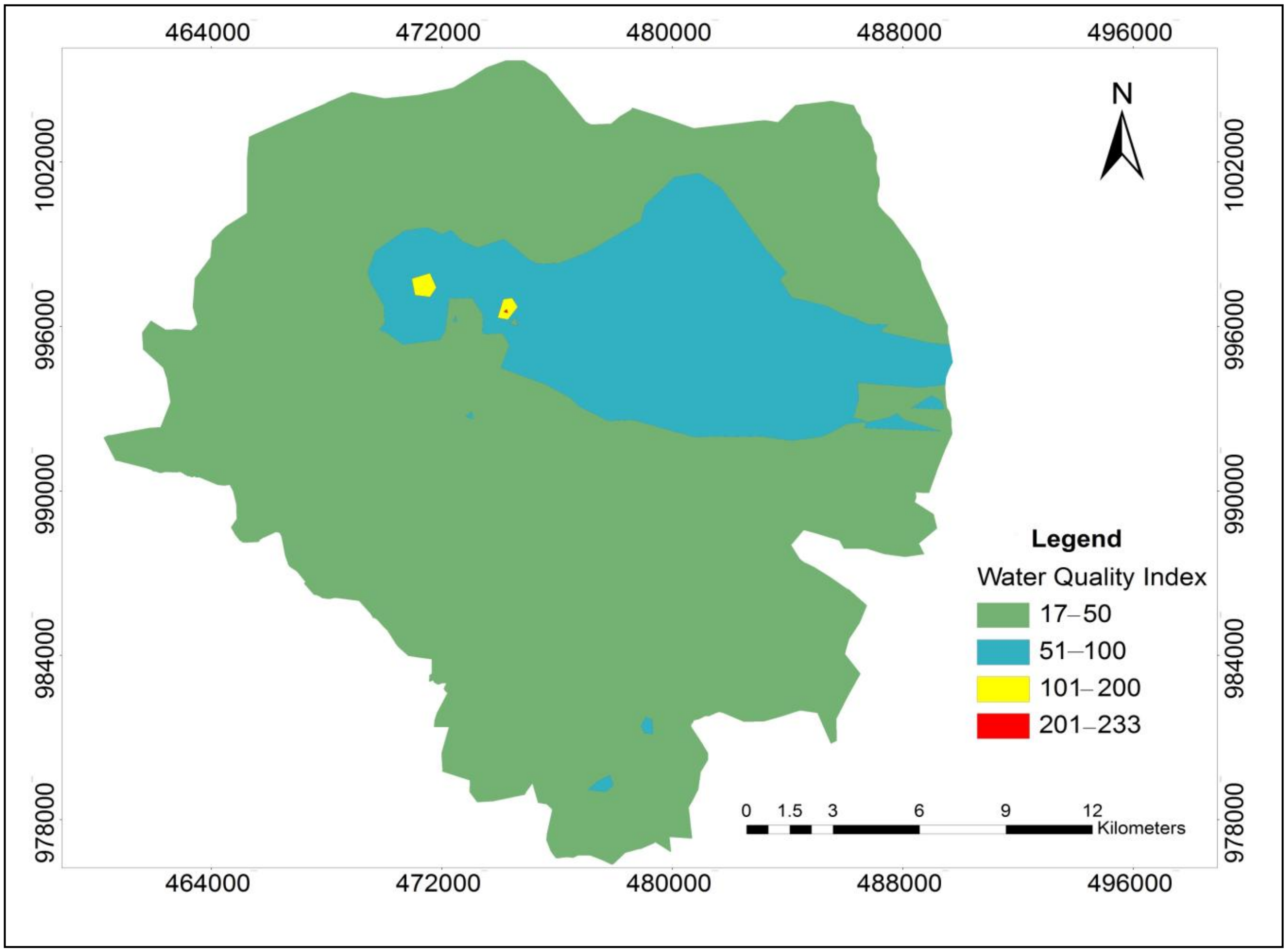


Fig. 20: Ground water quality index of the study area.

From the above map of ground water quality index , shows that most part of the study area is ranged the value between 17 up to 50, where as very smallest portion of the city is ranged between 201 and 233. Based on table 7 the water quality index was reclassified into four classes. These four classes are: Excellent, good, poor and very poor.

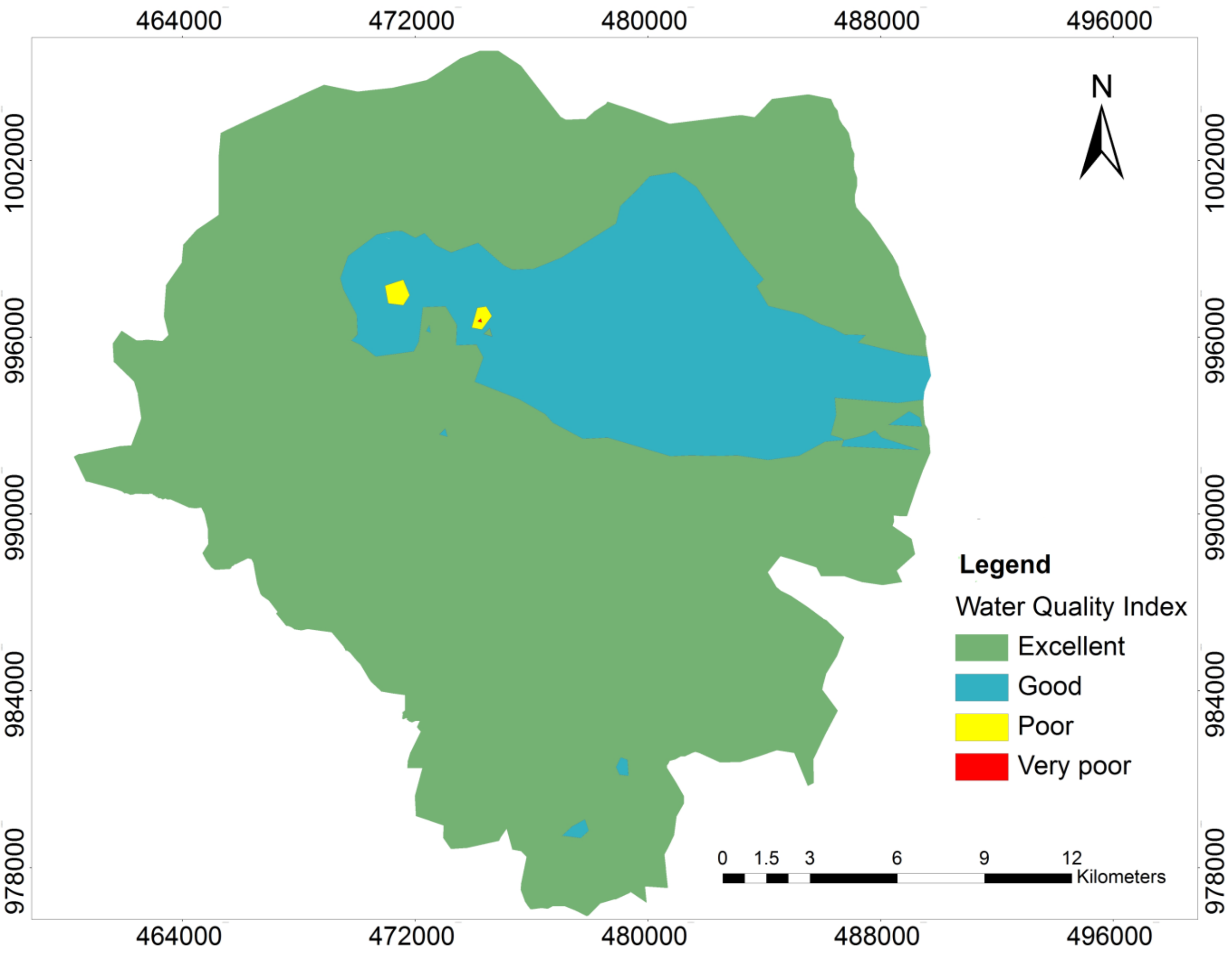


Fig.21: Reclass map of ground water quality index

The reclassed map showed that 78.18 % (422.17 km^2) of the groundwater of the city were found to be in the excellent water class, 20.86 % (112.62 km^2) good, 0.9 % (4.87 km^2) poor and the remaining 0.06 % (0.34 km^2) was classified under very poor water class based on the computed WQI classification results.

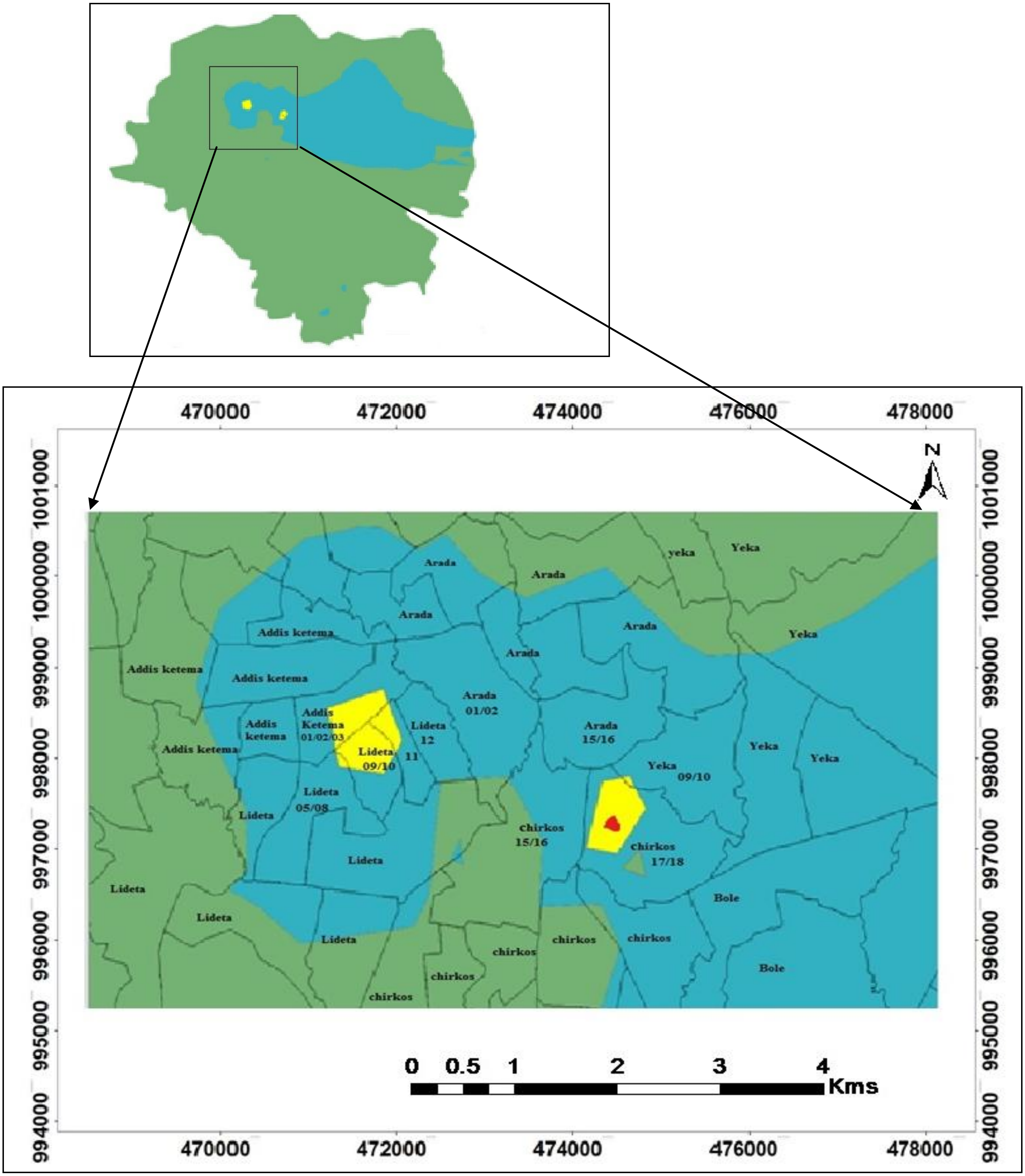


Fig.22: Polluted areas of the city

From WQI in above figure shows that in Chirkos sub city specifically in the local administrative kebele 17/18 there is very poor water quality. In addition to this, in Chirkos sub city kebele 17/18 and in the border line of Addis Ketema (Kebele 01/02/03), Lideta (kebele 09/10) and Lideta (Kebele 11) there is poor water quality.

Generally from water quality index map the places which are located with poor and very poor WQI they are found at risk. So the bore hole that is found in this area has negative impact on the health of human beings.

CHAPTER FIVE

5. Conclusion and Recommendation

5.1 Conclusion

The primary objective of this study was to map and evaluate the groundwater quality in Addis Ababa City. Spatial distribution of groundwater quality parameters were carried out through GIS and geostatistical techniques. These techniques have successfully demonstrated its capability in groundwater quality mapping of Addis Ababa City.

- The present study has been undertaken to analyze the spatial variation of major groundwater quality parameters such as Total Dissolved Solids, total hardness, Sulphate, nitrate, chloride, magnesium and Calcium using GIS approach. The spatial variation maps of these groundwater quality parameters shows that there is uneven water quality distribution.
- Nitrate is highly concentrated in the central part of the city which has over the maximum recommended value.
- Chloride distribution in the whole study area is less than WHO and Ethiopian standard, but relatively higher concentration of chloride is observed in the northwestern and south western part of the Addis Ababa.
- Mostly in the central part of the city there is high concentration of nitrate, TDS, total hardness. But from those parameters chloride, Magnesium, calcium and sulphate have low concentration below the world health Organization standard.
- The final map, which is groundwater quality Index map, shows that majority parts of the city has optimum groundwater quality (Excellent), and, very small area of the central part has poor and very poor water quality. In general, the groundwater quality decreases from marginal part towards the central part of the city.

5.2 Recommendation

Effective management of water resources is a core issue for the provision of reliable and safe water supply. By recognizing the reality of ground water quality distribution from the study, the following recommendations should be considered.

1. It is highly recommended to use GIS tools and its application to produce maps to communicate Ground water situation in the city.
2. It requires further investigation of other highly polluted chemicals with high precision instruments must be carried out in order to study the degree of pollution and anthropogenic effect on surface and groundwater of the study area.
3. Continuous monitoring of groundwater table level along with quality study will minimize the chances of further deterioration.
4. Both in Addis Ababa water and sewerage authority and Ministry of water office the storage and management of data is poor, so it would be good to build up better data base management, because the quality of a study is dependent on the availability of data.

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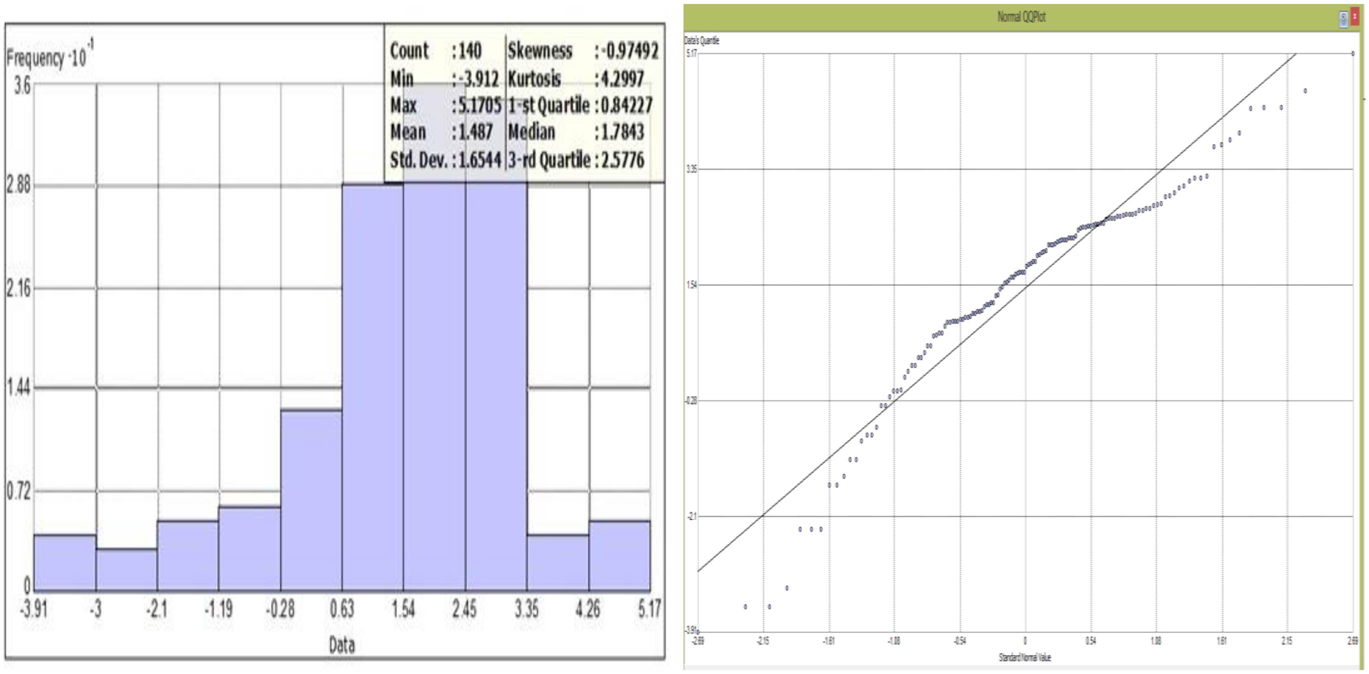
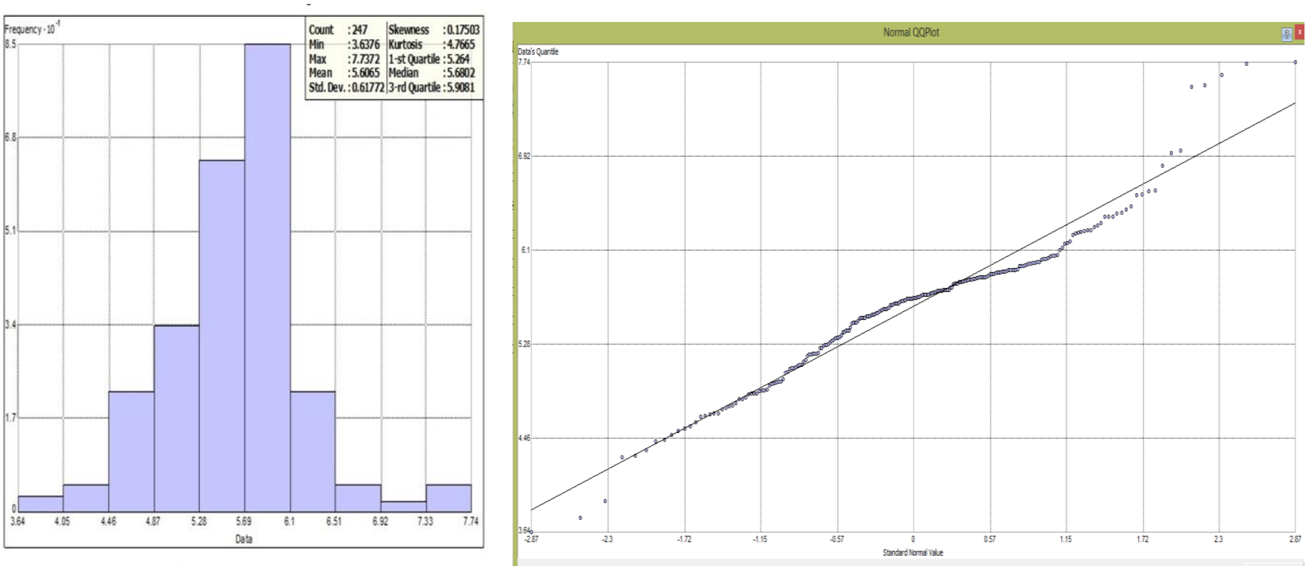
Appendices

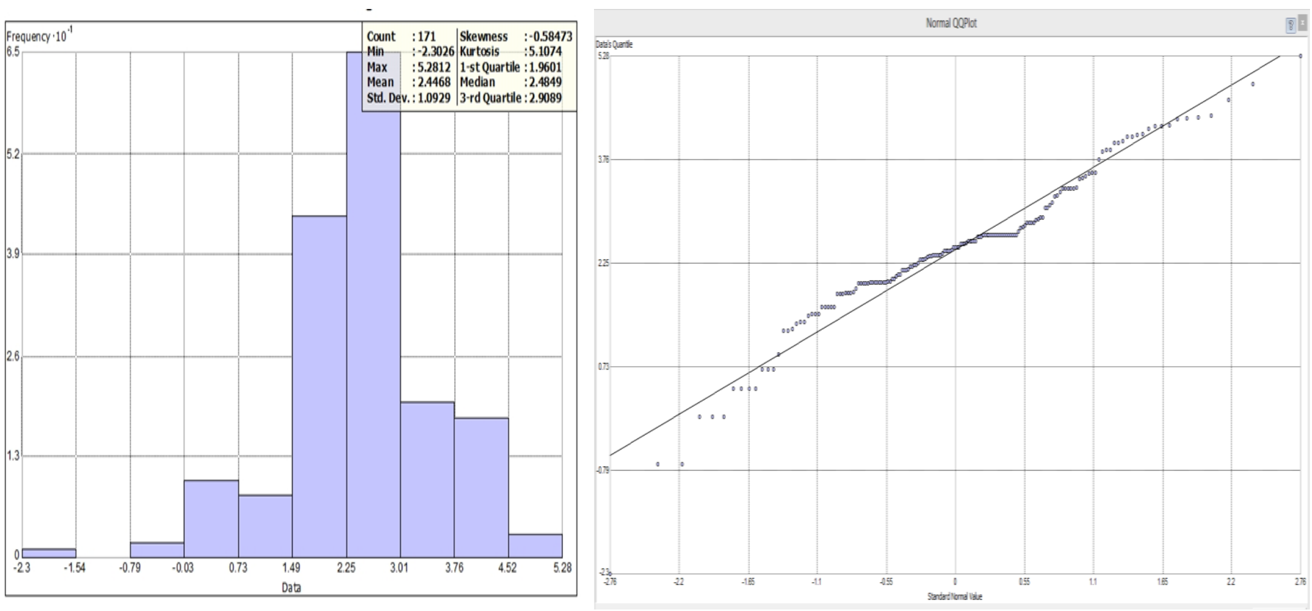
Appendix 1: Log transformed Histogram & QQ plot of Water Quality Parameters.



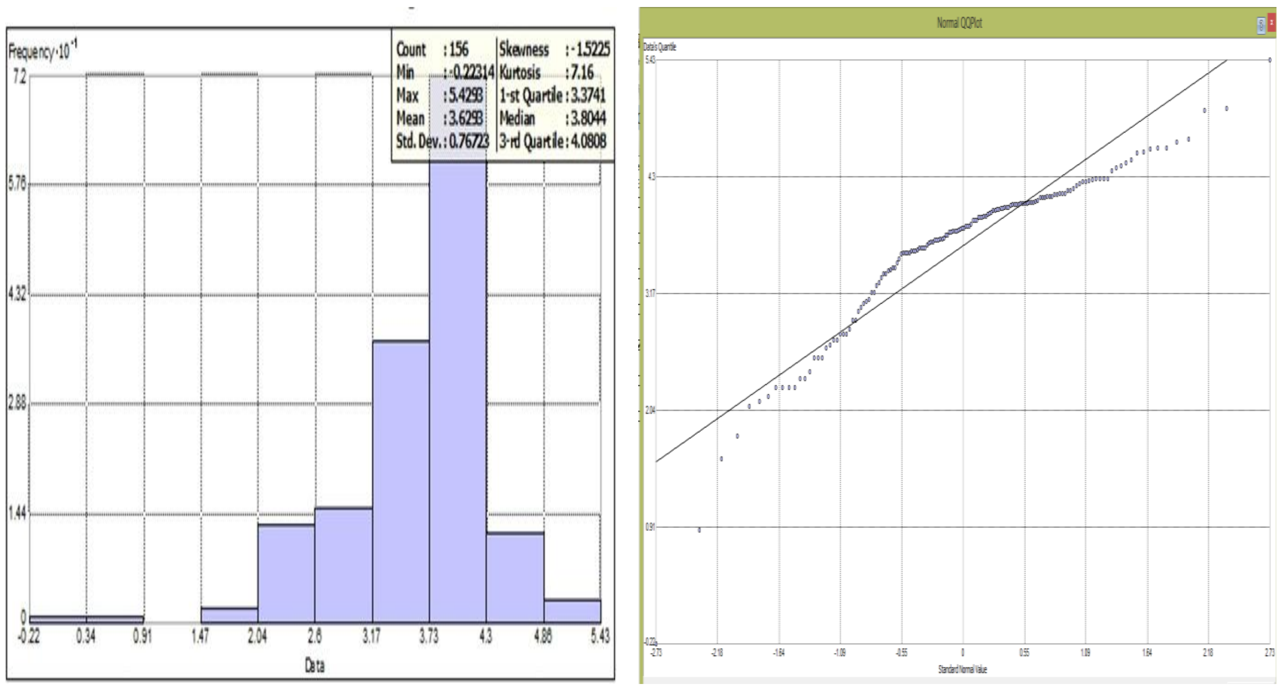
Histogram and QQ plot of NO_3 after log transformation



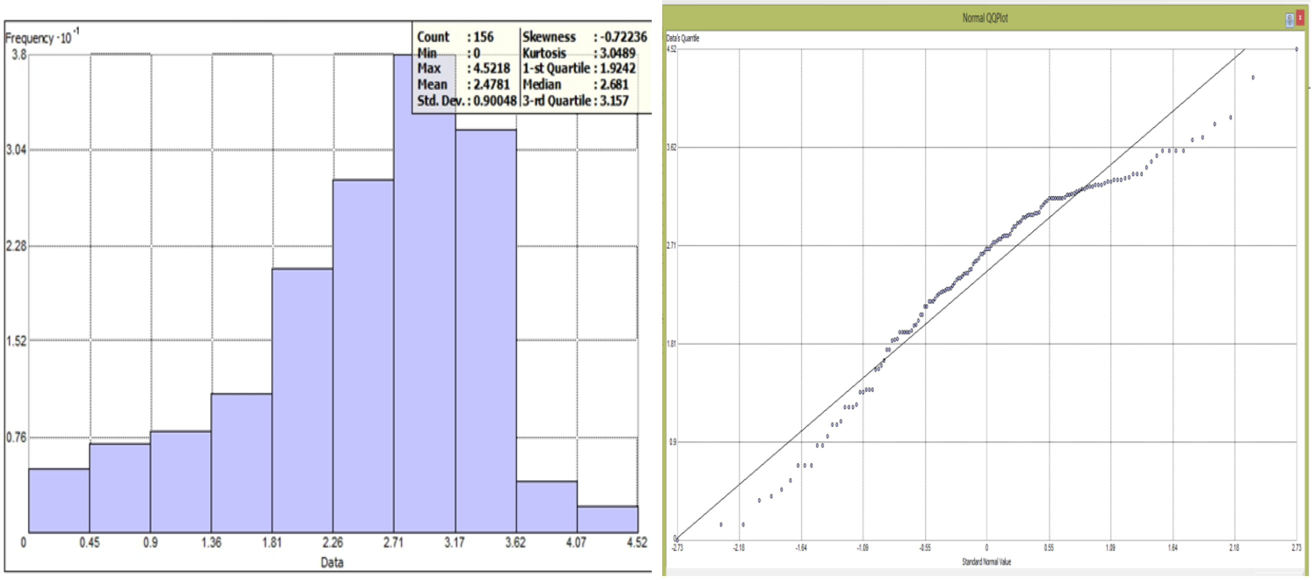
Histogram and QQ plot of TDS data after transformation.



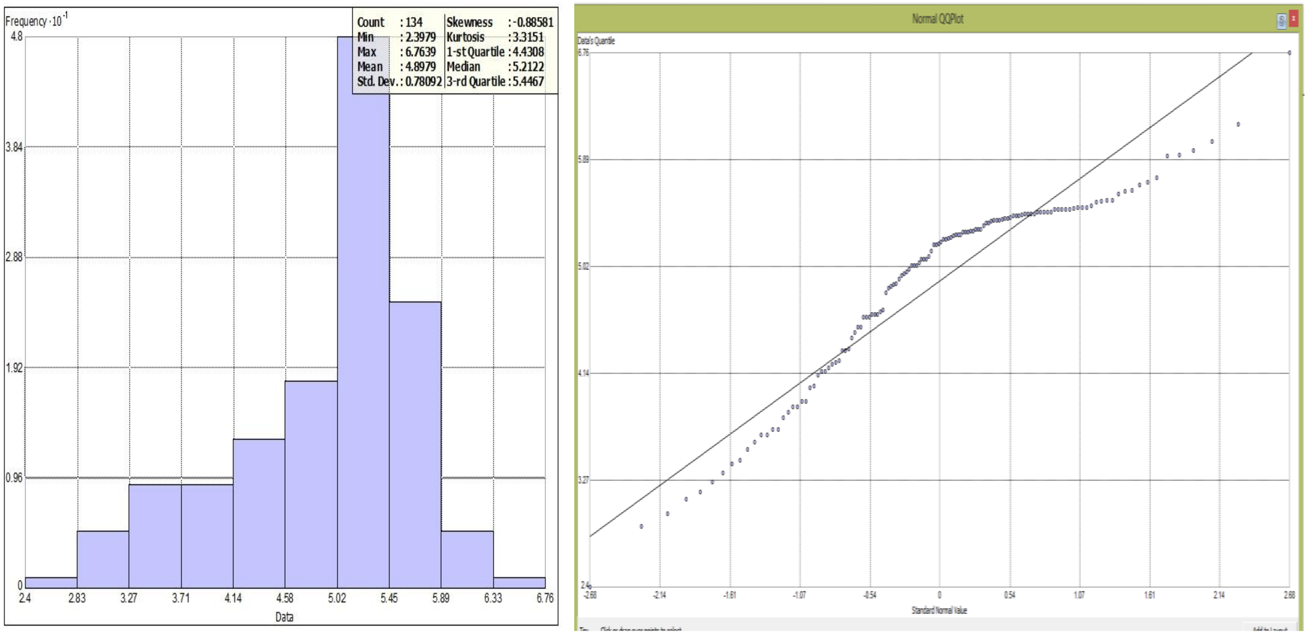
Histogram and QQ plot of Cl data after transformation.



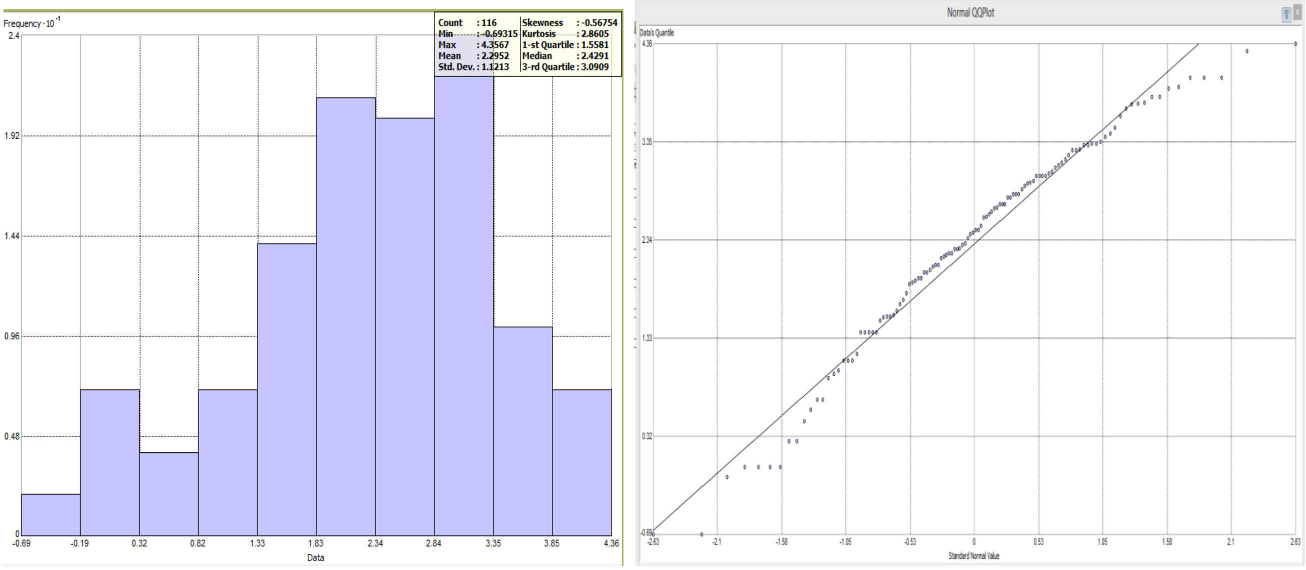
Histogram and QQ plot of Ca data after transformation.



Histogram and QQ plot of Mg after transformation.



Histogram and QQ plot of Hardness after transformation.



Histogram and QQ plot of Sulphate after transformation.

Appendix 2: sample well locations used for water quality index map.