Assessment of Groundwater Nitrate Level and Source of Pollution within Dire Dawa City, Dire Dawa, Eastern Ethiopia

MSc Thesis

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Assessment of Groundwater Nitrate Level and Source of Pollution within Dire Dawa City, Dire Dawa, Eastern Ethiopia

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Approval Sheet of the MSc Thesis

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As members of the Examining Board of the Final MSc Open Defense, we certify that we have read and evaluated the thesis prepared by Mr. Mesfin Sahele Gebreyes entitled Assessment of Groundwater Nitrate Level and Source of Pollution within Dire Dawa City, Dire Dawa, Eastern Ethiopia and recommend that it be accepted as fulfilling the thesis requirement for the degree of Master of Science in Water Resource Engineering and Management

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Dedication

To my father SAHELE GEBREYES, and my mother LAKECH TAFESSE for nursing me with affection and love and for their dedicated partnership in the success of my life.

Declaration

I declare that this research is my genuine work and all sources of materials used for this research have been duly acknowledged. I solemnly declare that this research is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

Name: Mesfin Sahele………………... ………………….**Signature:**……….……………

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Mesfin Sahele

Abbreviations

%	Percent
^0C	Degree centigrade
AE	Associated Engineering
AESL	Associated Engineering Service Limited
AutoCAD	Automated Computer Aided Design
B.C	British Columbia
BH	Borehole
CSA	Central Statistical Authority
DD	Dire Dawa
DGC	Department of Graduate Council
E	East
EC	Electrical conductivity
EIGS	Ethiopian Institute of Geological Survey
EPA	Environment Protection Authority
ES	Ethiopian Standard
FMoH	Federal Ministry of Health
FMoWIE	Federal Ministry of Water, Irrigation and Electricity
G.C	Gregorian Calendar
GIS	Geographic Information System
GPS	Global Positioning System
GO	Governmental Organization
HDW	Hand dug well
HMIS	Health Management Information System
Hb	Hemoglobin

Km	kilo meter
l/s/m	liter per second per meter of drawdown
MAC	Maximum Acceptable Concentration
M	Meter
masl	meter above sea level
MetHb	Methaemoglobinaemia
mm	millimeter
mg/l	milligram per liter
MoWR	Ministry of Water Resource
MS Word	Micro Soft Word
MSc.	Master of Science
N	North
NA	Not Applicable
NGO	Non-governmental Organization
nitrate-N	nitrate-Nitrogen
pH	Potential Hydrogen
PLC	Private Limited Company
PW	Pumping well
QSA	Quality and Standards Authority
TDS	Total Dissolved Solid
UNICEF	United Nation Children Fund
UNOPS	United Nation Office for Project Service
UTM	Universal Transverse Mercator
USEPA	United State Environment Protection Authority
USS	Upper Sandstone

VIP	Ventilated Improved Pit
WASH	Water Sanitation and Hygiene
WSSA	Water Supply and Sewerage Authority
WWDSE	Water Works Design and Supervision Enterprise
WHO	World Health Organization

Table of Content

List of Tables

List of Figures

List of Tables in the Appendix

List of Figures in the Appendix

Abstract

This research was conducted to study the ground water nitrate level, bacterial contamination and its sources. To achieve the objective, water samples were collected from 32 water points in both rural and urban areas for testing nitrate, chloride, sulfate and fecal coliform using photometer and membrane filtration method. The research revealed that nearly 86 percent of the study area was polluted with nitrate which exceed the natural/normal 9 mg l^{-1} nitrate in the groundwater. The pollution was very high in the urban center and advances from the southeastern part towards the north and northwestern part of the study area. The maximum concentration of nitrate (89 mg l^{-1}) was found in Addis Ketema and Ras Hotel area while minimum concentration (0.86 mg l^{-1}) at Tome area which is far away from the town. Moreover, the result showed that the concentration of nitrate unevenly declines with increasing water well depth. The research also finds out that the source of nitrate was mainly attributed to infiltration of sewage from the pit latrines. Moreover, fecal coliform was found in 36 percent of the water wells covering nearly 56 percent of the study areas. The presence of fecal coliform clearly indicates the source of pollution is feces. The main determinant factor for the presence or absence of bacterial contamination is the confined aquifer nature of the water well. The correlation plot of nitrate versus chloride and sulfate indicated that there was low or no correlation in the urban center while average correlation away from the town area mainly related to the presence of excreta (single factor) that contribute for the rise of chloride. In general, the nitrate and bacterial pollution covers 86 percent and 56 percent of the study areas with the pollution source is mainly traced back to infiltration of sewage from the pit latrines.

Keywords: *chloride, correlation, Dire Dawa, fecal coliform, groundwater quality, nitrate, pollution source, sample, sulfate, water well, water wellfield*

CHAPTER 1: INTRODUCTION

1.1 Background

Water is vital for the existence of all living organisms, but this valued resource is increasingly being threatened as human populations grow (UNEP GEMS, 2008; Dessie, 2010).

One of the targets of the Sustainable Development Goal is to achieve universal and equitable access to safe and affordable drinking water for all by the year 2030. Recent statistics confirm that 6.6 billion (91%) people worldwide and 51.7 million (57%) Ethiopians had access to safe water (UNICEF and WHO, 2015).

Water quality for human and other uses is clearly indicated in the Ethiopian Water Resource Management policy. Some of this policy areas are:

- Develop water quality criteria, guidelines and standards
- Formulate receiving water quality standards and legal limits for pollutants

The Quality and Standards Authority (QSA) and Federal Ministry of Water,

Irrigation and Electricity (FMoWIE) of Ethiopia have stipulated drinking water quality specifications (i.e. ES 261:2001) in 2001 for the physico-chemical, microbiological and radiological parameters (FMoH, 2011).

Nitrate (NO_3^-) is a primary contributor to groundwater pollution, due to its stability, high solubility and mobility. Nowadays, NO_3^- contamination in groundwater has become a widely concerned environmental problem (Xue et al., 2009). Several studies have shown that increased levels of NO_3^- in groundwater are primarily caused by anthropogenic activities such as the overuse of nitrogen fertilizers and animal manures, the discharge of domestic and industrial sewage, and the elevated atmospheric N deposition (Dubrovsky et al., 2010; Gu et al., 2012; Kaushal et al., 2011; Xue et al., 2009).

Similarly, nitrate (NO_3^-) pollution is a major problem of water wells in Dire Dawa city. Many water wells showed more than two-fold increase in two decades (Taye, 1999). The maximum concentration of 45 mg/l of nitrate was observed in the groundwater sampled from the middle of the city (Greitzer, 1959), 320 mg/l (Ketema, 1982) while 266 mg/l (MoWR, 2003) in food complex water well (Eyilachew, 2010).

Under aerobic conditions, nitrate can percolate in relatively large quantities into the aquifer when there is no growing plant material to take up the nitrate and when the net movement of soil water is downward to the aquifer. Under anaerobic conditions, nitrate may be denitrified or degraded almost completely to nitrogen (van Duijvenboden & Loch, 1983; Mesinga et al., 2003; Fewtrell, 2004; Dubrovsky & Hamilton, 2010).

Groundwater NO_3^- contamination is a threat to human health (Gu et al., 2013). Drinking water containing elevated levels of nitrate has been associated with the risk of methemoglobinemia or 'blue baby syndrome' (Fan and Steinberg, 1996; Pastén-Zapata et al., 2014) and cancer through the formation of carcinogenic N-nitroso compounds (Weyer et al., 2001). Because of these issues, the World Health Organization (WHO) has set an upper limit of 50 mg/L for drinking water (WHO, 2011).

Nitrate concentrations above the WHO's maximum contamination level are relatively common in some regions, especially in the emerging developing countries (Burow et al., 2010; Gu et al., 2013). In Dire Dawa, the occurrence of groundwater nitrate pollution has accompanied the population growth (Taye, 1999).

1.2 Problem Statement

Reliable city water supply in a sustainable manner requires careful consideration of all factors that affect the entire system.

The current trend of settlements over the Sabian water wellfield & unmanageable liquid wastes are accountable for contamination of the groundwater. The unlimited human activities endanger the water quality as most residential areas are not provided with proper waste disposal systems (WWDSE, 2004). Since the constructed wellheads are poorly designed & completed (MS Consult, 2011), they could also contribute towards an access for pollution of groundwater.

Some abandoned water wells did not properly seal to avoid groundwater pollution. 89% of the people use very poor unlined pit latrines. Due to these facts, groundwater pollution remains the major problems (CSA, 2007).

Re-assessment of Sabian wellfield by Ethiopian Institute of Geological Survey (EIGS, 1986) showed that nitrates concentration increased by 70% from 1994 (22.8 mg/l) to 1999 (38.9 mg/l) in Sabian water wells (WWDSE, 2002). In addition, the feasibility study and Water Abstraction report for Harar Water Supply project clearly showed that the nitrate amount in Aseliso water wells are 0 to 0.3mg/l of nitrate against 50 mg/l of WHO guideline value (WHO, 2008 and MS Consult, 2011).

From what has been observed so far, the Dire Dawa city groundwater needs updating of its nitrate level as over 13 years have passed since WWDSE revised and produced the nitrate zonation map.

Therefore, this research is targeted to perform a detailed study of the groundwater quality of the Dire Dawa city with respect to nitrate, chloride and possible source of nitrate pollution.

1.3 Objective

1.3.1 General objective

To assess and evaluate the nitrate level and source of pollution of the groundwater of the Dire Dawa city.

1.3.1.1 Specific objectives

- To assess the groundwater nitrate level and produce nitrate zonation map
- To assess the bacteriological contamination of the groundwater
- To identify the source of nitrate pollution

Research questions

The research tried to provide explanation on the list of question raised in relation to the specific objectives. These include:

- What is the current level of nitrate in the groundwater?
- What is the extent of nitrate pollution and areal coverage? and
- What favorable conditions are prevalent in Dire Dawa?
- Is there bacterial contamination?

- What is the level bacteriological contamination?
- Are there areas free of bacterial contamination? If so, why?
- What is the source of nitrate pollution?

1.3.2 Significance of the study

The study result brings verifiable groundwater nitrate data, contributed to addressing problems related to sustainable utilization of groundwater, thereby defined the degree of nitrate contamination. In addition, it will also help to improve the awareness the concerned institutions towards water quality of the area and the likely public-health burden related to nitrate.

The City Administration especially the Dire Dawa City Administration Water Supply and Sewerage Authority and Environmental Protection Authority will use the result to plan and mitigate the nitrate problem

1.3.3 Scope of the study

This study was limited to collecting and analyzing 28 water samples from the water wells located within the Dire Dawa city. In addition, three more water samples were taken from deep water wells in rural areas and two more from the dug wells in the city. Samples were analyzed for nitrate, chloride, sulfate and fecal bacteria. Furthermore, previous water quality analysis report was assessed and used in case where water wells were found either nonfunctional or without pump.

CHAPTER 2: LITERATURE REVIEW

2.1 General

In water, nitrate has no taste or scent and can only be detected through a chemical test. The Maximum Acceptable Concentration (MAC) for nitrate in drinking water in British Columbia is 45 milligrams per liter (mg/l). For laboratory, tests reported as nitrate-nitrogen (NO_3-N, the amount of nitrogen present in nitrate) the MAC is 10 mg/l (B.C, 2007).

Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. The nitrate ion (NO_3^-) is the stable form of combined nitrogen for oxygenated systems. Although chemically unreactive, it can be reduced by microbial action (ICAIR Life Systems, Inc., 1987).

2.2 Nitrate of the Dire Dawa Area

Nitrate (NO_3^-) pollution is a major problem of water wells in Dire Dawa city. Taye's, 1999 study was based on the review of previous studies, random water sampling of deep and dug wells and springs and revision of the settlement pattern of Dire Dawa city and possible pollutant sources. Many water wells showed more than two-fold increase in two decades, (Table 2.1) (Taye, 1999).

Table 2.1. Temporal groundwater quality change on selected water sources

name of water point	**Nitrate as N**	
	1960	1982
Cotton factory BH2	Trace	62
Cotton factory BH39	-	86
High Way BH	45	110

name of water point	Nitrate as N	
	1960	1982
Dire Dawa Hospital BH	45	-
Tony Farm HDW	-	49
Chandris HDW	Trace	48
Ras Hotel HDW	35	-
Lege Hare Spring	45	38

source: Taye, 1999 BH-Borehole HDW-hand dug well

Other researchers indicated that maximum concentration of 45 mg/l of nitrate was observed in the groundwater sampled from the middle of the city (Greitzer, 1959), 320 mg/l (Ketema, 1982) while 266 mg/l (MoWR, 2003) in food complex water well (Eyilachew, 2010). This shows rapid increase in nitrate level of the groundwater. As per the study of Associated Engineering PLC, though it lacked detail analysis of the trend of nitrate pollution in relation to the general groundwater movement, showed that the groundwater quality of Sabian wellfield meet the WHO standard for domestic uses. The wellfield was flooded with settlement and the nitrate pollution has encroached into the wellfield. However, the nitrate pollution of the city may encroach on the wellfield, it can be overcome by blending the water with water from other sources (AE, 1990).

The analysis result of Sabian water well showed that nitrate concentration has increased by about 9 times in PW4 &5 located in the center of the wellfield whereas the results of PW7 & 9 located along Butiji dry river valley were like that of 1990. The team has concluded that the nitrate increment is not uniform and it was indicating that the wellfield was slowly moving towards nitrate equilibrium (MoWR, 1999).

Although overall compliance for nitrate was 97% cumulative average in Ethiopia while it was 67% in Dire Dawa with nitrate concentrations of up to 208 mg/l (Dagnew et al., 2010). Except Taye’s 1999 systematic random sampling, the remaining studies took nitrate as part of water quality analysis in the hydrogeological investigation and water well drilling and construction operations. Hence, lacks systematic water sampling.

2.3 Major Sources of Nitrate in Drinking Water

Nitrate is an inorganic chemical that is highly soluble in water. Nitrate is one of the most abundant chemical constituents/contaminants of water bodies worldwide (Howard et al., 2003 and WHO, 2004). Major sources of nitrate in drinking water include fertilizers, sewage and animal manure. Nitrates also occur naturally in plants, for which it is a key nutrient, in the environment, in mineral deposits like caliche, soil, seawater, freshwater systems, and the atmosphere (Hazen, 2006; WHO, 2011 and Taye, 1999).

Nitrate can reach both surface water and groundwater because of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater treatment and from oxidation of nitrogenous waste products in human and animal excreta, including malfunctioning septic tanks and construction sites using explosives. Shallow water wells are more susceptible to nitrate contamination than bedrock wells (Hazen, 2006 and WHO, 2011).

2.4 Environmental Fate

In soil, fertilizers containing inorganic nitrogen and wastes containing organic nitrogen are first decomposed to give ammonia, which is then oxidized to nitrite and nitrate. The nitrate is taken up by plants during their growth and used in the synthesis of organic nitrogenous compounds. Surplus nitrate readily moves with the groundwater (USEPA, 1987; van Duijvenboden & Matthijsen, 1989).

Under aerobic conditions, nitrate can percolate in relatively large quantities into the aquifer when there is no growing plant material to take up the nitrate and when the net movement of soil water is downward to the aquifer. Under anaerobic conditions, nitrate may be denitrified or degraded almost completely to nitrogen. The presence of high or low water tables, the amount of rainwater, the presence of other organic material and other physicochemical properties are also important in determining the fate of nitrate in soil (van Duijvenboden & Loch, 1983; Mesinga et al., 2003; Fewtrell, 2004; Dubrovsky & Hamilton, 2010).

2.4.1 Hydrogeology

The geological setup and water wells drilled in the plains of Dire Dawa generally shows that the alluvial deposit is underlain in depth by tertiary basalt or, upper sandstones and limestone (WWDSE, 2004). The hydrogeology of the Dire Dawa area is classified into two main aquifers (Figure 2.1) (Mesfin, 1981):

- Hard rock aquifer (consolidated water bearing formation)
    - Localized volcanic rocks aquifer with fracture permeability
    - Extensive sedimentary formation aquifer (sandstones and limestones) with fracture permeability
    - Localized metamorphic rocks aquifer with fracture permeability
- Alluvial aquifer (unconsolidated water bearing formation)
    - Extensive alluvial sediments aquifer with intergranular permeability

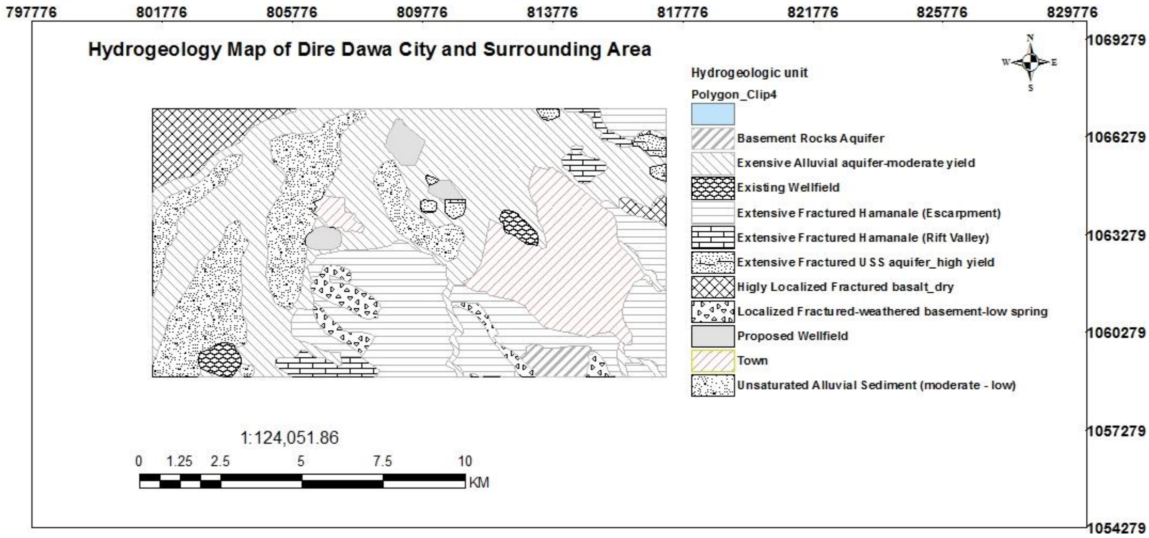


Figure 2.1. Hydrogeological Map of Dire Dawa & surrounding area (modified after WWDSE, 2004)

2.4.1.1 Alluvial aquifer

The alluvial sediment overlies the basalt, upper sandstone and limestone at different places and it occurs as river sand and travertine with limited area extent and alluvium sediments with large aerial extent (WWDSE, 2004). The groundwater depth ranges from 5 to 45 meters and the transmissivity varies from 8 to 700 m^2/day.

The major chemical composition of the water in the alluvial aquifer include: Ca-Mg-HCO_3, Ca-HCO_3-Cl, Ca-Mg-HCO_3-Cl, Ca-Na-HCO_3-Cl, Na-Ca-Mg-HCO_3-SO_4, etc. The water type with chlorides, sulfates and sodium are the modification due to human interference in the Dire Dawa city (WWDSE, 2004).

2.4.1.2 Tertiary volcanic rocks

Water wells drilled in the basalts are practically dry except at Hurso area with a maximum specific capacity of 0.01 l/s/m. The formation is generally considered as a regional aquiclude. The major chemical composition of the water in the volcanic aquifer include Ca-

HCO_3, Ca-Mg-HCO_3-Cl and Ca-Na-HCO_3. Similarly, the water with high concentration of chlorides are the result of human interference (WWDSE, 2004).

2.4.1.3 Upper sandstone

The upper sandstone outcrops in a small aerial extent at Aseliso, north of Dire Dawa at the airport and northwest of Dire Dawa city and it is overlain by alluvium at the Sabian water wells (WWDSE, 2004).

The aquifer is generally confined with groundwater striking depth varied between 100 to 120 m, piezometer water level ranges from 50 to 60 meters below the ground. Likewise, the transmissivity of the aquifer varies from 9 to 5512 m^2/day. The sandstone at the Sabian area also considered as confined aquifer although the pumping test results showed leaky aquifer (WWDSE, 2004).

The water quality is generally hard and the major chemical composition of the water in the sandstone aquifer include Ca-HCO_3, Ca-Mg-HCO_3 and the water at Dire Dawa city and the Sabian has high chlorides and the water chemical composition changed to Ca-HCO_3-Cl, Ca-Mg-HCO_3-Cl, and Ca-Cl-HCO_3-SO_4 due to contamination of the aquifer by human interference (WWDSE, 2004).

2.4.1.4 Hamanalei limestone

The drilling results showed that the limestone underlies the upper sandstone. The limestone at Dire Jara area is highly fractured and karasted while massive with low groundwater productivity at the DD city area and most of the water wells that penetrates only the limestone were abandoned (AE, 1990). The limestone displays and share similar water type with sandstone.

In general, there are no geologic formations that contains caliche rock which is rich in nitrate salt. In addition, there is no halite or evaporite deposit associate with chloride. However, there is shale and marine sediment intercalated in the limestone and sandstone deposits that are known to contain gypsum which is rich in sulfate (WWDSE, 2004; MS consult, 2015).

2.4.2 Influence of sanitation on groundwater quality

The 2007 CSA reports of Dire Dawa toilet facilities by housing unit can be further categorized into pit, VIP, flush and no toilet facilities condition. It is possible to summarize that 89% of latrines are potentially discharging excreta directly into the alluvial deposit where the latrines are constructed (Table 2.2). This deposit is known to be moderately permeable, productive and source of water for hand dug wells. The contamination of the alluvial deposit could have dual effect of contaminating the shallow aquifer and the underlying main sandstone and limestone aquifer (WWDSE, 2004; MoWR, 1999; AE, 1990 and Ketema, 1982).

The surficial exposure of alluvial deposit with moderate permeability and presence of shallow groundwater circulation and pit latrine nature of the toilet are the favorable conditions that facilitate the contamination and easy percolation of the groundwater into the underlying aquifer.

From the 2007 CSA report, it was only 11% of the latrines that have sealed containment and were contributing to the protection of the groundwater contamination.

Table 2.2. Number of toilet facilities in DD

s.n	Description	Number of toilet	% of latrine
1	No toilet	10,272	20
2	Flush toilet	5,444	11
3	VIP latrine	7,348	14
4	PIT latrine	28,530	55

Source: modified after CSA, 2007

2.5 Health Effects of Nitrate

Conversion of nitrate to nitrite takes place in the saliva of people of all age groups, and in the gastrointestinal tract of infants. Infants convert approximately double, or 10 percent of ingested nitrate to nitrite compared to 5 percent in older children and adults (Hazen, 2006).

2.5.1 Methaemoglobinaemia

The toxicity of nitrate to humans is mainly attributable to its reduction to nitrite. The effect of nitrite in humans is its involvement in the oxidation of normal Hb to metHb (Hazen, 2006 and WHO, 2011). A correlation study among children aged 1–8 years in the USA showed that all the metHb levels were within the normal range that consumed 22–111 mg of nitrate-nitrogen per liter and <10 mg of nitrate-nitrogen per liter. Hence it is suggesting that older children are relatively insensitive to the effects of nitrate (Craun et al., 1981).

2.5.2 Long-term (chronic) effects

No convincing evidence was found of an association between gastric cancer and the consumption of drinking-water in which nitrate concentrations of up to 45 mg/l were present. No firm evidence was found at higher levels either, but an association could not be excluded because of the inadequacy of the data available.

In 1995, a committee from the National Academy of Science reviewed the scientific data available for nitrate. They concluded that "… exposure to the nitrate and nitrite concentrations found in drinking water in the United States is unlikely to contribute to human cancer risk." There is no strong evidence that nitrate and nitrite can cause cancer in the absence of the amine- containing substances necessary for the formation of nitrosamines in the body. Therefore, nitrate and nitrite would be classified in Group D, inadequate evidence to determine carcinogenicity, under the old U.S. Environmental Protection Agency cancer categorization scheme. Under the new EPA cancer guidelines, it would be appropriate to classify them into the "inadequate information to assess carcinogenic potential" category (Hazen, 2006).

2.6 Environmental Level-Water

The natural nitrate concentration in groundwater usually does not exceed 4–9 mg/l of NO_3^- (WHO, 2011; Alexandre et al., 2010). Therefore, the presence of nitrate in groundwater greater than 9 mg/l usually reflects the impact of human activities on groundwater quality, or there must be other source which could lead to violation of such natural state and need to be assessed to device a mechanism to minimize the subsequent pollution.

CHAPTER 3: MATERIALS AND METHODS

3.1 Description of the study area

Dire Dawa is located 510 km east of Addis Ababa and it is generally characterized by arid or semi-arid climate without perennial stream, with mean annual temperature and rainfall of 25.3^{0}C and 618mm respectively (WWDSE, 2004). The study area covers UTM 1059754 N to 1067650 N and 804511 E to 816913 E (Figure 3.1). It has an estimated land of 9,962.6 ha with a mean altitude of 1160 masl and an estimated population of 232,854 (67.5%) urban people (CSA, 2007).

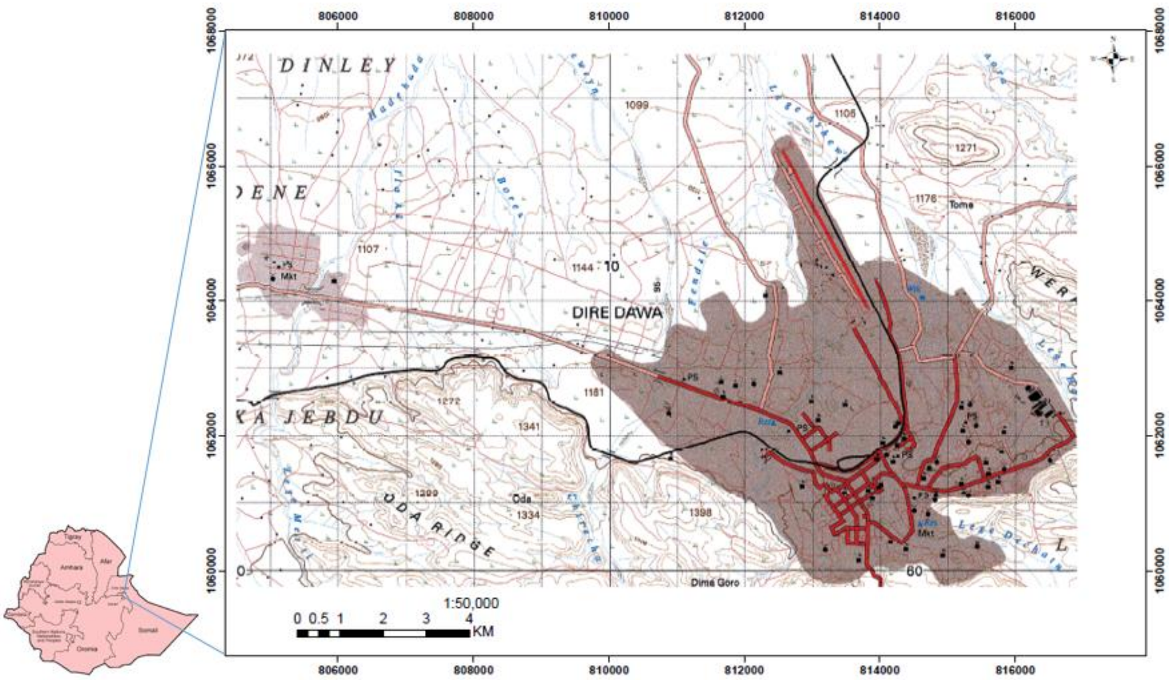


Figure 3.1. Location map of the study area (EMA, 2000)

The first piped water supply for the city was constructed in the year 1914 using Lega Hare spring. The current water supply system designed as Phase-I by the Associated Engineering Service Limited (AESL) and was commissioned in 1992 to serve until 2002 G.C. These systems consisted of the Lega Hare spring and nine boreholes from Sabian wellfield (MS Consult, 2011).

3.2 Methods

Both primary and secondary data sources were assessed to generate data for the research. The first phase was desk review of the available and pertinent literatures, reports and maps to nitrate and Dire Dawa. The second phase was primary data generation through collection of groundwater samples, preparation of 1:50,000 base map, GPS location of water sources, photographing and videoing of water sources and laboratory analysis of water for nitrate, chloride, sulfate and fecal coliform.

Data obtained from the fieldwork, laboratory analysis and literature was assessed from water quality perspective. To gain more information and to counter check the various data obtained from the secondary and primary sources, the nitrate and fecal coliform bacteriological data were interpreted against the field observation and Ethiopia and WHO guideline values.

3.2.1 Sampling and sample size determination

In many water bodies the issues of where to sample and how many samples to take in order to give representative results for the whole water body need more than an intuitive choice of sampling design. Nevertheless, the task of deciding the optimum number of samples to take and the most suitable locations in a water body in order to characterize its water quality in a meaningful way, and with the most economic use of resources, can be quite discouraging (Deborah, 1996).

3.2.1.1 Data to be collected

Groundwater samples including geographic coordinates (Table 3) were manually collected from the 29 water wells against the planned 28 water samples. The water wells were grouped into five locations with each group consisting of 13, 4, 3, 5 and 3 water wells at Dire Dawa central area, Sabian, Tome, Boren & Melka respectively (Figure 3.2 and Figure 3.3). The basis of the stratification includes population density, relative age of settlement (old or young), presence of wellfield (old & new), exposed surface geologic material (sand or clay) and relative location of the water well (fully in town or town periphery). In addition, three deep water well water samples were taken from different rural areas and two hand dug wells in the town. These additional samples were served as comparator between hand dug wells to depth of 30 meter and deep water well above 60 m depth range in rural and urban water wells.

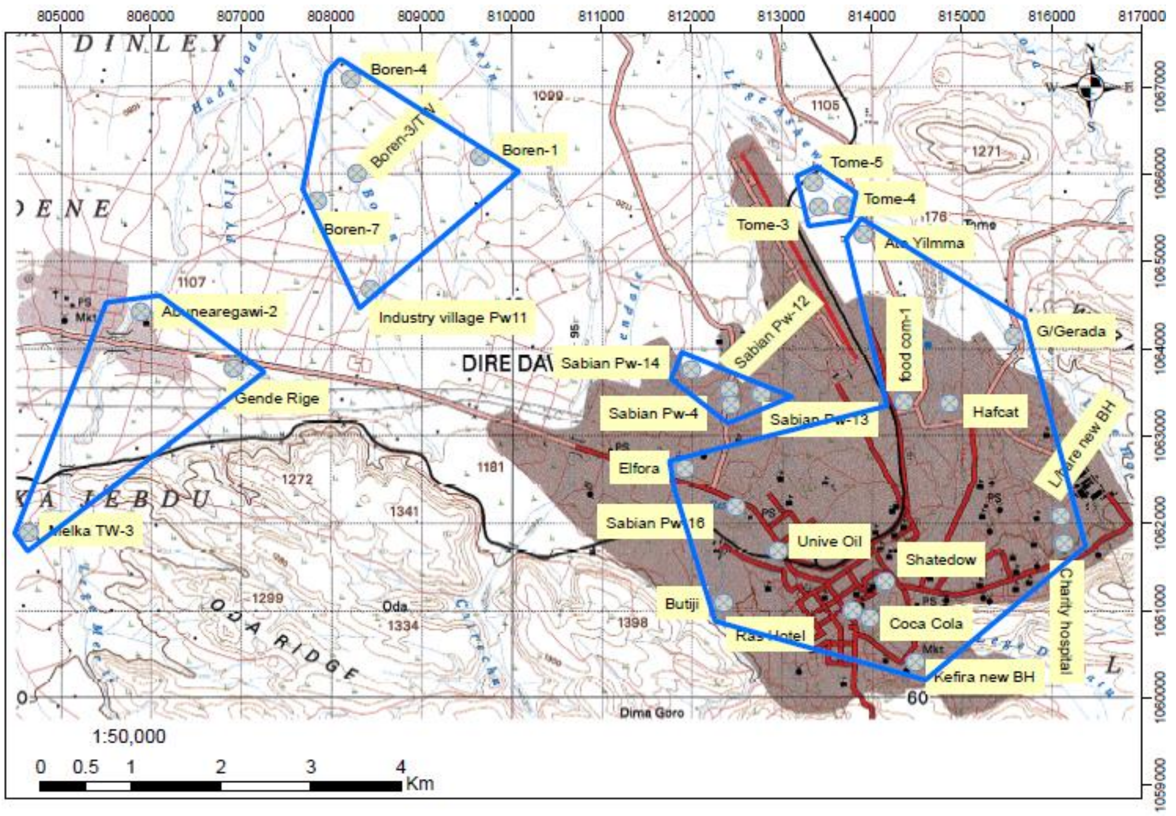


Figure 3.2. Spatial distribution of sampled water wells

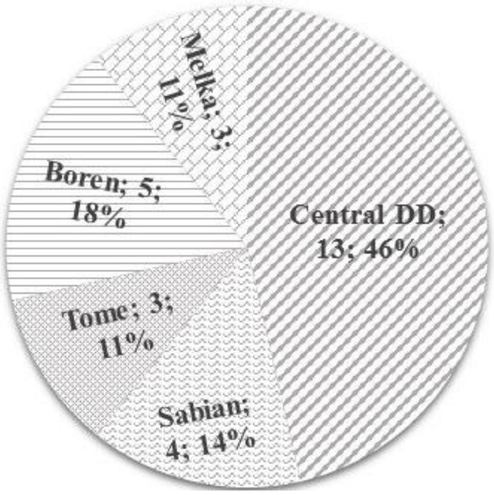


Figure 3.3. Proportion of groundwater samples

The groundwater samples were collected during the field work in December 2016 from 25 deep water wells located within the Dire Dawa city and 4 water samples from Dire Dawa water wellfield located in Somali Regional state of Siti zone. Furthermore, secondary water quality data was used for Elfora. The collected one-liter groundwater samples were kept in plastic bottle, properly labeled (coded and dated), stored in light insulated ice box with ice bag until submitted to the Dire Dawa Water Supply and Sewerage Authority Laboratory within two hours of collection.

3.2.1.2 Population to be sampled

In this research, the target population was 56 deep water wells which were functional and available within Dire Dawa town. The sampled population was 28 water wells (28 of 56 water wells or about 50%) as obtained from sample size determination employed in section 3.2.1.4.

3.2.1.3 The Sample frame

Before selecting the sampled water wells, the water wells were divided into parts that were called sampling units, or units. These units covered the whole 56 functional water wells available in the town and every water well in the population belongs to one and only one unit. In sampling the water wells in Dire Dawa city, the unit was an individual water well.

3.2.1.4 Sampling size determination

The sample size was determined using point estimate for proportion of sample method with water wells having nitrate exceeding 45mg/l. In this regard, available data on water wells having nitrate exceeding 45mg/l were taken into consideration to identify the proportion of polluted samples as this cutoff point causes blue baby syndrome under the age of 6 month infants. Hence, about 21.4% proportion of polluted sample was calculated from record of previous water quality studies (WWDSE, 2004). This proportion of sample together with 90% confidence level and 10% margin of error were taken to calculate the sample size for this research. The sample size was determined based on the following formula (Getu et al., 2005) and adjustment for sample size:

$$n = \left(\frac{Z_{\alpha/2}}{E}\right)^2 * p * (1-p) \quad \text{and} \quad n_1 = \frac{n}{\left(1 + \frac{n}{N}\right)}$$

Where

n - estimated sample size (number of groundwater sample to be collected)

N- population size (number functional deep water wells) which is 56

n_1- adjusted sample size

$Z_{\alpha/2}$ - confidence level at 90% is equivalent to 1.64 ensure optimum sample size

E – margin of error, assume 10%

p - proportion of polluted sample, 21.4% from previous study record

1-p – proportion of non-polluted sample, 78.6%

$$n = \left(\frac{1.96}{0.10}\right)^2 * 0.214 * 0.786 = 45.24 \approx 46$$¨è

$$n_1 = \frac{n}{\left(1 + \frac{n}{N}\right)} = \frac{46}{\left(1 + \frac{46}{56}\right)} = 25.25 \approx 26$$

3.2.1.5 Selection of the sample

This research employed stratified groundwater sampling as there was heterogeneity in the location of water wells and age of settlement (history of settlement) of the water wells. In view of this, simple random sampling was then employed to draw samples from the five stratum/sampling area that appear to be "representative" of average conditions. The sample size of each strata was determined by using probability proportion to sampling size method (Maskurul et al., 2015) (Table 2).

3.2.1.6 Organization of the fieldwork

Data collection methodology and data collection sheet with labeling, total number of the sampled water wells, collection schedule and instrumentation completed ahead of actual field work. In addition, plans were made for handling no response associated with failed/disfunctional water wells. In case the water wells were not fitted with pump or the water well was not functional, nearby water wells were sampled or recent groundwater analysis result was consulted in the overall study of the research.

3.2.2 Data entry and analysis

The data entry was performed using personal computers into excel 2016, AutoCAD 2007 and GIS softwares which is ArcGIS 10.3, Surfer 10 and Global mapper 12. The software was used to generate graphs and maps of nitrate, chloride, sulfate and bacteria.

Photometer 7100 and membrane filtration instruments were also employed to analyze the nitrate, and fecal coliform bacteriological condition of the collected groundwater samples mainly to understand the degree of nitrate pollution and the sources associated with it. The research was also considered chloride and sulfate concentration as there was positive correlation between these ions and concentration of nitrate in the groundwater (Taye, 1999; WWDSE, 2004; Eyilachew, 2010 and Qianqian et al., 2015). In order to efficiently use the thesis budget and time, relevant nitrate, chloride, sulfate and fecal coliform load of Dire Dawa water wells were dealt mainly to substantiate the study subject. Finally, the results were used to generate the nitrate level, the bacteriological load of the groundwater in the city and to indicate the source of nitrate pollution.

3.3 Materials

The study employed the following materials and instrumentation during the primary and secondary assessment of the research work in the sampling to analyze the sampled data.

- Half liter plastic bottle, marker and masking tape for water sample collection and labeling
- Icebox and ice bag for storage and transportation of collected water samples
- 1:50,000 topographic map (printed and scanned copy) for locating the sampling points,
- GPSmap 76 for locating of water sources,

- Digital photo and video camera,
- Photometer 7100 and Pathoscreen for testing the sampled water
- MS Word and Excel 2016, computer, AutoCAD 2007, ArcGIS 10.3, Surfer 10 and Global mapper 12 GIS software for data entry, analysis, mapping and reporting

3.3.1 Spectrophotometer

As the color of the solution deepens, it is inferred that its concentration also increases. This is an underlying principle of spectrophotometry: the intensity of color is a measure of the amount of a material in solution. A second principle of spectrophotometry is that every substance absorbs or transmits certain wavelengths of radiant energy but not other wavelengths. Thus, the absorption or transmission of specific wavelengths is characteristic for a substance, and a spectral analysis serves as a "fingerprint" of the compound.

3.3.2 Membrane filtration method

The accepted approach in tracing microorganism in water is to analyze for indicator organisms that inhabit the gut in large numbers and are excreted in human/animal feces. The presence of these indicator organisms in water is evidence of fecal contamination (UNEP/WHO, 1996 and Potakit, 2011).

The group of indicator bacteria tested for with the Potakit + are called Coliforms; more specifically the focus is on the enumeration of Thermotolerant Coliforms (sometimes called Fecal Coliforms). These are bacteria that originate from fecal sources (UNEP/WHO, 1996 and Potakit, 2011).

Thermotolerant Coliforms or Fecal Coliforms are used in water microbiological testing to denote coliform organisms which grow at 44 or 44.5°C (UNEP/WHO, 1996 and Potakit, 2011).

In practice, some organisms with these characteristics may not be of fecal origin and the term Thermotolerant Coliforms is therefore more correct and is becoming more commonly used. Nevertheless, the presence of Thermotolerant Coliforms nearly always indicates fecal contamination (UNEP/WHO, 1996 and Potakit, 2011).

Usually, more than 95% of Thermotolerant Coliforms isolated from water are the gut organism Escherichia coli (E. coli), the presence of which is definitive proof of fecal contamination (UNEP/WHO, 1996 and Potakit, 2011).

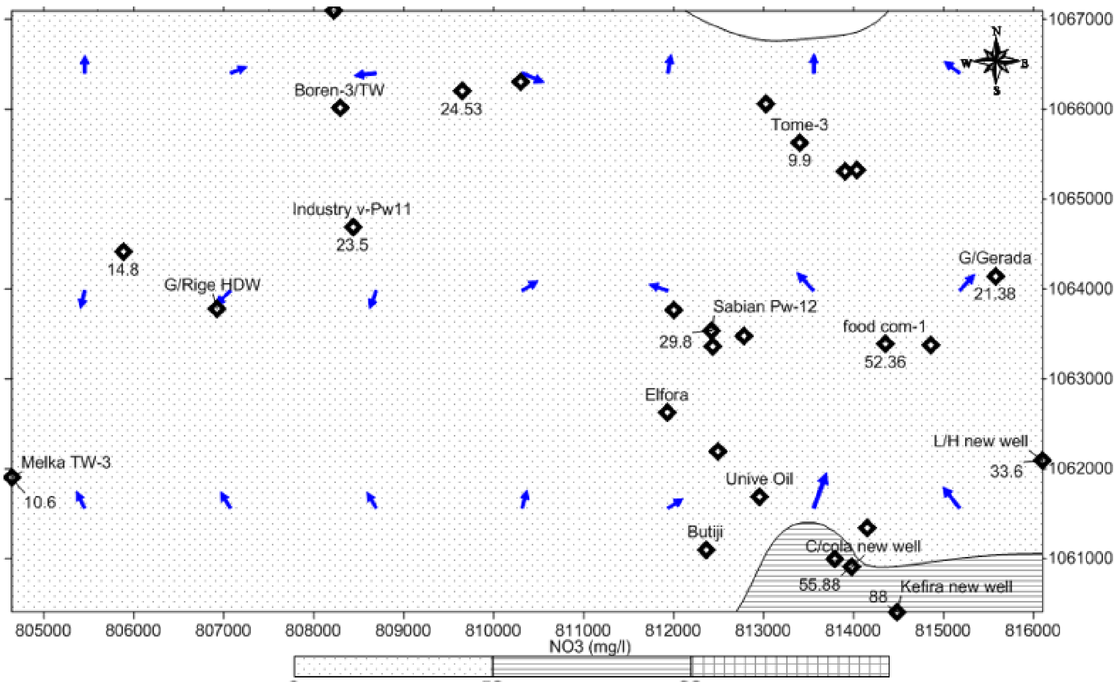
CHAPTER 4: RESULTS AND DISCUSSION

4.1 Groundwater Nitrate Level

The analysis result of the 28 water samples indicated that the concentration of nitrate spatially varied between 0.86 mg/l and 88.9 mg/l within the study area (Table 4). The summary of nitrate analysis of groundwater indicated that 13.8% of the groundwater samples which cover 2.9% of the study area have nitrate values above 50 mg/l (Table 4.1). The nitrate concentration in the central part of the city is above 50 mg/l exceeded the WHO and Ethiopia standard of nitrate in drinking water (WHO, 2011; ESA, 2013). Therefore, the 2.9% groundwater area has been seriously affected by the nitrate pollution and limits its suitability as drinking water source. The remaining 86.2% of groundwater samples from the areas which covers 96.5% of the total study area had nitrate values below 50 mg/l and it is in full compliance with WHO and Ethiopia drinking water guideline value of below 50 mg/l nitrate (WHO, 2011; ESA, 2013) (Figure 4.1) and are safe for drinking water need of the city.

Table 4.1. Percentage & areal coverage of nitrate

Nitrate (mg/l)	**No. of samples**	**% sample**	**Area (ha)**	**% area**
<50	25	86.2	7,412	96.5
>=50	4	13.8	219	2.9
No data	NA	NA	52	0.68



Legend: ⟶ NO_3 flow direction & ◆ selected water well NO_3 level

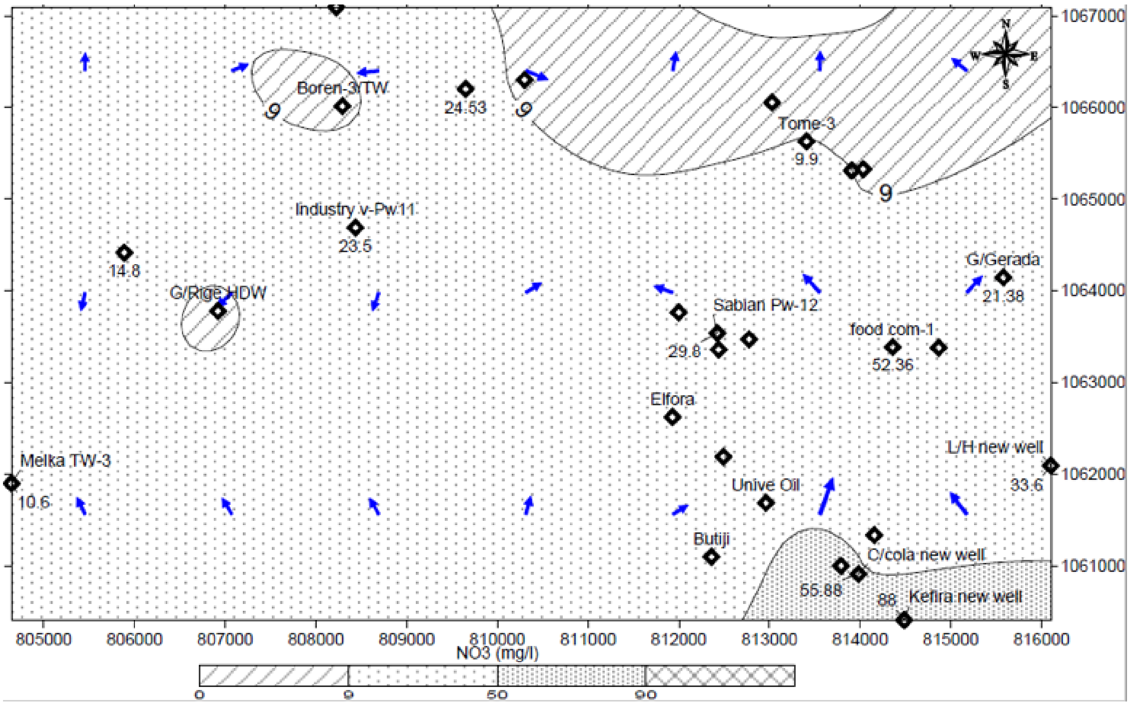
Figure 4.1. Spatial distribution of nitrate in groundwater

The normal/natural groundwater nitrate concentration is up to 9 mg/l (WHO, 2007; Alexandre et al., 2010), any values that exceed 9 mg/l is indicative of nitrate pollution. Hence, the current analysis of DD city groundwater indicated that 79.3% of groundwater samples with 85.7% of areal coverage have nitrate values above 9 mg/l (Table 4.2, Figure 4.2). This is a clear sign of nitrate pollution of which 13.8% of groundwater source with 2.9% of areal coverage have potential threat to induce blue baby syndrome. However, it is only 20.7% of groundwater samples with 13.5% of areal coverage have the natural value of nitrate concentration in the groundwater.

Table 4.2. Percentage and areal coverage of nitrate

Nitrate (mg/l)	**No. of samples**	**% sample**	**Area (ha)**	**% area**
<=9	6	20.7	1,036	13.5
>9 & <50	19	65.5	6,363	82.8

Nitrate (mg/l)	No. of samples	% sample	Area (ha)	% area
>=50	4	13.8	220	2.9%
No data	NA	NA	65	0.9



Legend: → NO_3 flow direction & ◆ selected water well NO_3 level

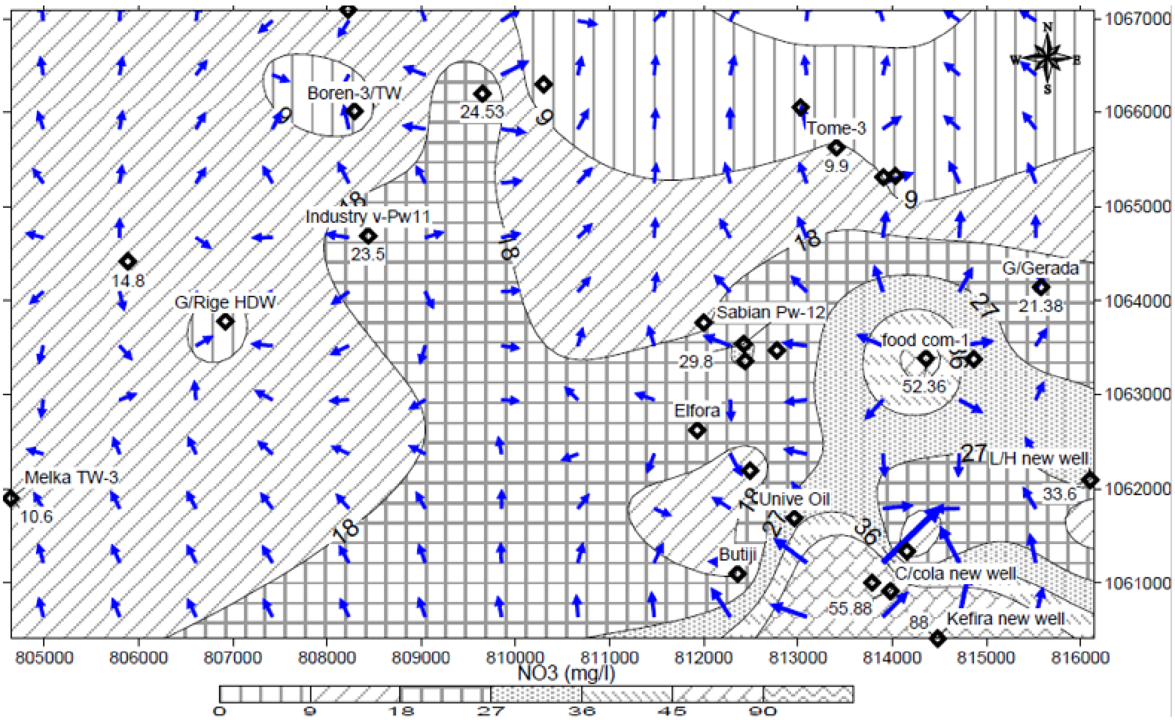
Figure 4.2. Spatial distribution and flow direction of nitrate

4.1.1 Spatial variability of nitrate

The spatial distribution and flow direction of nitrate indicate the spatial variability of nitrate concentration (Figure 4.3). Accordingly, the southeast and south part of the study area (central part of the DD city) has the maximum/peak nitrate concentration of 88 mg/l at Ras Hotel and Addis Ketema areas where as the minimum/lowest value of 0.86 mg/l and 2.91 mg/l of nitrate found in Tome and Boren water wellfields respectively.

Different scholars indicated that groundwater nitrate concentrations have gradually increased with rapid urbanization, economic development and population density. These scholars indicated that domestic waste discharge was the main source of pollution during rapid urbanization. The high levels of urbanization and population density would appear to be causing high levels of domestic wastewater being discharged into the environment, and resulting in the increased nitrate concentration in the groundwater (Taye, 1999; Eyilachew 2010 and Qianqian, 2015).

Similarly, the Ras Hotel and Addis Ketema areas which are known to be the old settlement with high population density 690 and 803 person/ha and containing moderately permeable sandy/alluvial surficial deposit directly overlying the main sandstone and limestone aquifer. In addition, the groundwater level is at 80m, 100m and 120m higher than the groundwater level at Sabian, Melka and Tome-Boren areas respectively. As a result, the central part of the city is highly polluted (88 mg/l of NO_3^-) and the higher water table in these areas drive polluted water to advance towards the low water table and relatively low nitrate areas in Sabian, Melka and Tome-Boren sites.



Legend: ⟶ NO_3 flow direction & ◆ selected water well NO_3 level

Figure 4.3. Spatial distribution of nitrate with flow direction and some spot values

In addition, 89% of the people in the DD city uses pit latrine (CSA, 2007) that are fully built in the moderately permeable sandy soil (WWDSE, 2004) (Table 2.2). Hence, the areas have been discharging toilet waste for decades and are accountable for the high (89 mg/l) concentration of nitrate in the central part of the city (Addis Ketema and Ras Hotel). Furthermore, the presence of high nitrate along with high groundwater level at the central part of the city act as the main driving force for the transport of nitrate towards the low concentration and low groundwater level in Sabian, Melka and Tome-Boren areas.

The permeability characteristic of the top layer immediately overlying the main sandstone and limestone aquifer is one of the limiting factors for the high/low concentration of nitrate. For instance, the average nitrate concentration of the water wells is about 39 mg/l where the surface geologic material is sand with hydraulic conductivity of 5 m/day in the central part of the city compared to 14 mg/l where the top layer is mainly clay in Sabian, Melka and Tome-Bore areas with hydraulic conductivity of 1 m/day (Table 4.3).

Table 4.3. Concentration of nitrate in clay and sand

Geology	**Hydraulic conductivity (m/day)**	**Mean NO_3^- (mg/l)**
clay	1	14
Sand	5	39

Furthermore, population density is also another determinant factor for the high/low concentration of nitrate in the water wells. Similarly, the increase in population density results an increase in nitrate concentration (Figure 4.4). Though there is high population density in Hafcat and Lege Hare areas, there is not much increase in nitrate probably due to presence of Dechatu ephemeral river which seasonally recharge the aquifer and the recharge area location of Legehare. In addition, there might be confining layer that prevent direct infiltration of sewage in Legehare area.

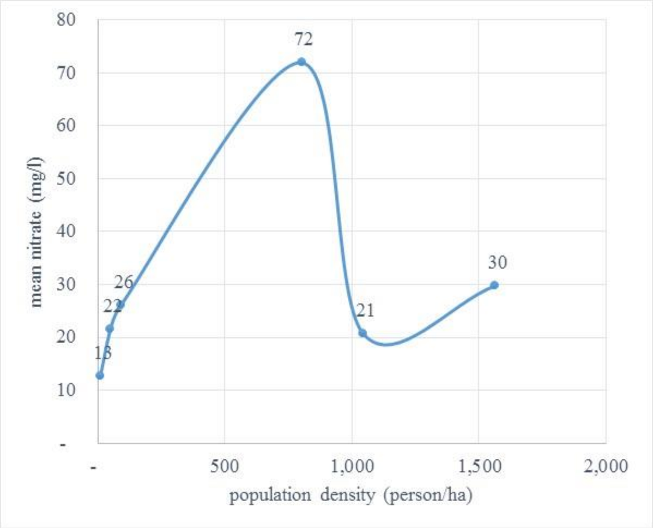


Figure 4.4. Plot of nitrate versus population density

As compared to the central part of the city, the concentration of nitrate declines towards north, northwest and west of the study area and reach its lowest level at the downstream peripherals (Figure 4.3). Accordingly, the peripheral places located in Tome and Boren areas have the minimum/lowest nitrate concentration of 0.86 mg/l. These areas are characterized by low population density of 0 to 20 people/ha and deep groundwater level. It has also impermeable clay soil surficial material overlying the main sandstone and limestone aquifer and presence of fully confined aquifer (Figure 4.6). The overlap of high groundwater level with high nitrate concentration and their flow directions easily assist the movement of nitrate towards the low concentration places at Sabian, Melka and Tome-Boren areas.

The local high nitrate concentration at the Industry village appears to be attributed to the open well construction of the well itself, leakage of human waste from Defense force hospital and presence of nearby industry village.

The nitrate contour/zonation map together with nitrate flow direction indicated that the southeastern (central part) of the city has the highest nitrate concentration among all groundwater sources sampled in the study area (Figure 4.3). Hence, nitrate is moving from this part of the city to other parts of the city polluting the existing and new groundwater fields found in Sabian and Tome-Boren areas respectively. The direction of the arrow indicates the nitrate flow direction while the length of the arrow indicates the magnitude of the nitrate flow. The flow is faster or steeper where the groundwater flow direction is steeper around Coca and food complex/Hafcat area (Figure 2.2 and 4.3). The flow of nitrate is generally along the groundwater flow direction and currently threatening the wellfield. If nitrate had flowed against the groundwater flow direction, it had an opportunity to retard the advection movement of the contaminant. However, it is unfortunate that the nitrate and groundwater flow direction currently coincided and bring threat to the water wellfield. As a result, only few and small pocket areas shaded in gray at Boren, Tome and Melka have the natural nitrate values up to 9 mg/l while the remaining areas are seriously and moderately affected that account 2.9% and 82.8% of the study area respectively.

From water level measurement of water wells located in upper sandstone and alluvial aquifer indicated that the groundwater in Dire Dawa City area has two main flow directions, i.e. southeast to northwest and south to north (Figure 4.5). It generally follows and aligns with the surface flow direction and the gradient of the area. The groundwater flow is steeper and faster at Sabian while flat and slower around Melka Jebdu town area.

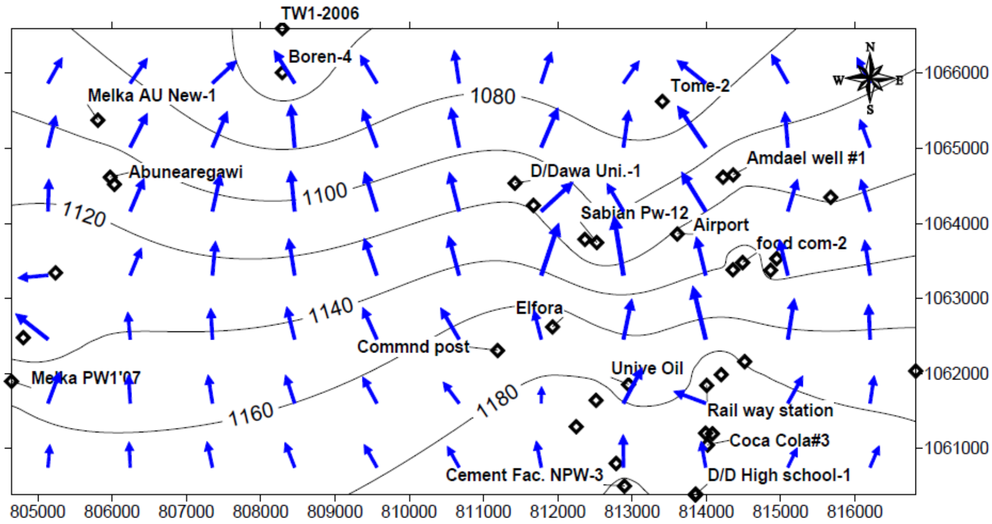


Figure 4.5. DD groundwater level with flow direction

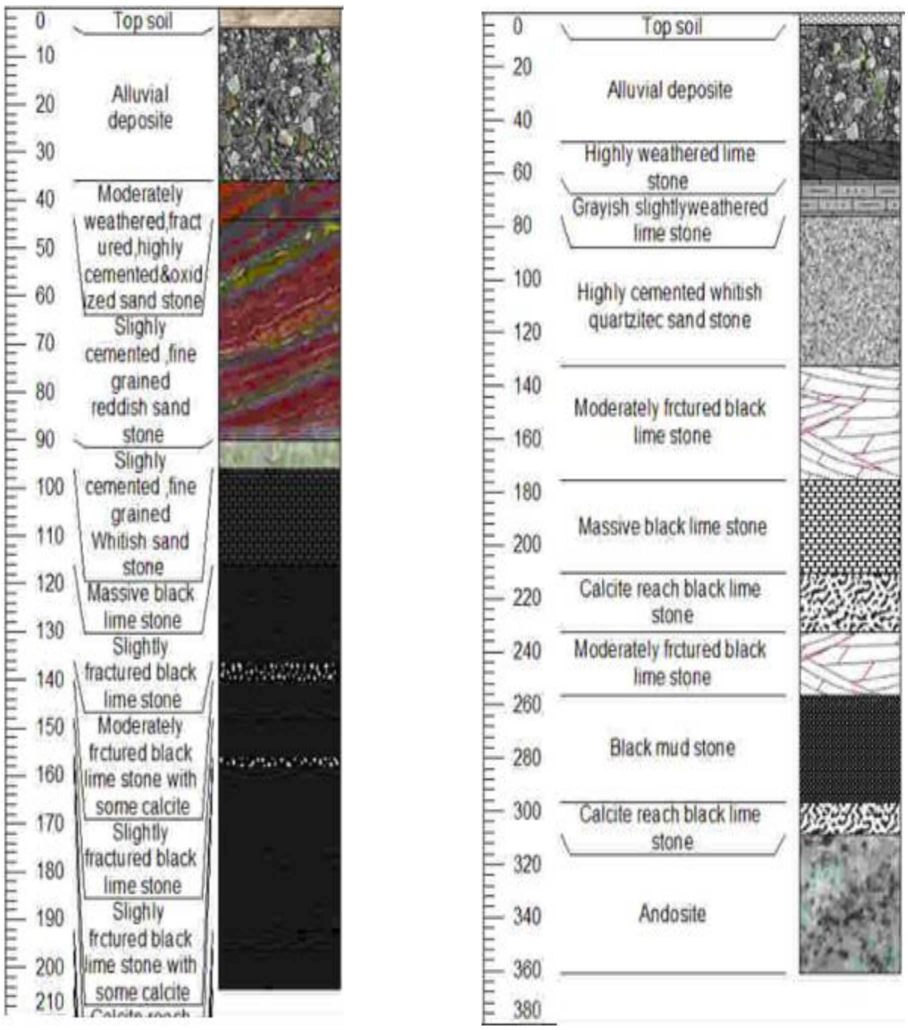


Figure 4.6. Geologic log of Tome-4 and Boren-3 water wells (MS consult, 2015)

4.1.2 Nitrate concentration with depth

The plot of nitrate against the depth of sampled water well indicated that shallow water wells are more liable to contamination and have high concenration of nitrate as compared to deep water wells (Figure 4.7). The concentration of nitrate tends to decline with increasing depth in the groundwater (Alexandre et al., 2010).

The water quality analysis carried out by EIGS in 1986 mainly collected water samples from hand dug wells and shallow water wells that were highly prone to contamination and located in the center of the city. Unlike EIGS 1986, water samples were mainly collected from the deep water wells where nitrate tend to reduce as a result of possible reduction in nitrate pollution due to prevalence of anaerobic environment. The plot of nitrate with depth indicated that the maximum and minimum concentration of 320 mg/l and 5 mg/l value were recorded in shallow water wells of depth 54.9 m and 45.7 m in the central and peripheral part of the town at railway and cotton factory areas respectively. Similarly, the maximum and minimum values 88.9 mg/l and 0.86 mg/l of nitrate is recorded in the water wells at depth of 120 m and 361 m respectively.

In general, the decrease of nitrate with depth is mainly attributed to the prevalence of anaerobic environment that lead to denitrification or degrading of nitrate to nitrogen. The sampled water wells clearly indicated uneven decrease of nitrate with increasing water well depth mainly attributed to presence of nearby local seasonal river channel, relative age of settlement and location in the town. For instance, consider Sabian PW-16 at water well depth of 195m has 13.4 mg/l nitrate concentration while Sabian PW-12 same 195m water well depth has 29.8 mg/l nitrate. The variation is mainly due to the presence of seasonal ephemeral river channel which seasonally recharge the groundwater with immediate effect of the nearby water well like Sabian PW-16 against Sabian PW-12 that is fully located in residential areas and far away from seasonal stream to periodically recharge and affect the nitrate concentration.

Similarly, the comparison of a specific well (Ato Yilma's) of 120m deep against 125m deep Coca Cola water well reveals that the nitrate concentration of 5m deeper Coca Cola water well is 55.9 mg/l against 10.6 mg/l of Ato Yilma's water well. The variation however, explained and mainly related to the center town location of Coca Cola water well in which there is a tendency to receive significant nitrate pollution emanated from the pit latrine of the dense urban settlement for many decades against the peripheral located Ato Yilma's water well with very sparse population settlement and mainly practicing open defecation in hot and dry environment. Moreover, there is no direct contact of Ato Yilma's water well with the nitrate pollution and the nitrate of the water well is only due to groundwater flow associated with advection and diffusion of nitrate.

The concentration of nitrate tends to decrease with increasing water well depth in the rural areas and conform with the general principle of nitrate concentration decline with increasing water well depth. Factors like population density, utilization of latrine and age of settlement are similar in the rural areas compared to the water wells located in the urban area. For instance, Jeldessa rural water well at depth of 90 m has 13.3 mg/l of nitrate against 11.5 mg/l of 119.4 m Aselisso water well. Similarly, Aselisso and Ato Yilma water wells which are found almost at same depth level of 119.4m and 120m have similar nitrate concentration of 11.5 and 10.56 mg/l respectively.

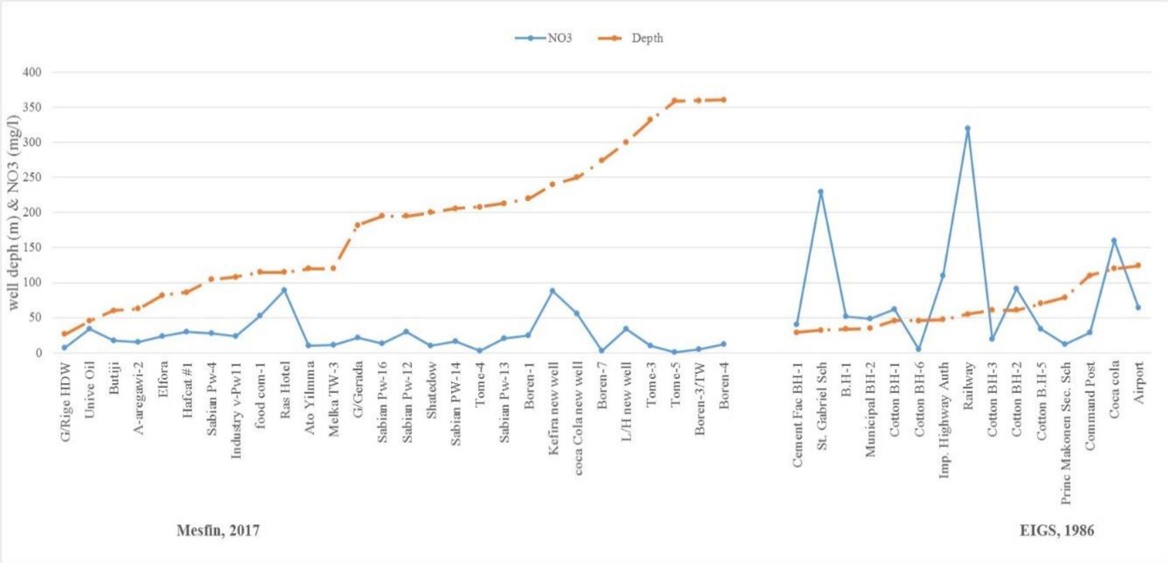


Figure 4.7. Occurrence of nitrate in shallow and deep water wells

Table 4.4. Nitrate versus depth two tail independent t-test

	NO_3	*Depth*
Mean	24.544	178.11
Variance	488.93	10564.34
Observations	29	29
Hypothesized Mean Difference	0	
df	31	
t Stat	-7.87	
P(T<=t) one-tail	3.5285E-09	
t Critical one-tail	1.31	
P(T<=t) two-tail	7.05699E-09	
t Critical two-tail	1.7	

The above t-test indicate that the t Stat absolute value is greater than the t Critical two tail. Hence, the result is statistically significant and the decrease in nitrate with increasing water depth do not happen a matter of chance rather the decrease is associated to systematic reason like prevalent of reducing environment.

4.2 Bacteriological Analysis

The critical level in terms of fecal pathogen indicator is 0.0 E. coli per 100 ml of water (WHO, 2006). The use of poorly constructed pit latrine in permeable sandy formation like Dire Dawa, may result in drinking water contamination due to pollutants leaching into an aquifer. The bacteriological analysis of the 28 water samples indicated that 35.7% of the sampled groundwater sources covering 56.2% of the study area were contaminated with fecal coliform (Figure 4.8). The largest bacterial colony count (32 count/100 ml) is found in the unprotected 26 m deep in town located hand dug well followed by 24, 16 and 14 bacterial colony count at water well depths of 119 m, 250 m deep water well and 108 m in Aselisso, Coca and Industry villages respectively (Figure 4.9). The Coca water well which is deeper than both Aselisso and Industry village should have low bacterial count. However, its mid-town location and probably semiconfined nature of the aquifer that might have facilitated direct recharging of contaminated surface runoff contributed to the high bacterial count against the relatively shallower depth of rural located water wells in Aselisso and Industry village.

The spatial distribution of these contaminated sources also indicated that 28.6% of the contaminated groundwater source falls within the urban areas where as 7.1% of the groundwater sources were from the wellfields located in the rural setting (Figure 4.8). Hence, the presence of fecal coliform in the urban and rural water wells clearly indicated that the source is mainly human excreta as only Hafcat and Amdale areas had animal farming nearer to the sampled groundwater sources as compared to the presence and utilization of 89% pit latrine that were built in the permeable sandy layer.

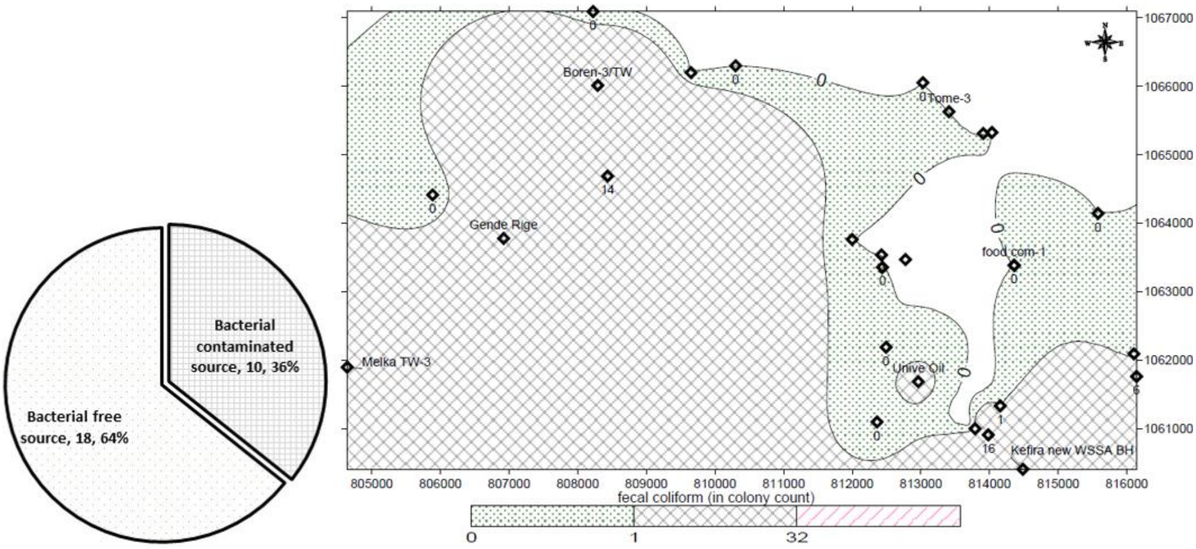


Figure 4.8. Proportion and spatial distribution of fecal coliform in sampled sources

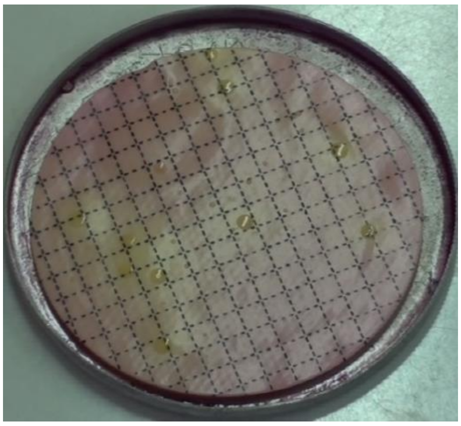


Figure 4.9 Ije Aneni bacterial colony in petri-dish

Similarly, the 28 urban (27 deep and 1 dug wells) and 3 rural water wells indicated that bacterial contamination was found in 38.7% of the sampled groundwater sources. The contamination of urban groundwater sources accounted 32.3% (10 of 31 water samples) whereas the remaining 6.4% contaminated groundwater sources found in the rural areas. The relative percentage of bacterial contamination indicated that 35.7% and 66.67% of water sources were polluted with fecal coliform. However, the higher figure in the rural areas is due to small sample size considered mainly for comparison need of the study. The presence of fecal coliform in all the contaminated 12 water samples confirms that feces is the main source of bacterial contamination of the groundwater sources.

The bacterial free water sources were distributed all over the sampled area (Figure 4.8). The plot of bacterial free and contaminated sources against the depth of the water well confirmed that depth of water well is not the limiting factor for the presence or absence of bacteria (Table 4.5). The closer examination of the bacterial free groundwater sources (running from DD food comp-1 to Abunearegawi) signifies that depth of deep water well and relative location of the water well in the urban and rural setting are not the only determinant factor. It is rather indicated that the confined aquifer nature of the water well was the main limiting factor. In addition, tubeless-ness and openness of the hand dug wells were also the determinant factor for the presence of bacterial contamination.

Table 4.5. Fecal coliform versus depth of water wells

Name of water	**Depth (m)**	**Remark**
Butiji	60	bacterial free
A-aregawi-2	63	
Sabian Pw-4	104.6	
food com-1	115	
Ato Yilma	120	
G/Gerada	182	

Name of water	**Depth (m)**	**Remark**
Gende Rige HDW	26.5	bacterial contaminated
Unive Oil	45	
Hafcat #1	86	
Industry v-Pw11	108	
Melka TW-3	120	
Shatedow	200	

Name of water	Depth (m)	Remark
Sabian Pw-16	195	
Sabian Pw-12	195	
Tome-4	208	
Sabian Pw-13	213	
Boren-1	220	
Boren-7	274	
Tome-3	332	
Tome-5	359	
Boren-4	361	

Name of water	Depth (m)	Remark
Addis Ketema new well	240	
C/cola new well	250	
Boren-3/TW	360	

Absence of fecal coliform in some water wells indicated that confining layer might have acted as the hydraulic barrier between the contaminated source and the underneath main groundwater. As a result, bacteria could not reach the groundwater. However, the presence of bacteria along with nitrate contamination indicated that there might be hydraulic link between the bacterial contaminated sludge and the groundwater source. The measurement and monitoring of water level in hand dug wells while pump test was run in Sabian wellfields confirm that the water level was continuously lowering in the hand dug well which confirms the hydraulic connection between the shallow and deep well aquifer or the presence of semiconfined aquifer in Sabian area.

4.3 Source of Groundwater Nitrate Pollution

The presence of fecal coliform in 12 of the sampled water wells is a clear indicator that fecal contaminant is attributed to the pollution of the water well with fecal origin. It is evident from the discussion of hydrogeology of the Dire Dawa area and associated groundwater quality of the geologic formations, there is lack of Caliche rock in the area that naturally contribute for nitrate in the groundwater (WWDSE, 2004). In addition, the low concentration of nitrate in the rural water well as opposed to high concentration in the urban center signifies that fertilizer is not the main source of nitrate concentration in the groundwater of Dire Dawa.

4.3.1 Nitrate concentration in urban and rural water wells

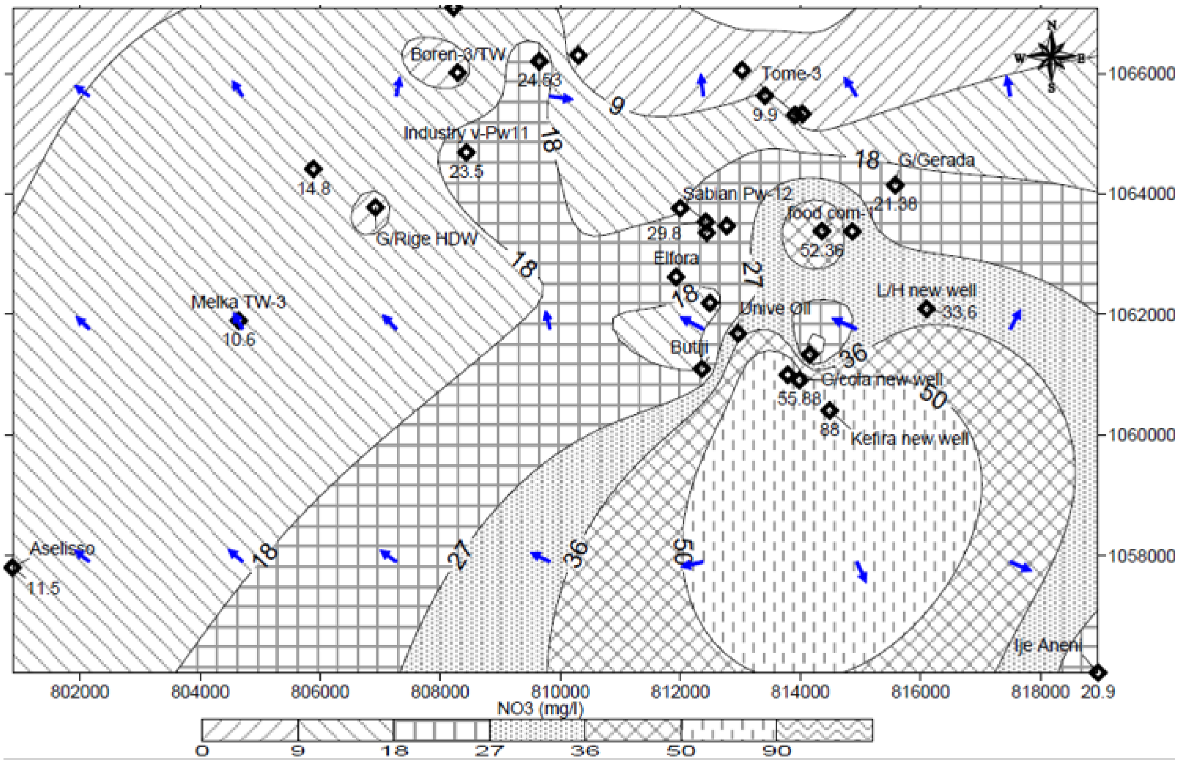
The rapid growth of urban population in developing countries leads to unplanned settlements where limited pit latrines or septic tanks are the only options available for sewage disposal (Wakida, 2008). Urban sources of nitrate-N may have a high impact on groundwater quality because of the high concentration of potential sources in a smaller area than agricultural land (Wakida and Lerner, 2005).

The plot of nitrate including water wells in the rural areas (Figure 4.10) indicated that urban areas are more polluted with an average of 30.2 mg/l of nitrate against 11 mg/l of rural areas. In addition, the maximum nitrate concentration of 89 mg/l was found in the urban against 24.5 mg/l in the rural are recorded (Table 4.6, Figure 2). The high concentration of nitrate in the urban center is mainly attributed to 89% households utilize pit latrine built in permeable sand layer that facilitate easy infiltration of excreta into the groundwater. In addition, the high urban population density mainly 20 to 100 and 100 to 200 persons per hectare against 0 to 20 persons per hectare in the rural areas. More people per hectare means more waste generated and discharge into the groundwater.

In rural areas, there is 97.7 % of open defecation practice in dry and hot environment that mostly dried up before contaminating the groundwater (HMIS, 2017). It is in rainy season that the open feces in rural areas has the chance to infiltrate into the groundwater. In addition, the nitrate plot of 27 urban and three rural groundwater samples confirmed that nitrate is migrating towards the rural areas (WWDSE, 2004; Eyilachew, 2010). If fertilizer was the major source of nitrate, there should be high concentration of nitrate in the rural water wells than urban water wells and the nitrate might have been flowing from rural towards urban areas as agricultural activities and application of fertilizers are limited in the rural area.

Table 4.6. Nitrate in the urban and rural water wells

Description	**Maximum (mg/l)**	**Minimum (mg/l)**	**Mean (mg/l)**	**Standard deviation (mg/l)**
Urban	89	6.9	31.5	23.9
Rural	24.5	0.86	11.5	8.1



Legend: → NO_3 flow direction & ◆ selected water well NO_3 level

Figure 4.10. Nitrate zonation including rural area water wells

The nitrate analysis between urban and rural water wells showed different mean. Hence, it was required to statistical test the significance of this result. Accordingly, two tail t-test with independent unequal variance was undertaken and found to be statistically significant with p-value of 0.03 which is less 0.1. In addition, t Stat (2.34) > t critical two tail (1.74). therefore, the difference of mean nitrate concentration of the groundwater is not by chance.

Table. 4.7. Urban versus rural two tail independent t-Test

Description	Urban NO_3 (mg/l)	Rural NO_3 (mg/l)
Mean	30.2	11.5
Variance	563.4	25.1
Observations	21	3

Description	Urban NO_3 (mg/l)	Rural NO_3 (mg/l)
Hypothesized Mean Difference	0	
df	17	
t Stat	2.35	
P(T<=t) one-tail	0.016	
t Critical one-tail	1.33	
P(T<=t) two-tail	0.031	
t Critical two-tail	1.74	

4.3.2 Chloride and sulfate analysis

Widory et al. (2005) and Lee et al. (2008), found out that there is no such relationship between the $NO_3{}^-$ and Cl^- in the PRD region of China due to more complex sources of pollution. Similarly, the plot of chloride versus nitrate and sulfate versus nitrate indicated there is very weak/poor correlation in the DD city area as the contamination is not limited to human waste but also it includes wastes from beverage, textile, garages, oil and flour industries (Figure 4.11).

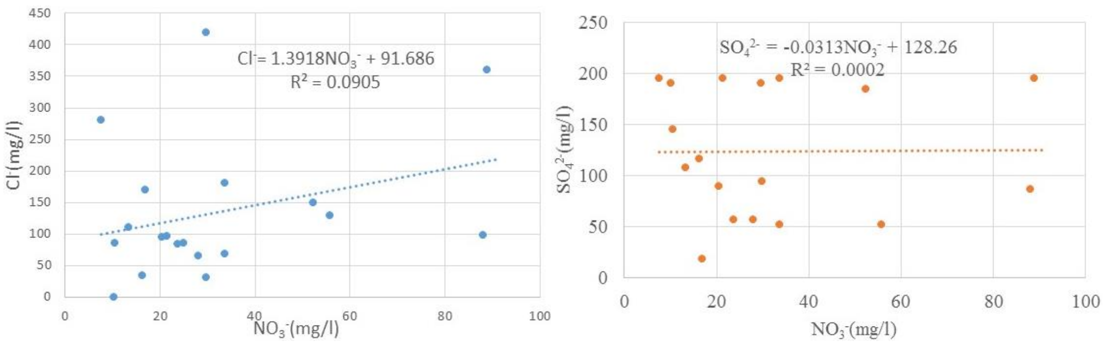


Figure 4.11. Nitrate versus chloride and sulfate within DD city

Generally, the concentration of Cl− in sewage and manure is relatively high, and Cl− is thus an indicator of sewage. Plotting $NO_3{}^-$ versus Cl^- is widely used to identify the sources of nitrate pollution (Lee et al., 2008; Li et al., 2010; Widory et al., 2005). There is positive correlation of nitrate versus chloride and negative correlation for sulfate for water sources located away from DD and in the rural areas (Tome, Boren, Melka, Aseliso, Jeldessa and Ija Aneni) as the contamination is mainly related to human induced waste (Figure 4.12). In some places like Tome and Boren, the natural contribution of sulfate is high. The geologic well log also confirm the presence of marine sediment rich in sulfate (MS consult, 2015) (Figure 4.7) which enhance the high concentration of sulfate in the groundwater in the specific localities mentioned above.

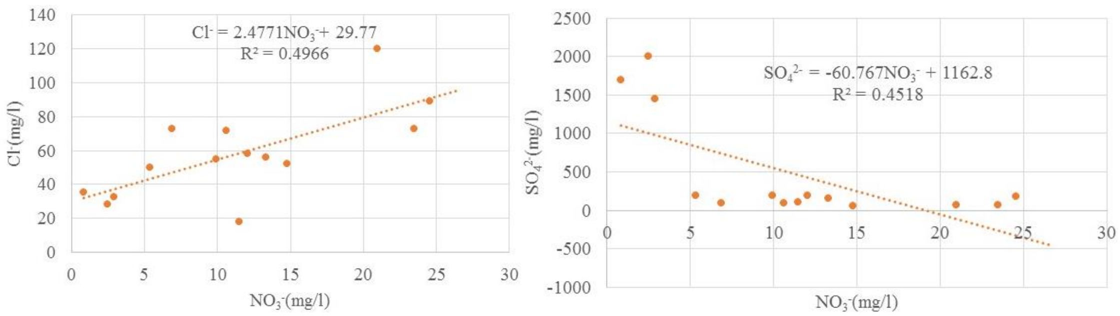
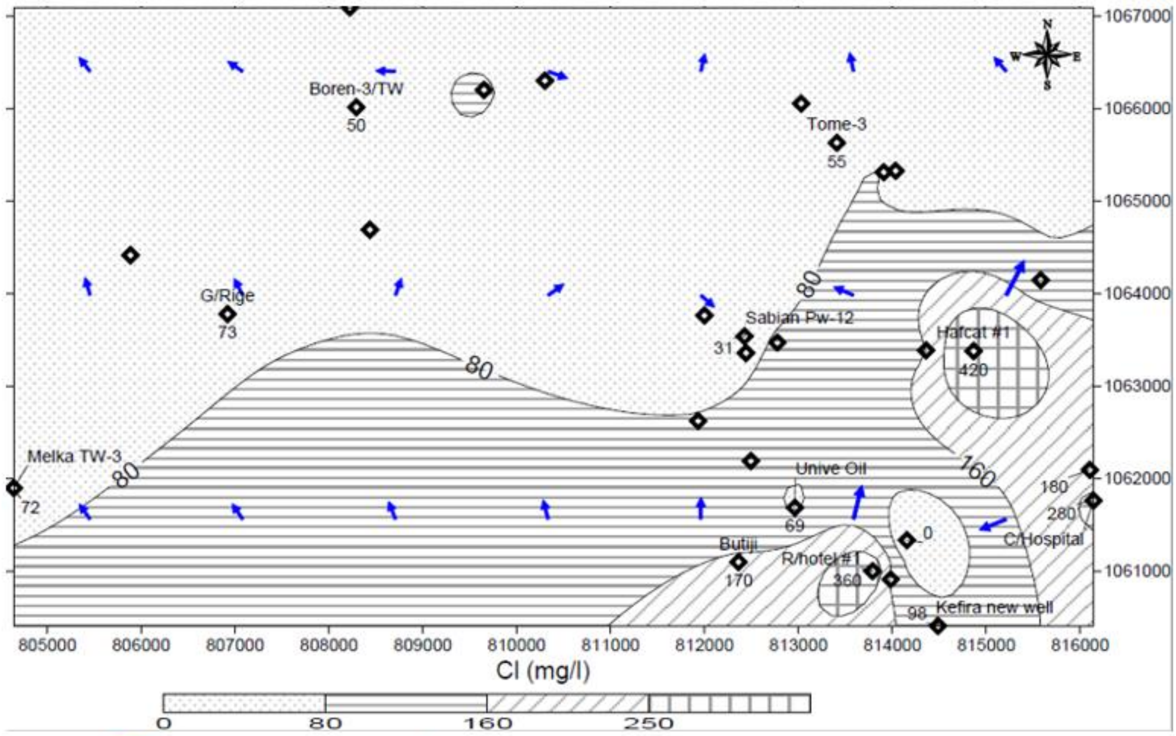


Figure 4.12. Correlation of Nitrate with chloride and sulfate away from DD

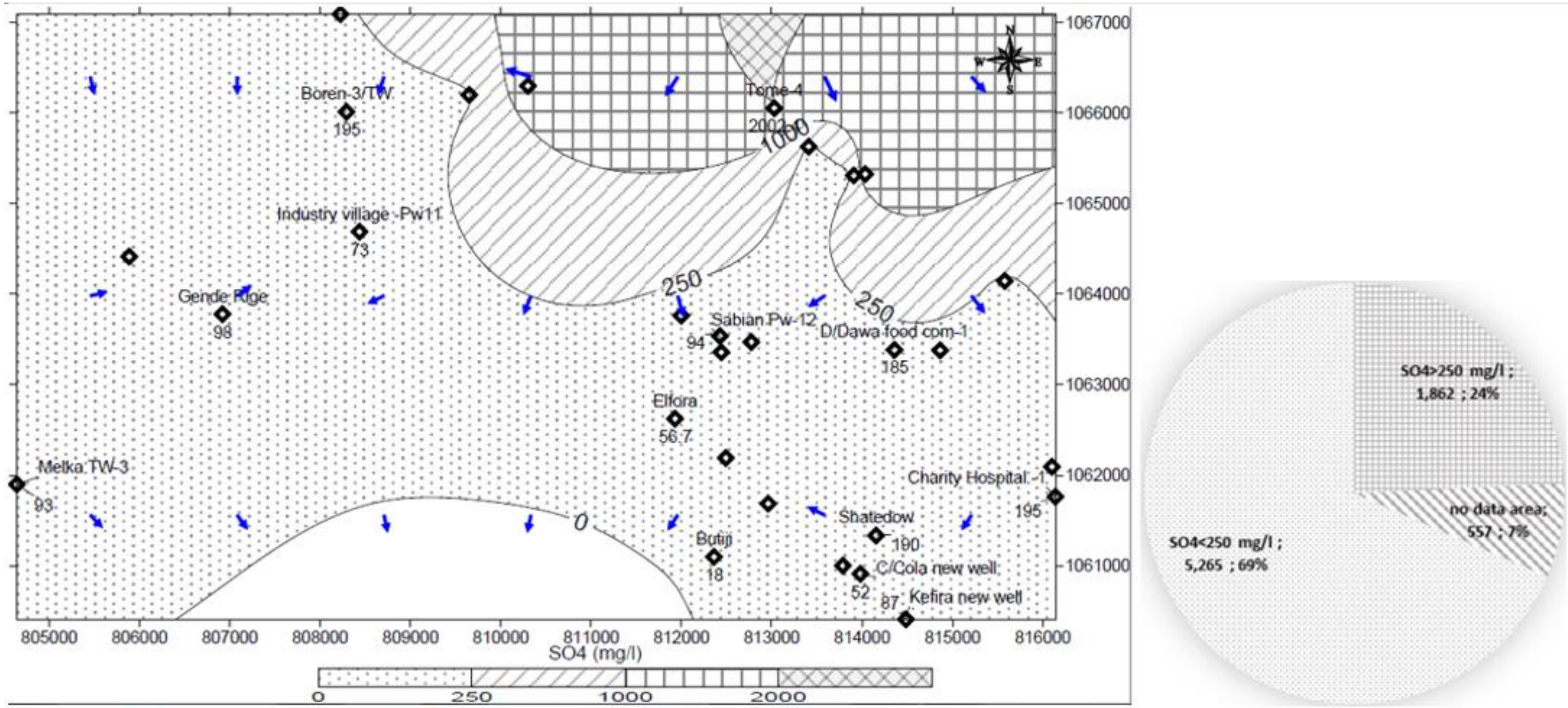
The spatial mapping and distribution of the analyzed groundwater samples indicated that 10.3% of groundwater sources covering 1.8% of the studied area exceeded the 250 mg/l chloride guideline value (WHO, 2011; ESA, 2013) (Figure 4.13). These high-level chloride concentration areas lie within the DD city and overlap with the high concentration of nitrate in the specific localities of coca cola and Hafcat. The flow of high concentration chloride is from the central part of the DD city towards the north, northwest and western part of the city.



Legend: → Cl flow direction & ◆ selected water well Cl level

Figure 4.13. Chloride zonation mapping and flow direction

Similarly, the analysis of groundwater samples for sulfate indicated that 10.3% groundwater sources with 24.2% area coverage exceeded the 250 mg/l guideline value (WHO, 2011; ESA, 2013) (Figure 4.14). Unlike nitrate and chloride, sulfate showed reversed flow direction, i.e. from Tome and Boren areas towards the DD city. The high concentration of sulfate in Tome and Boren area is attributed to the presence of sulfate rich geologic formation like marine sediment known to contain sulfate (MS consult, 2015).



Legend: → SO_4 flow direction & ◆ selected water well SO_4 level

Figure 4.14. Spatial distribution and areal coverage of sulfate

In general, the central part of the DD city is contaminated with nitrate, chloride and fecal coliform that signifies human excreta accounted for the pollution of the DD groundwater. The concentration of sulfate is naturally very high due to sulfate rich layer in Tome and Bore areas.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The section summarizes the main findings associated with nitrate, bacterial contamination and source of nitrate pollution in the DD city groundwater where samples were mainly collected from deep wells.

The current analysis of DD city groundwater indicated that 79.3% of groundwater samples with 85.7% areal coverage have nitrate values above 9 mg/l of which 13.8% of groundwater source with 2.9% areal coverage have potential threat to induce blue baby syndrome.

The spatial distribution of nitrate indicated that the southeast and south part of the study area has the maximum nitrate concentration of 88 mg/l at Ras Hotel and Addis Ketema areas where as the concentration of nitrate declines towards north, northwest and west of the study area and reach its lowest value of 0.86 mg/l and 2.91 mg/l at Tome and Boren wellfields respectively.

The plot of nitrate including the water wells in the rural areas indicated that urban areas are more polluted with maximum and average values of 88.9 mg/l and 30.2 mg/l of nitrate against 24.5 mg/l and 11.5 mg/l of rural areas. If fertilizer was the major source of nitrate, there should be high concentration in the rural water wells than urban water wells and the nitrate might have been flowing from rural towards urban areas. Rather nitrate is currently advancing from urban centers towards the periphery and rural areas.

The plot of nitrate with depth also indicated that the maxmum concentration of 320 mg/l was found in shallow water well (54.9 m depth) at the location of railway where as minimum (0.9 mg/l) nitrate concentration was recorded in deep water well (361 m depth) respectively. Generally, nitrate tends to decline with depth mainly attributed to the prevalance of anaerobic environment that lead to denitrification or degrading of nitrate to nitrogen.

The spatial distribution of fecal coliform contaminated sources indicated that 28.6% of the contaminated groundwater source falls within the urban areas where as 7.1% of the groundwater sources were from the wellfield located in the rural setting. Hence, the presence of fecal coliform in the urban and rural water wells clearly indicated that the source is mainly human waste specifically excreta as only Hafcat and Amdale areas had animal farming nearer to the sampled groundwater sources as compared to presence and utilization of 89% pit latrine mainly built in the permeable sandy layer.

The closer examination of bacterial free groundwater sources signifies that water well depth and relative location of the water well in the urban and rural setting are not the sole determinant factor rather the confined aquifer nature of the water well was the main limiting factor.

There is very weak/poor correlation between nitrate with chloride and sulfate which shows that the contamination is not limited to anthropogenic source alone. However, there is positive correlation of nitrate versus chloride and negative correlation for sulfate for water sources located in the rural areas as the contamination is mainly related to human induced waste. In some places like Tome and Boren, the natural contribution of sulfate is highly significant and the geologic well log shows the presence of marine sediment rich sulfate (MS consult, 2015).

The spatial mapping and distribution of chloride indicated that 10.3% of groundwater sources covering 1.8% of the studied area exceeded the 250 mg/l chloride guideline value (WHO, 2011; ESA, 2013). These high-level chloride concentration areas lie within the DD city and overlap with the high concentration of nitrate in the specific localities of coca cola and Hafcat.

Similarly, the analysis of sulfate indicated that 10.3% groundwater sources with 24.2% area coverage exceeded the 250 mg/l guideline value (WHO, 2011; ESA, 2013). Unlike nitrate and chloride, sulfate showed reversed flow direction. The high concentration of sulfate in Tome and Boren area is attributed to the presence of sulfate rich geologic formation like marine sediment known to contain gypsum (MS consult, 2015).

In general, it could be concluded that there was uneven high (88 mg/l) concentration of nitrate in the urban center and it declines towards the periphery and rural areas. The research also finds out that 87% of the study area showed above normal/natural (9 mg/l) concentration of nitrate in the groundwater. Furthermore, shallow water wells are more polluted than deep water wells and the concentration of nitrate declines with increasing water well depth. The fecal coliform was found in 36% of the water wells covering nearly 56% of the study areas. Hence, the source of nitrate pollution is mainly attributed to infiltration of sewage from the pit latrines.

5.2 Recommendation

In areas, like Dire Dawa where groundwater is the sole source, proper excreta management is crucial. Hence, the city administration together with DD WSSA, Environment and Sanitation and Beautification Agency should consider the following recommendations:

- Delineate buffer zone based on simulation of nitrate propagation
- Resident should have to construct water tight/proof latrine substructure
- High nitrate concentration water wells should be excluded from the list of water distribution source for drinking needs for instance Addis Ketema
- The DD city Water Supply and Sewerage Authority must always disinfect the water prior to distribution
- The DD Water Supply and Sewerage Authority could make use of drilling deep water wells as a temporary solution to reduce the effect of nitrate

REFERENCES

Alexandre Bonton, Alain Rouleau, Christian Bouchard, Manuel J. Rodriguez, 2010. Assessment of groundwater quality and its variations in the capture zone of a pumping well in an agricultural area. ELSEVIER

Associated Engineering PLC (AE), 1990. Groundwater exploration and production wells construction and testing at Dire Dawa

Bibby Scientific, 2010. Spectrophotometers Operating Manual. http://www.bibby-scientific.com [Accessed on Nov. 28 2016]

British Columbia Groundwater Association, 2007. Nitrate in Groundwater. Water Stewardship Information Series. http://www.for.gov.bc.ca/hfd/library/documents/bib106076_nitrate.pdf [Accessed on 16 February 2016]

Burow, K.R., Nolan, B.T., Rupert, M.G., Dubrovsky, N.M., 2010. Nitrate in groundwater of the United States, 1991–2003. Environ. Sci. Technol. 44, 4988–4997.

Craun GF, Greathouse DG, Gunderson DH, 1981. Methaemoglobin levels in young children consuming high nitrate well water in the United States. *International Journal of Epidemiology*, 10:309–317.

CSA, 2007. Summary and Statistical Report of the 2007 Population and Housing Census.

CSA, 2007. The 2007 Population and Housing Census of Ethiopia: Statistical Report for Dire Dawa City Administration" for the users

Dagnew Tadesse, Assefa Desta, Abera Geyid, Woldemariam Girma, Solomon Fisseha, Oliver Schmoll, 2010. Rapid assessment of drinking-water quality in the Federal Democratic Republic of Ethiopia: country report of the pilot project implementation in 2004-2005.

Deborah Chapman, 1996. Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring - Second Edition

Dessie N., 2010. Water Balance and Groundwater Quality of Koraro Area, Tigray, Northern Ethiopia

Dubrovsky N, Hamilton P, 2010. Nutrients in the nation's streams and groundwater: national findings and implications. Reston, VA, United States Geological Survey (Fact Sheet 2010-3078; http://pubs.usgs.gov/fs/2010/3078/).

Ethiopian Mapping Authority, 2000. Dire Dawa Sheet, 0941 B4. Series ETH 4.

Ethiopian Standards Agency, 2013. Compulsory Ethiopian Standard, Drinking Water Specification. CES 58

Eyilachew Y. Abate, 2010. Anthropogenic Impacts on Groundwater Resources in the Urban Environment of Dire Dawa, Ethiopia. MSc Thesis, University of Oslo.

Fan, A.M., Steinberg, V.E., 1996. Health implications of nitrate and nitrite in drinking water: an update on methemoglobinemia occurrence and reproductive and developmental toxicity. Regul. Toxicol. Pharmacol. 23, 35–43.

Fewtrell L, 2004. Drinking-water nitrate, methaemoglobinaemia, and global burden of disease: a discussion. *Environmental Health Perspectives*, 112(14):1371–1374.

FMoH, 2011. National Drinking Water Quality Monitoring and Surveillance Strategy. Unpublished report, Addis Ababa

Getu Degu, Fasil Tessema, 2005. Biostatistics Lecture Note for Health Students, Gondar University. Ethiopia Public Health Training Initiative.

Greitzer Y, 1959. Stratigraphy, Hydrogeology and Jurassic Ammonites of the Harar and Dire Dawa area, Ethiopia. Ph. D thesis submitted for the Degree-Doctor of Philosophy, Hebrew University, Israel

Gu, B., Dong, X., Peng, C., Luo, W., Chang, J., Ge, Y., 2012. The long-term impact of urbanization on nitrogen patterns and dynamics in Shanghai, China. Environ. Pollut. 171, 30–37.

Gu, B., Ge, Y., Chang, S.X., Luo, W., Chang, J., 2013. Nitrate in groundwater of China: sources and driving forces. Glob. Environ. Chang. 23, 1112–1121.

HMIS, 2017. Federal Ministry of Health unpublished 4-month report.

Howard G, Ince M, Smith M., 2003. *Rapid assessment of drinking-water quality: a handbook for implementation (draft)*. Geneva and New York: World Health Organization and United Nations Children's Fund.

Hazen, 2006. Nitrate and Nitrite: Health Information Summary, Environmental Fact Sheet. New Hampshire Department of Environmental Service, 29 Hazen Drive, Concord, New Hampshire 03301. www.des.nh.gov [Accessed on 16 February 2015]

ICAIR Life Systems, Inc., 1987. *Drinking water criteria document on nitrate/nitrite*. Washington, DC, United States Environmental Protection Agency, Office of Drinking Water.

Kaushal, S.S., Groffman, P.M., Band, L.E., Elliott, E.M., Shields, C.A., Kendall, C., 2011. Tracking nonpoint source nitrogen pollution in human-impacted watersheds. Environ. Sci. Technol. 45, 8225–8232.

Ketema Tadesse, 1982. Hydrogeology of the Dire Dawa Area. EIGS, Addis Ababa. Unpublished Technical Report (880-551-17), EIGS

Lee, K.-S., Bong, Y.-S., Lee, D., Kim, Y., Kim, K., 2008. Tracing the sources of nitrate in the Han River watershed in Korea, using δ 15 N-NO 3− and δ 18 O-NO 3− values. Sci. Total Environ. 395, 117–124.

Li, S.-L., Liu, C.-Q., Li, J., Liu, X., Chetelat, B., Wang, B.,Wang, F., 2010. Assessment of the sources of nitrate in the Changjiang River, China using a nitrogen and oxygen isotopic approach. Environ. Sci. Technol. 44, 1573–1578.

Maskurul Alam, Sharmin Akter Sumy, Yasin Ali Parh, 2015. Selection of the Samples with Probability Proportional to Size. Science Journal of Applied Mathematics and Statistics. http://www.sciencepublishinggroup.com/j/sjams [Accessed on February 20, 2017]

Mesfin Aytenfisu, 1981. Hydrogeology of Northeastern part of Haraghe, MSc Thesis

Mesinga TT, Speijers GJA, Meulenbelt J, 2003. Health implications of exposure to environmental nitrogenous compounds. *Toxicological Reviews*, 22(1):41–51.

MoWR, 1999. Technical Assessment for Immediate Rehabilitation of Dire Dawa Water Supply System

MS Consult, 2015. Drilling Supervision Final Report. Drilling of Twelve Production and Two Monitoring Wells.

MS Consult, 2011. Design Review and Detail Design Preparation of the 2nd Phase of Dire Dawa Water Supply Project.

Pastén-Zapata, E., Ledesma-Ruiz, R., Harter, T., Ramírez, A.I., Mahlknecht, J., 2014. Assessment of sources and fate of nitrate in shallow groundwater of an agricultural area by using a multi-tracer approach. Sci. Total Environ. 470, 855–864.

Potakit, 2011. Basic Portable Water Quality Laboratory. http://www.palintest.com/. Accessed on Apr. 16, 2016

Qianqian Zhang, Jichao Sun, Jingtao Liu, Guanxing Huang, Chuan Lu, Yuxi Zhang, 2015. Driving mechanism and sources of groundwater nitrate contamination in the rapidly urbanized region of south China.

Taye A., 1999. Contamination of the Hydrogeologic System in Dire Dawa. 25th WEDC Conference, Addis Ababa Ethiopia.

UNEP GEMS 2008. Water Quality for Ecosystem and Human Health. 2nd Edition ISBN 92-95039-51-7 Burlington, Ontario, L7R 4A6 CANADA. http://www.gemswater.org/. Accessed on Oct. 7, 2014

UNICEF and WHO, 2015. Progress on Sanitation and Drinking Water – 2015 update and MDG assessment.

UNEP/WHO, 1996. Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes.

US EPA, 1987. *Estimated national occurrence and exposure to nitrate and nitrite in public drinking water supplies.* Washington, DC, United States Environmental Protection Agency, Office of Drinking Water.

van Duijvenboden W, Matthijsen AJCM, 1989. *Integrated criteria document nitrate*. Bilthoven, National Institute for Public Health and the Environment (RIVM Report No. 758473012).

van Duijvenboden W, Loch JPG, 1983. Nitrate in the Netherlands: a serious threat to groundwater. *Aqua*, 2:59–60.

Wakida F.T, 2008. Sources of nitrate in urban groundwater, Universidad Autonoma de Baja California Facultad de Ciencias Quimicas e ingenieria Calzada Universidad, Tijuana Baja California Mexico.

Wakida, F.T. and Lerner, D.N, 2005. Nonagricultural sources of groundwater nitrate: a review and a case study. Water research 39: 3-16.

Weyer, P.J., Cerhan, J.R., Kross, B.C., Hallberg, G.R., Kantamneni, J., Breuer, G., Jones, M.P., Zheng, W., Lynch, C.F., 2001. Municipal drinking water nitrate level and cancer risk in older women: The Iowa Women's Health Study. Epidemiology 12, 327–338.

WHO, 2011. Guidelines for Drinking-Water Quality: 4th Edition. World Health Organization

WHO, 2008. Guidelines for Drinking-water Quality: incorporating 1st and 2nd addenda, Vol.1, Recommendations. – 3rd ed. World Health Organization.

WHO, 2007. Nitrate and Nitrite in Drinking Water. Background Document for Development of WHO Guidelines for Drinking-water Quality. World Health Organization, WHO Press, 29 pp.

WHO, 2006. Guidelines for Drinking Water Quality. World Health Organization. WHO Press, 597 pp.

WHO, 2004. Guidelines for drinking-water quality, 3rd Edition, Volume 1: recommendations. Geneva: World Health Organization (www.who.int/water_sanitation_health).

Widory, D., Petelet-Giraud, E., Négrel, P., Ladouche, B., 2005. Tracking the sources of nitrate in groundwater using coupled nitrogen and boron isotopes: a synthesis. Environ. Sci. Technol. 39, 539–548.

WWDSE, 2004. Dire Dawa Administrative Council Integrated Resource Development Master Plan Study Project, unpublished report

WWDSE, 2002. Dire Dawa Administrative Council Integrated Resource Development Master Plan Study Project, unpublished 2nd draft report

Xue, D., Botte, J., De Baets, B., Accoe, F., Nestler, A., Taylor, P., Van Cleemput, O., Berglund, M., Boeckx, P., 2009. Present limitations and future prospects of stable isotope methods for nitrate source identification in surface-and groundwater. Water Res. 43, 1159–1170.

APPENDICES

List of Table in the Appendix

Table 1. List of BH with groundwater level

S.n	Easting	Northing	GW level (m)	Well name
1	814361	1064650	1116.95	Amdael water well #1
2	814225	1064619	1110.95	Amdael #2
3	813609	1063862	1122	Airport
4	814516	1062161	1176.85	Bisrate Gebriel
5	814082	1061201	1191.2	Coca Cola EAB #2
6	814015	1061051	1188.16	Coca Cola EAB #3
7	811190	1062310	1174	Command post
8	814358	1063386	1140.23	D/Dawa food com-1
9	814489	1063482	1150.23	D/Dawa food com-2
10	813853	1060386	1195.39	D/D High school-1
11	813990	1061208	1185.47	Dil Chora Hospital
12	811930	1062624	1173.13	Elfora
13	814865	1063379	1135.69	Hafcat #1
14	814947	1063534	1135.69	Hafcat #2
15	816819	1062037	1172.05	High way author
16	805239	1063345	1139.05	Melka Jebdu #2
17	814005	1061845	1183	Rail way station
18	812365	1063790	1109.76	Sabian Pw-5
19	812525	1063749	1100.33	Sabian Pw-12

S.n	Easting	Northing	GW level (m)	Well name
20	815674	1064352	1118.4	Sabian Pw-18
21	813857	1060398	1196.39	D/D High school #2
22	812515	1061646	1187.76	Cement Fac. NPW-1
23	812786	1060805	1196.2	Cement Fac. NPW-2
24	812898	1060504	1202	Cement Fac. NPW-3
25	812248	1061295	1179	Cement Fac. NPW-4
26	814200	1061988	1200.8	NoterDam School
27	811424	1064540	1114.2	D/Dawa Uni.-1
28	811673	1064244	1118.75	D/Dawa Uni.-2
29	804646	1061899	1157.35	Melka PW1'07
30	805809	1065379	1092.7	Melka AU New-1
31	806031	1064524	1108.54	Abunearegawi
32	805975	1064618	1111.02	Abunearegawi
33	812952	1061856	1171.86	Unive Oil
34	808291	1066600	1059.42	TW1-2006
35	804805	1062481	1121	Al-Falath -Melka
36	813408	1065629	1064	Tome-2
37	808291	1066013	1048	Boren-4

Table 2. Sample sizing for the stratified sampling locations

S.n	**Name of sampling location (A)**	**No of water wells (B)**	**Sample size for each location (26/56*B)**	**Rounded to the nearest**
1	Dire Dawa central area	26	12.1	13
2	Sabian	8	3.7	4
3	Tome	6	2.8	3
4	Boren	10	4.6	5
5	Melka	6	2.8	3

Table 3. Location of sampled water wells

Well name	Kebele, specific locality name	Geographic coordinate (UTM)		Alt
		E	N	
Coca Cola EAB #1	03, Coca	813981	1060911	1229
Ras Hotel #1	03, Ras Hotel	813788	1061001	1227
Shatedow	03, Old Municipal Office	814155	1061335	1227
Unive Oil	03, MOPACK	812961	1061687	1218
Elfora		811930	1062624	1197
Mission of Charity	08, Mission of Charity Lege Hare	816141	1061763	1229
Lege Hare new BH	08, Lege Hare	816102	1062094	1205
D/Dawa food com-1	05, food complex	814358	1063386	1184
Hafcat #1	09, Hafcat	814865	1063379	1179
Gende Gerada	09, Gende Gerada	815579	1064145	1173
Addis Ketema new WSSA BH	05, Addis Ketema	814485	1060409	1262
Butiji	02, Butiji	812360	1061099	1226
Ato Yilma	0	813908	1065311	1150

Well name	Kebele, specific locality name	Geographic coordinate (UTM)		Alt
		E	N	
Sabian Pw-16	___K, Sabian pumping station	812492	1062191	1199
Sabian Pw-13	02, Gende Tesfa	812774	1063471	1181
Sabian Pw-12	02, Gende Tesfa	812425	1063538	1181
PW-14	02, Gende Tesfa	811998	1063764	1162
PW-4	02, Gende Tesfa	812440	1063358	1221
Tome-3	Tome	813408	1065629	1149
Tome-4		813680	1065650	
Tome-5		813350	1065900	
Industry village - Pw11		808435	1064689	1145
Boren-1	Boren	809650	1066200	
Boren-7		807850	1065700	
Boren-3/TW		808291	1066013	1102
Boren-4		808223	1067092	1108
Gende Rige	01; Melka	806920	1063779	1148
Abunearegawi-2	01, Melka	805886	1064415	1134

Well name	Kebele, specific locality name	Geographic coordinate (UTM)		Alt
		E	N	
Melka TW-3	01, Melka DD WSSA new BH nearer Melka wellfield	804642	1061899	1181
Jeldessa	Jeldessa	182980	1075738	1109
Ije Aneni	Ije Aneni	818956	1056061	1405
Aselisso	Aselisso	800875	1057804	1264
hand dug	02, Sabian Jerba	810566	1062226	1191

Table 4. Dire Dawa city groundwater analysis

Well name	Locality	Physical Test			Chemical Test				Fecal coliform	Geographic coordinate			water well depth (m)
		TDS (mg/l)	EC (µS/cm)	PH	Cl^-	Na^+	SO_4^{2-}	NO_3^-		Easting	Northing	Altitude	
Coca Cola EAB #1	03, Coca	617	1219	7.34	130	84.5	52	55.9	16	813981	1060911	1229	250
Ras Hotel #1	03, Ras Hotel	1200	2393	7.22	360	334	195	88.9	0	813788	1061001	1227	115
Shatedow	03, Old Municipal compound	1279	2572	7.06	0	0	190	10.2	1	814155	1061335	1227	200
Unive Oil	03, MOPACK	540	1084	7.25	69	44.9	52	33.6	2	812961	1061687	1218	45
Elfora		650	1080	7.16	83.4	50	56.7	23.8	0	811930	1062624	1197	82
Charity Hospital	08, Mission of	1571	3142	7.04	280	182	195	7.66	6	816141	1061763	1229	NA

Well name	Locality	Physical Test			Chemical Test				Fecal coliform	Geographic coordinate			water well depth (m)
		TDS (mg/l)	EC (µS/cm)	PH	Cl^-	Na^+	SO_4^{2-}	NO_3^-		Easting	Northing	Altitude	
-1	Charity Lege Hare												
Lege Hare new BH	08, Lege Hare	969	1939	6.84	180	117	195	33.6	0	816102	1062094	1205	300
D/Dawa food com-1	05, food complex	840	1677	7.6	150	97.5	185	52.4	0	814358	1063386	1184	115
Hafcat #1	09, Hafcat	1094	2213	7.11	420	273	190	29.7	1	814865	1063379	1179	86
G/Gerada	09, Gende Gerada	1986	997	7.24	97	63.1	195	21.4	0	815579	1064145	1173	182
Addis Ketema new WSSA BH	05, Addis Ketema	576	1153	7.16	98	63.7	87	88	1	814485	1060409	1262	240
Butiji	02, Butiji	703	1404	7.52	170	110.	18	16.9	0	812360	1061099	1226	60

Well name	Locality	Physical Test			Chemical Test				Fecal coliform	Geographic coordinate			water well depth (m)
		TDS (mg/l)	EC (µS/cm)	PH	Cl^-	Na^+	SO_4^{2-}	NO_3^-		Easting	Northing	Altitude	
						5							
Ato Yilma		669	1339	7.38	85	55.25	145	10.6	0	813908	1065311	1150	120
Sabian Pw-16	___K, Sabian pumping station	508	1014	7.6	110	71.4	108	13.4	0	812492	1062191	1199	195
Sabian Pw-13	02, Gende Tesfa	577	1091	6.94	95	61.8	89	20.5	0	812774	1063471	1181	213
Sabian Pw-12	02, Gende Tesfa	560	1121	7.5	31	20.2	94	29.8	0	812425	1063538	1181	195
Sabian PW-14	02, Gende Tesfa	594	1181	7.43	34	22.1	116	16.2	0	811998	1063764	1162	206
Sabian Pw-4	02, Gende Tesfa	544	1091	6.94	66	42.9	57	28	0	812440	1063358	1221	104.6
Tome-3	Tome	1143	2288	6.96	55	35.7	195	9.94	0	813408	1065629	1149	332

Well name	Locality	Physical Test			Chemical Test				Fecal coliform	Geographic coordinate			water well depth (m)
		TDS (mg/l)	EC (µS/cm)	PH	Cl^-	Na^+	SO_4^{2-}	NO_3^-		Easting	Northing	Altitude	
						5							
Tome-4		3146	4500	6.61	28.1	46	2002.4	2.48	0	813028	1066053		208
Tome-5		2538	4080	7.41	35.17	51	1691	0.86	0	814034	1065326		359
Industry village -Pw11		510	1020	7.54	73	47.5	73	23.5	14	808435	1064689	1145	108
Boren-1		808	1298	6.96	89.32	74	185.7	24.5	0	809650	1066200		220
Boren-7		2496	3590	6.61	32.76	74	1453	2.91	0	810300	1066300		274
Boren-3/TW	Boren	969	1861	7.03	50	32.5	195	5.37	7	808291	1066013	1102	360

		Physical Test			**Chemical Test**				**Fecal coliform**	**Geographic coordinate**			
Well name	**Locality**	**TDS (mg/l)**	**EC (µS/cm)**	**PH**	**Cl^-**	**Na^+**	**SO_4^{2-}**	**NO_3^-**		**Easting**	**Northing**	**Altitude**	**water well depth (m)**
Boren-4		820	1637	7.17	58	37.7	195	12.06	0	808223	1067092	1108	361
Gende Rige	01; Melka	477	954	7.62	73	47.5	98	6.9	4	806920	1063779	1148	26.5
Abunearegawi-2	01, Melka	466	935	7.68	52	33.8	64	14.8	0	805886	1064415	1134	63
Melka TW-3	01, Melka DD WSSA new BH nearer Melka wellfield	519	1036	7.05	72	46.8	93	10.6	5	804642	1061899	1181	120
HDW	02, Sabian Jerba	556	1118	7.12	85	55.2	66	25	32	810566	1062226	1191	25

Well name	Locality	Physical Test			Chemical Test				Fecal coliform	Geographic coordinate			water well depth (m)
		TDS (mg/l)	EC (µS/cm)	PH	Cl^-	Na^+	SO_4^{2-}	NO_3^-		Easting	Northing	Altitude	
						5							
Jeldessa	Jeldessa	458	914	7.56	56	36.4	160	13.3	0	182980	1075738	1109	90
Ije Aneni	Ije Aneni	547	1094	7.49	120	78	66	20.94	11	818956	1056061	1405	
Aselisso	Aselisso	418	838	7.33	18	11.7	104	11.5	24	800875	1057804	1264	119.4

Table 5. Signed List of Water Quality Analysis Result of Selected Borehole in Dire Dawa

Dire Dawa Water Supply and Sewerage Authority

Water Quality of Analysis of selected boreholes in Dire Dawa

Well name	Physical Test			Chemical Test				Fecal coliform bacteria
	TDS (mg/l)	EC (μS/cm)	pH	Cl^-	Na^+	SO_4^{2-}	NO_3^-	
Coca Cola EAB #1	617	1219	7.34	130	84.5	52	55.9	16
Ras Hotel #1	1200	2393	7.22	360	334	195	88.9	0
Shatedow	1279	2572	7.06	0	0	190	10.2	1
Unive Oil	540	1084	7.25	69	44.9	52	33.6	2
Charity Hospital -1	1571	3142	7.04	280	182	195	7.66	6
Lege Hare new BH	969	1939	6.84	180	117	195	33.6	0
D/Dawa food com-1	840	1677	7.6	150	97.5	185	52.4	0
Hafcat #1	1094	2213	7.11	420	273	190	29.7	1
G/Gerada	1986	997	7.24	97	63.1	195	21.4	0
Kefira new WSSA BH	576	1153	7.16	98	63.7	87	88	1
Butiji	703	1404	7.52	170	110.5	18	16.9	0
Ato Yilmma	669	1339	7.38	85	55.25	145	10.6	0
Sabian Pw-16	508	1014	7.6	110	71.4	108	13.4	0
Sabian Pw-13	577	1091	6.94	95	61.8	89	20.5	0
Sabian Pw-12	560	1121	7.5	31	20.2	94	29.8	0
Sabian PW-14	594	1181	7.43	34	22.1	116	16.2	0
Sabian Pw-4	544	1091	6.94	66	42.9	57	28	0
Tome-3	1143	2288	6.96	55	35.75	195	9.94	0
Industry village-Pw11	510	1020	7.54	73	47.5	73	23.5	14
Boren-3/TW	969	1861	7.03	50	32.5	195	5.37	7
Boren-4	820	1637	7.17	58	37.7	195	12.06	0
Gende Rige	477	954	7.62	73	47.5	98	6.9	4
Abunearegawi-2	466	935	7.68	52	33.8	64	14.8	0
Melka TW-3	519	1036	7.05	72	46.8	93	10.6	5
Sabian Jerba, HDW	556	1118	7.12	85	55.25	66	25	32
Jeldessa	458	914	7.56	56	36.4	160	13.3	0
Ije Aneni	547	1094	7.49	120	78	66	20.94	11
Aselisso	418	838	7.33	18	11.7	104	11.5	24

Analyzed By: Musse Kalil Date:

Approved: Date:

List of Figures in the Appendix

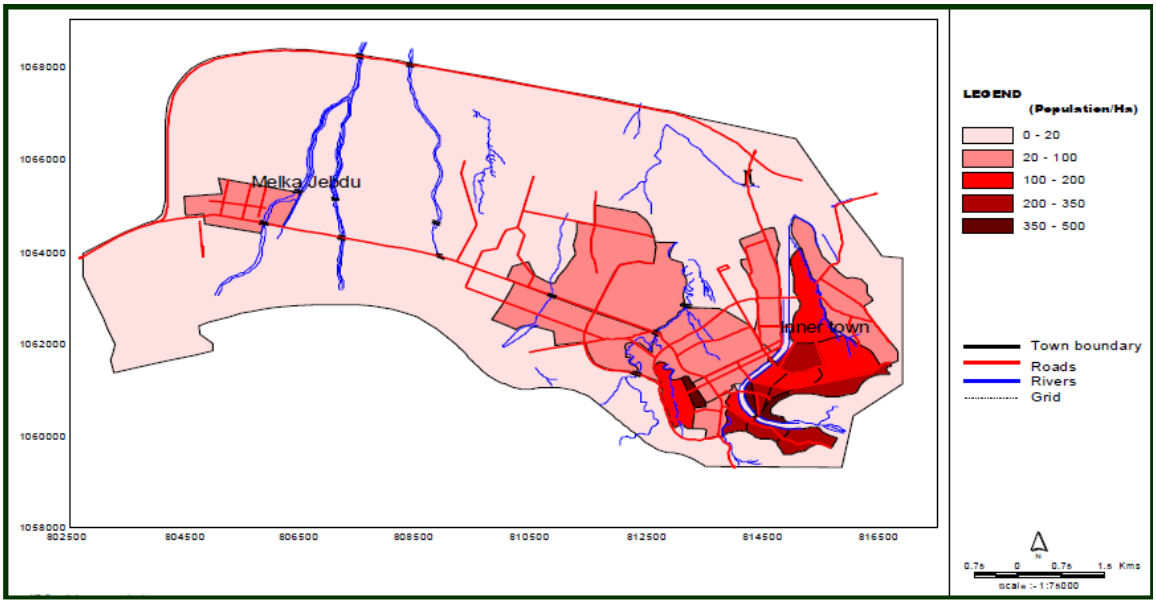


Figure 1. Population density (Persons/ha) map of Dire Dawa (Eyilachew, 2010)

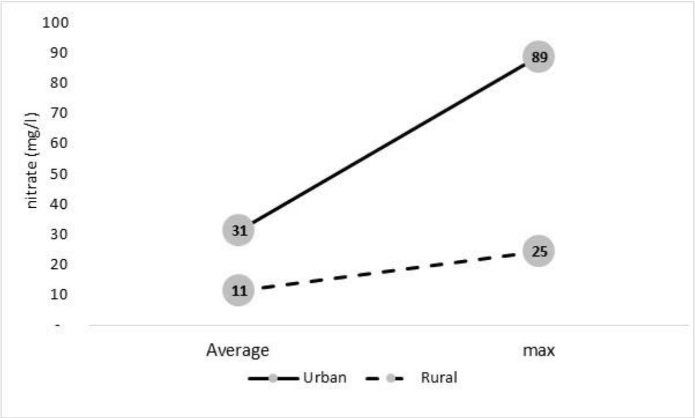


Figure 2. Max & mean nitrate in urban-rural deep water well

Sketch of Biography

Mesfin Sahele was born in 1972 GC in the town of Harar, married and has a son. Mesfin took his diploma, 1st and 2nd degree in Management, Geology and Hydrogeology from Haromaya University and Addis Ababa University in 2005, 1996 and 2001 GC respectively. Mesfin has 17 years of GO, NGO and UN WASH Project Management experience and worked at Nejat Computer, Dire Dawa Water Mines and Energy Office, Dire Dawa Water Supply and Sewerage Authority, Water Action, GOAL Ethiopia, Save the Children International and UNOPS at the capacities of Computer Instructor and Area Manager, Hydrogeologist and Team leader, Operation and Technic Department Head, Senior WASH Project Officer, WASH Project Manager, Senior WASH Project Manager and Program Manager respectively.