# CHARACTERIZATION OF THE AQUIFER SUITE WITHIN NAIROBI COUNTY AND ITS ENVIRONS WITH RESPECT TO THE CHEMICAL COMPOSITION AND DEPTH

**BY**

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**2018**

**DECLARATION**

I declare that this dissertation is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

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## DEDICATION

I dedicate this project to God Almighty my creator, my strong pillar, my source of wisdom, knowledge and understanding. He has been the source of my strength throughout this program. I also dedicate this work to my husband, Peter, my daughters Laura and Kimberly, who have encouraged me all through the stages of my work. To my friends Theresa, Gilbert, Maurice, Emmy and Dr. Sophie, whose encouragement has made sure that I give it all it takes to complete my work.

Thank you. My love for you all can never be quantified. God bless you

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## ABSTRACT

Chemical characteristics of natural waters depend on several factors such as the lithology of the geological strata in which groundwater is flowing, time of residence of water and environmental conditions. Normally, small number of substances constitute the chemical composition of water (major ions), but other ions (minor ions) can also be found in low concentrations. Due to interactions with the atmosphere, soils, bedrocks and the surfacial environment, groundwater can dissolve a wide range of elements that expose it to a widely dynamic environment. With regards to geochemistry, it tends to dissolve more of the mineral elements than surface water. The study area is geologically sandwiched between a massive Neoproterozoic basement, which outcrops, to the East and the highly elevated volcanic formation to the West, representing Lukenya and Ngong' hills respectively. It forms a huge depression right at the eastern edge of the Great Rift Valley. This depression was filled with Cainozoic volcanics and sediments (Old land surfaces and lake sediments).This dissertation gives a detailed account of analyzed different sets of data from various sources including aerial photographs, borehole data and, most importantly, the chemical analysis. Fluoride, Sodium, Chloride, Iron, Nitrates, Sulphates and Manganese are considered ideal for discussion. Since the scope of this study is confined to the critical chemical analysis with direct influence to human health, other factors/chemicals are considered non-significant having no maximum permissible limits. These include Free Carbon dioxide, Permanganate Value, Total Dissolved Solids, Total Alkalinity, Potassium, Magnesium and Calcium. Generally, extreme fluoride levels as analyzed, tabulated and represented in graphical format in the results section was sampled from The Basement – Kapiti phonolite series aquifer characterized by intercalated lake sediments near Mozambiquan basement dome around Syokimau area. Apart from the Kapiti lake sediments, Fluoride is also detected above the acceptable limit in both the Upper and Middle Athi series. The presence of sodium in a number of these aquifers: Athi series and Kapiti series gave a new angle to the source of the highly concentrated fluoride within these specific aquifers. Iron and Manganese detected in both the Athi series and the Kapiti aquifers increases towards western part of the study area. Safer regions as delineated by this study can be towards the North Eastern areas though minerals that were detected above the WHO guideline are Fluoride, Sulphate and Iron in a number of aquifers.

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| | | |
|---|---|---|
| ***WHO*** | : | *World Health Organization* |
| ***agl*** | : | *above ground level* |
| ***Amsl*** | : | *above mean sea level* |
| ***bgl*** | : | *below ground level* |
| ***E*** | : | *East* |
| ***EC*** | : | *electrical conductivity (S/cm)* |
| ***Hr.*** | : | *hour* |
| ***L*** | : | *liter* |
| ***M*** | : | *meter* |
| ***N*** | : | *North* |
| ***PWL*** | : | *pumped water level* |
| ***Q*** | : | *discharge* ($m^3$*/hr.)* |
| ***s*** | : | *drawdown (m)* |
| ***S*** | : | *South* |
| ***RB*** | : | *Red beds* |
| ***LT*** | : | *Limuru Trachyte* |
| ***SWL*** | : | *static water level* |
| ***T*** | : | *transmissivity* ($m^2$*/day)* |
| ***NT*** | : | *Nairobi Trachyte* |
| ***UAS*** | : | *Upper Athi Series* |
| ***MAS*** | : | *Middle Athi Series* |
| ***VES*** | : | *Vertical Electrical Sounding* |
| ***LAS*** | : | *Lower Athi Series* |
| ***KPS*** | : | *Kapiti Phonolite Series* |
| ***W*** | : | *West* |
| ***WAB*** | : | *Water Apportionment Board* |
| ***WRA*** | : | *Water Resources Authority* |
| ***WSL*** | : | *water struck level* |
| ***S/cm*** | : | *micro-Siemens per centimeter: Unit for electrical conductivity* |
| ***°C*** | : | *degrees Celsius: Unit for temperature* |
| ***"*** | : | *Inch* |
| ***KVS*** | : | *Kerichwa Valley Series* |
| ***COD*** | : | *Chemical Oxygen Demand* |
| ***DEM*** | : | *Digital Elevation Model* |
| ***IMG*** | : | *Image* |

# CHAPTER 1: INTRODUCTION

## 1.1 Background information

Chemical characteristics of natural waters depend on several factors such as the lithology of the geological strata in which groundwater is flowing (i.e. the aquifer), time of residence of water in the aquifer, and environmental conditions. Normally, a small number of substances constitute the chemical composition of water (major ions), but other ions (minor ions) can also be found in low concentrations. Other substances (pollutants) can be present in water because of anthropogenically initiated pollution processes.

Boreholes which are narrow holes dug into the ground are one of the avenues of exposing aquifers to get water for purposes such as domestic. Nairobi and its surrounding towns get borehole water which comes from the Kerichwa Athi series and Kapiti series – Basement contact aquifers. Chemical analysis of the water obtained from boreholes is vital in determining the most suitable use of that water. The amount of the minerals, for example, sodium and nitrate in the water is considered in knowing the best use of that water. There are some recommended amounts by WHO of the mineral contents, and when these values are exceeded the water is considered unsuitable for use. For instance, water that has a high amount of chlorine is not suitable for drinking.

The aquifers are prone to contamination due to several reasons, such as disposing of waste in open dumps and natural geologic factors. When it rains, water dissolves some contents from the wastes or minerals in rocks they infiltrate which probably contains high concentration of organic and inorganic substances. The water then percolates into the earth having a high potential to pollute the underground water. Nairobi city is vulnerable when it comes to aquifer pollution because waste is mostly inappropriately disposed of creating leachates which infiltrates the ground. Water pollution leads to people complaining of water-borne diseases such as typhoid and cholera when they consume the contaminated water or highly mineralized borehole water. It is therefore essential to consider the quality of Kerichwa, Athi series and Kapiti series – Basement contact aquifers: among other aquifers with respect to their chemical analysis. This study tends to focus more on the natural groundwater mineralization from various geological formations.

## 1.2 Problem statement

Climate change has led to reduced levels of surface water while urbanization has led to water resources constraint. Nairobi city is faced by water scarcity problems, and this has necessitated the need for alternative sources, mainly groundwater. As a result, the rate of groundwater use has drastically increased in the recent years, and the trend will continue. It is, therefore, important that information on the quality of the groundwater is readily available to guide on the use. By 1964, Nairobi city had the most boreholes compared to any other area of the country (Gevaerts, 1964). Data from the Ministry of Water and Irrigation show that there are over two thousand five hundred (2,500) boreholes in Nairobi (GoK, 2009). Water Resources Authority (WRA) is responsible for monitoring water quality, but it is limited to few boreholes and few parameters due to lack of resources and the high cost of analysis.

Nairobi county and its environs has experienced population growth over the recent years due to various reasons, some of which include economic factors. This has increased the water demand of which a bigger part of the population has resorted to groundwater sources to supplement the water provided by the authorities. Due to this overdependence on the groundwater sources, over concentration of a number of these minerals i.e. Iron and Fluoride, has since caused havoc to the users. Some of these minerals can completely destroy the groundwater beyond plant or human use.

## 1.3 Objectives

### 1.3.1 General objective

To characterize the aquifer suite within Nairobi County and its environs with respect to the chemical composition and depth.

### 1.3.2 Specific Objectives

1. To chemically characterize the Nairobi aquifer suite with depth and determine the chemical concentration levels of each.
2. To establish the possible impact of the chemical elements within the abstracted aquifers to the consumers.
3. To provide a proper guideline in groundwater utilization within Nairobi County and its environs taking into consideration the chemical concentration.

## 1.4 Justification and Significance of the study

Nairobi has experienced a high increase in human population as people move from rural areas to the city to look for jobs. The high population and industrial expansion have caused the rise in water demand in the area. This has necessitated the need for alternative sources. As a result, the rate of groundwater use has drastically increased in the recent years, and the trend will continue (City council of Nairobi, n.d.). It is therefore important that information on the quality of the groundwater is readily available to guide on the use.

The naturally initiated groundwater mineralization is easily traceable and less expensive as compared to the anthropogenic pollutants. If the pollutants that infiltrate the aquifer contain elements that are above the required limits by WHO, then this becomes dangerous to the human health. Kenya has a plan known as 'Kenya Vision 2030' of transforming the nation into an industrializing middle-income country, providing every citizen with high-quality life by the year 2030. Achievement of this goal will be contributed by providing safe water to people in Nairobi and the rest of the country. It is therefore essential to conduct a study on the quality of groundwater to guide in policy formulation, planning and management of groundwater resources within the study area.

## 1.5 The study area

The study area covers the entire Nairobi County and extends to the peripheral parts of adjoining counties of Kiambu, Kajiado and Machakos as shown in Figure 1.1 below. The county of Nairobi forms one of the 47 counties in Kenya. It is the smallest county but the most populated of all the counties in Kenya. It also forms the capital city of Kenya with an area of 696km$^2$. As of 2009 census its population stood at 3.375 million with a population density of 4800/km$^2$. The county is composed of 17 constituencies which include Westlands, Dagoreti North, Dagoreti South, Langata, Kibra, Roysambu, Kasarani, Ruaraka, Embakasi south, Embakasi north, Embakasi Central, Embakasi East, Embakasi West, Makadara, Kamukunji, Starehe and Mathare as administrative units.

The study area extension into Kiambu County covers a good number of Nairobi satellite towns including Kikuyu, Ruiru, Juja, Thika and Limuru stretching at least 20km from the Nairobi border. Satellite towns within Kajiado County include Ngong' and Kiserian together with Athi river in Machakos County.

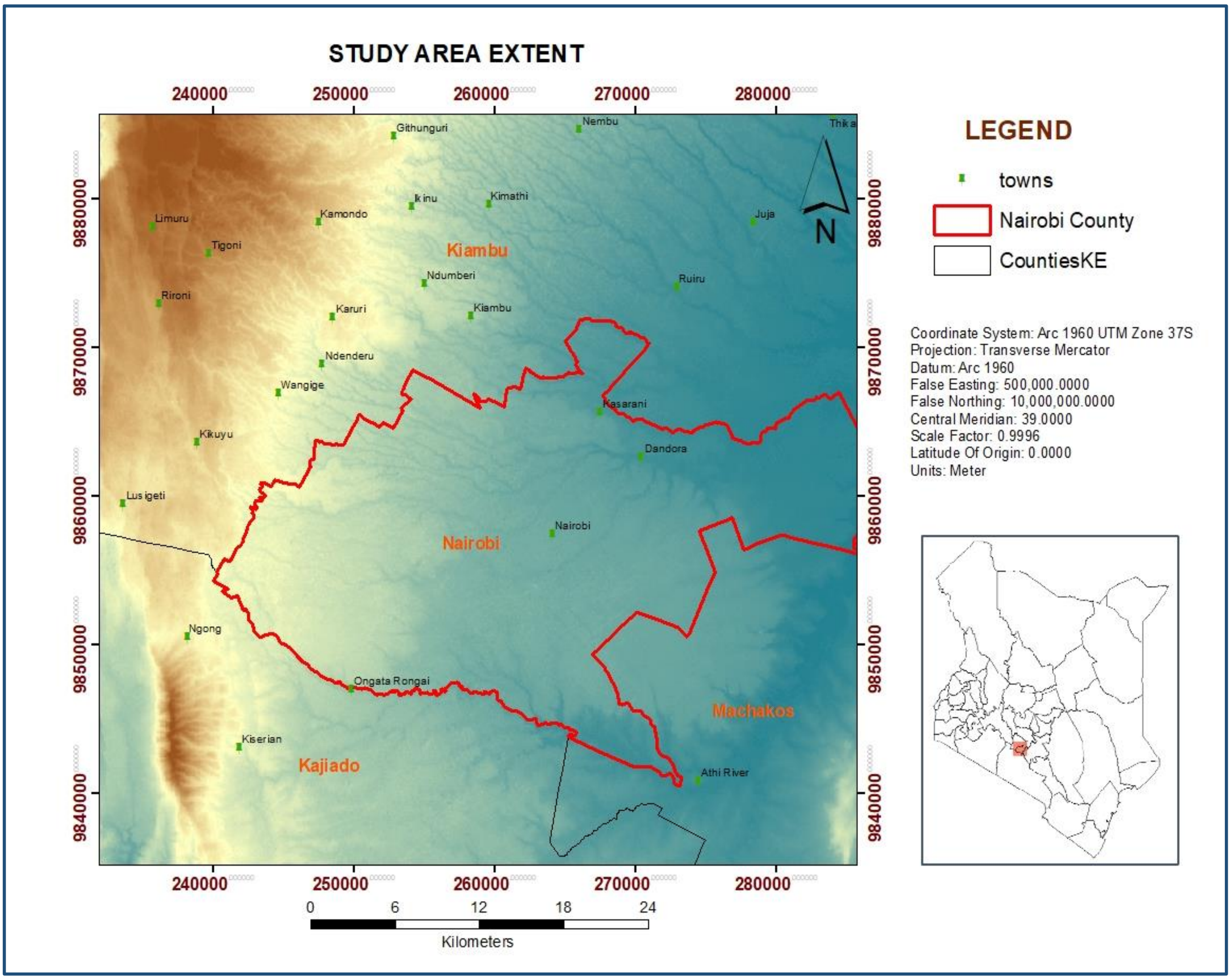


*Figure 1.1: Study area extent map*

### 1.5.1 Climate

#### 1.5.1.1 Precipitation

The general area receives an annual rainfall of 869mm. the month of July forms the driest with a monthly rainfall of 14mm of rainfall while April forms the wettest with an average rainfall of 191mm of rainfall.

*Table 1.1: Average annual climatic data (Adapted from Climate data.org)*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Av. Temp ($^0$C) | 19.7 | 20.2 | 20.7 | 20.2 | 19.1 | 17.8 | 16.7 | 17.2 | 18.6 | 19.8 | 19.3 | 19.2 |
| Rainfall (mm) | 46 | 48 | 92 | 191 | 144 | 36 | 14 | 19 | 21 | 50 | 128 | 80 |

The annual graphical representation of the above tabled data for the Nairobi area is as shown in figure 1.2 below. The highest precipitation can be observed to be received in April followed by the second highest in November. It can also be observed that the rainfall structure in the project area is bimodal with the first season running from March to May and the second season experienced in October to November.

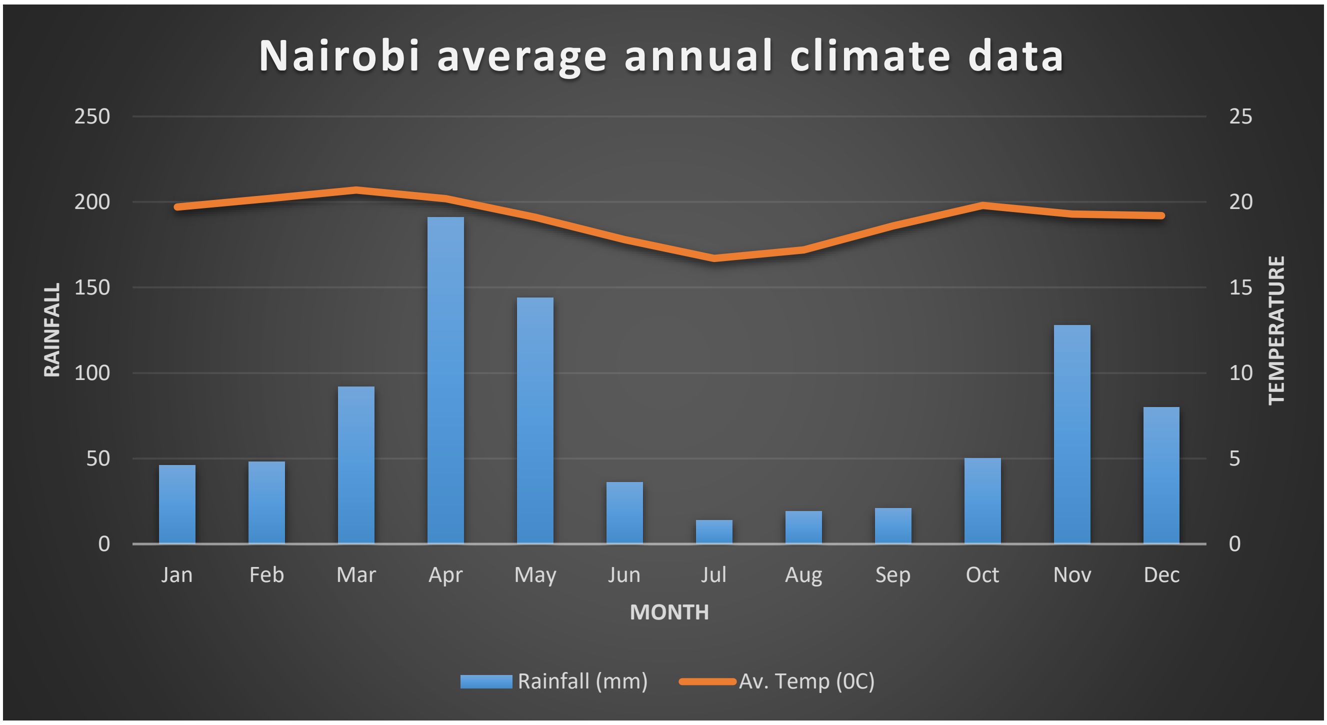


*Figure 1.2: Average annual climate data*

The area experiences a huge climatic variation due to the fact that elevation characterization of any specific area plays a very big role. This kind of climatic difference is brought about by the highly elevated western volcanic formations of Ngong' and Limuru areas known to be receiving higher rainfall of up to 1263mm a year as compared to the eastern lowlands that receives an average of 599mm a year.

*Table 1.2: Rainfall statistics from Nairobi (1), Athi River (2) and Limuru (3) in (mm)*

| Stat. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Mean Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 46 | 48 | 92 | 191 | 144 | 36 | 14 | 19 | 21 | 50 | 128 | 80 | 869mm |
| 2 | 34 | 39 | 73 | 137 | 77 | 17 | 6 | 6 | 10 | 37 | 107 | 56 | 599mm |
| 3 | 58 | 57 | 111 | 294 | 236 | 56 | 27 | 33 | 31 | 82 | 176 | 102 | 1263mm |

From figure 1.3 below, the Limuru highlands receives more rainfall that justifies the source of groundwater recharge from this area. Athi River area receives the least rainfall amount as compared with other areas within the study area though with a better groundwater potential.

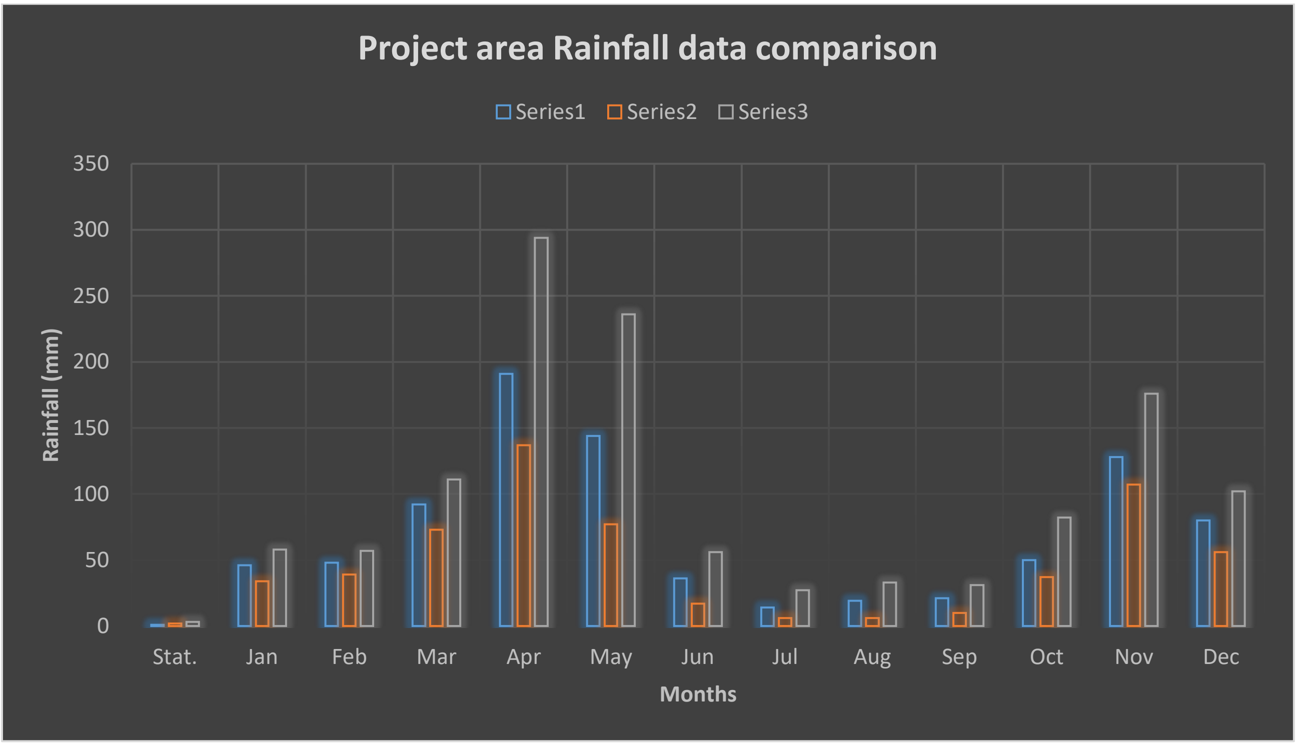


*Figure 1.3: Rainfall statistics from Nairobi (1), Athi River (2) and Limuru (3) in (mm)*

**1.5.1.2 Temperature**

Generally, the Nairobi area (part of the study area) is climatically graded as warm and temperate. It receives significant amount of rainfall throughout the year. The climate has also been considered to be of CFB in accordance to Koppen-Geiger climate classification. The month of March forms the warmest months and July the coldest with temperatures of 20.7 degrees and 16.7 degrees respectively as shown in Figure 1.2 above

The data obtained from climate data organization: the warmest month generally in Nairobi is March with a high of $20.7^0$. July proved to be the coldest with a minimum temperature of averagely $16.7^0$.

### 1.5.2 Physiography

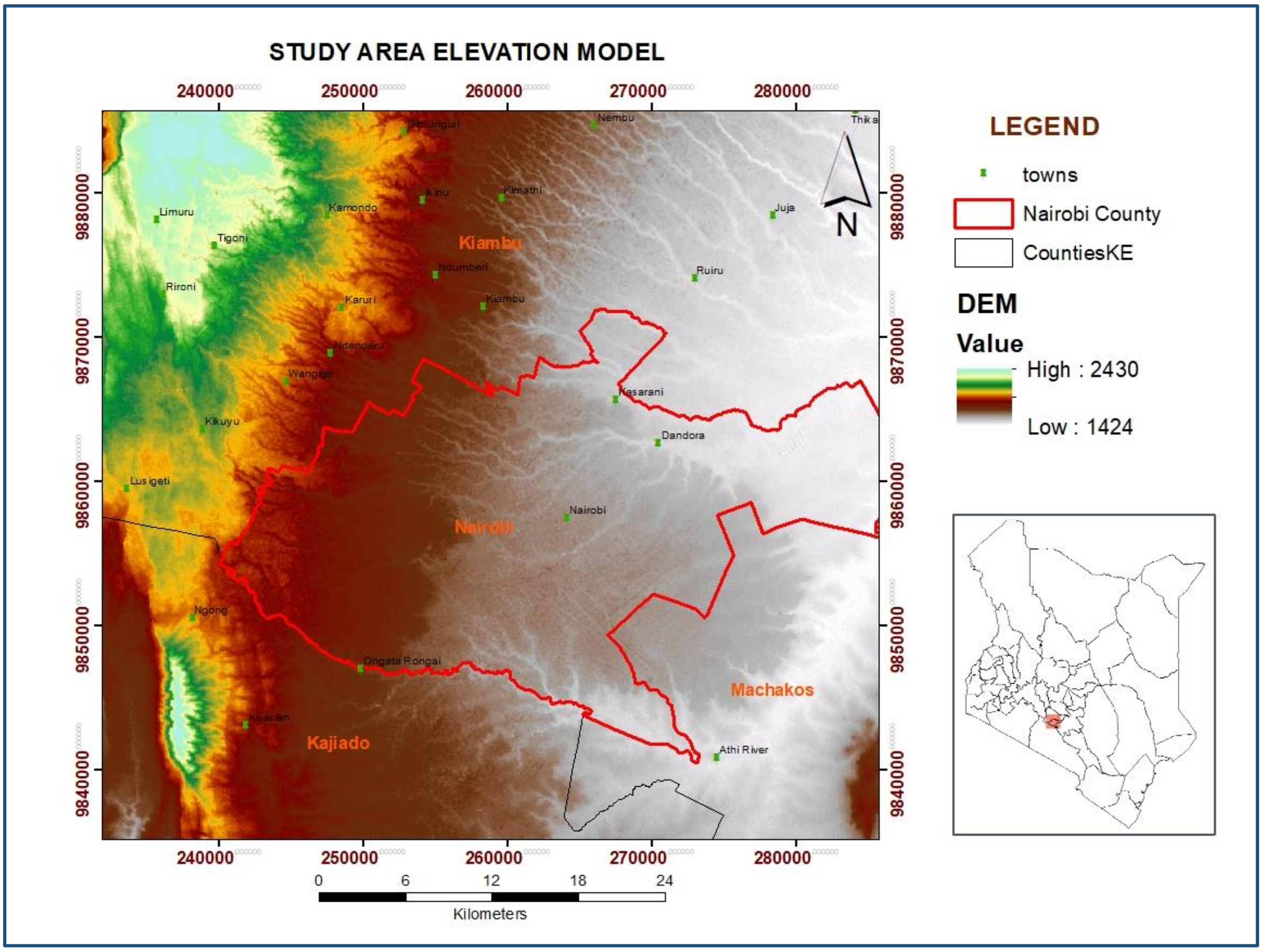


*Figure 1.4: Study area elevation map*

The study area generally shows a wide variation in terms of elevation that ranges from 1400m to more than 2430m as shown in figure 1.4 above. Ngong' and Limuru areas represents a height of > 2000m above seas level with the lowest areas towards the eastern part of the map: Athi River and Juja, indicating less than 1500m above seas level.

### 1.5.3 Drainage

Nairobi area and its environs are drained by many Nairobi River tributaries. The surface water is basically drained into the Nairobi basin that consists of three major rivers: Ngong', Nairobi and Mathare. Almost all the rivers tend to flow to the eastern direction being controlled with a unique elevation characteristic leaving behind a wide watershed. Most of these rivers originates from Ngong', Kikuyu and Limuru areas.

The main tributaries include Gitathuru, Kamiti, Ruiruaka, Mbagathi, Kasarani and Riara rivers all sharing a single catchment from Limuru – Kikuyu areas as shown in the figure 1.5 below.

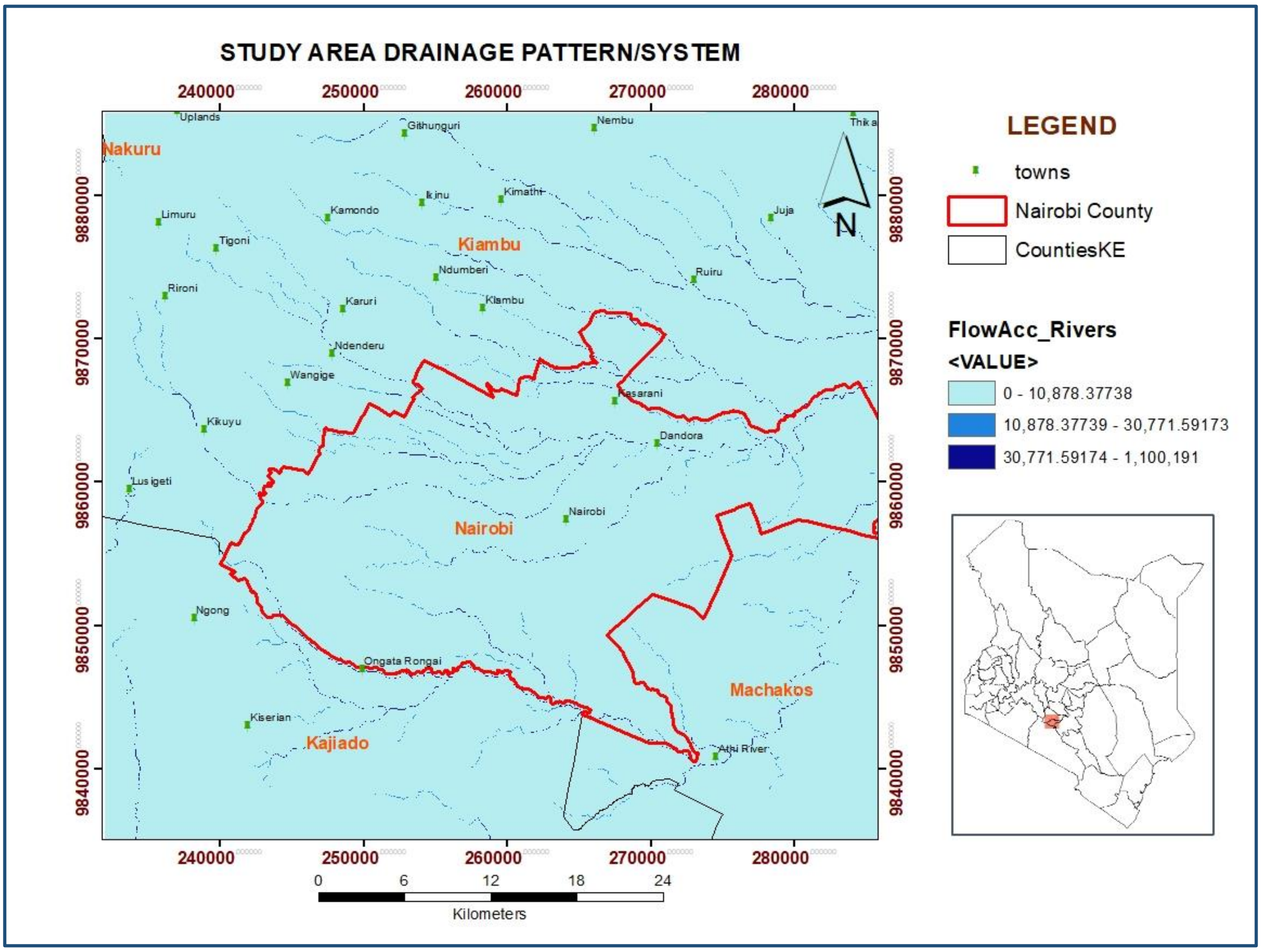


*Figure 1.5: Study area Drainage pattern/system*

The Nairobi river basin covers an average area of about 1,078km2 with urban centers, grasslands and forests. The above mentioned river channels within this basin flow eastwards into the Athi River and finally into the Indian Ocean. These rivers play a critical role in Nairobi aquifer suite recharge through percolation and infiltration through soils and weak zones since the study area is moderately disturbed by faults.

## 1.5.4 Land Cover

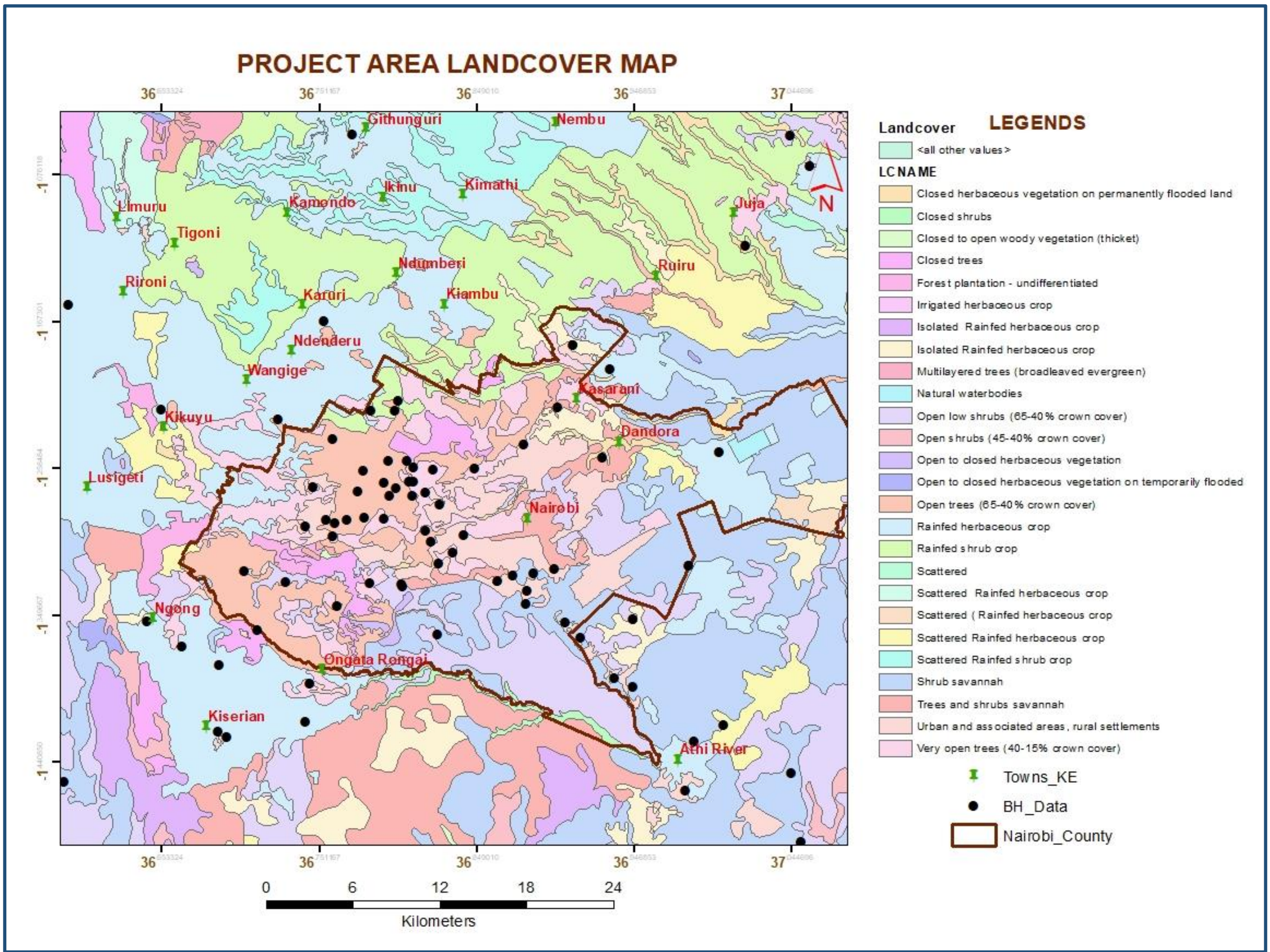


*Figure 1.6: Land cover map*

The study area as shown in figure 1.6 above is covered by a wider range of both natural growths and human made structures. A few Natural and planted forests, wild shrubs and herbs, water bodies, grasslands and urban settlement areas. The greater part of the study area is covered by herbaceous crops and planted vegetation. Urban settlement also commands a huge chunk of the study area portion. Urban settlement indicated by increase in built area has been noticed to be consuming the larger part of the natural land cover with a study done in 2010 with the help of satellite images proving a 47km$^2$ increase within 24years: from 1976 to 2000. The western part of the study area is highly forested (Covered by both artificial, natural forests and herbaceous growths) creating a perfect recharge zone and good catchment for the Nairobi aquifer suite and most of the rivers respectively.

### 1.5.5 Population

The biggest consumers of the groundwater abstracted from the studied Nairobi aquifer suite are within Nairobi County. The county has a population of about 3.4 million established by the 2009 national population census up from 2.1 million heads according to the 1999 national census. The current population is expected to be even much higher in 2017 due to the rapid population growth and rural urban movement experienced in the recent years: an estimated 20 million people in the year 2020. This number makes Nairobi the most populous city in East Africa and 12th in Africa with a population density of 4,509 per square Kilometer.

One of the disadvantages of a rapid population growth is pressure on some of the crucial resources like Water supply and sanitation, health and education facilities. Poor housing too has also led to development of unplanned settlements normally referred to as slums with poor water supply and deteriorated sanity. In order to supplement the available water sources, the residents have increased their dependence on groundwater sources. This has also come with numerous challenges including the chemical quality and pollution issues e.g. the fluoride content.

### 1.5.6 Geology

The geology of Nairobi area characterizes a keenly constructed geological history starting from the Cambrian to the Holocene with massive contribution by several geologists including (Clarke et al. 1990). Guth and Wood, (2013) documents the detailed works done by Baker et. al. (1988) and Clarke et al. (1990) with proper analysis in relation to the rock types and their geological ages. Longonot trachytic stratovolcano together with their accompanied sediments seem to be the youngest formation.

A lot of volcanic activity took place during the Pleistocene. A number of geological units including Kedong' valley tuffs, Baraj trachytes, Ol Tepesi alkaline basalts, Limuru, Karura, Kabete and Tigoni trachytes are related to this era. Ngong' hills located on the western part of the project area shows a little complicated geology that has so far been proven to a remnant of an original volcanic mountain believed to have covered about 11km diameter before being cut by the rift active volcanic activity. These volcanics are composed of nephelines, gneiss fragments and tephrites with the oldest volcanics believed to belong to the Miocene.

The youngest aquifer potential volcanic series have been identified to belong to the Pliocene. This is composed majorly of Kinangop and Kerichwa Valley tuffs. This formation is majorly composed of trachytic tuffs, often welded and found right above the non-porous Nairobi trachytes. The ages of these tuffs were revised by Baker et. al, (1988) in correlation with the Kinangop tuffs to be 3.3 – 3.7 Ma, a deduction from Saggerson, (1991) that have been considered as over exaggeration due to the presence of minor feldspars within this formation. Narok agglomerates, Nairobi and Kiambu trachytes together with Nairobi phonolites are also believed to belong to this era.

Esayeti volcanics, known to overlie most of the early Ngong' eruptive belongs to the Miocene. It's majorly composed of phonolites and has been exposed due to heavy erosion of the Ngong' hills. Kandizi phonolite, Mbagathi trachyte, Athi tuffs and Nairobi phonolite also belong to the same geological age as analyzed by Saggerson (1991). Athi tuffs has also been identified as a highly productive aquifer zone. So far, the formation has been sub divided into Upper Athi, Middle and Lower Athi series. Proper mapping of this geological unit has been met with numerous challenges. The most explored unit is the Upper Athi tuff: that is known to be porous and pervious with a huge groundwater potential is welded with materials believed to have been deposited though sub aerial means or through lacustrine settings.

The study area geological map shown in figure 1.7 below gives a brief visual geological extent of the discussed units above.

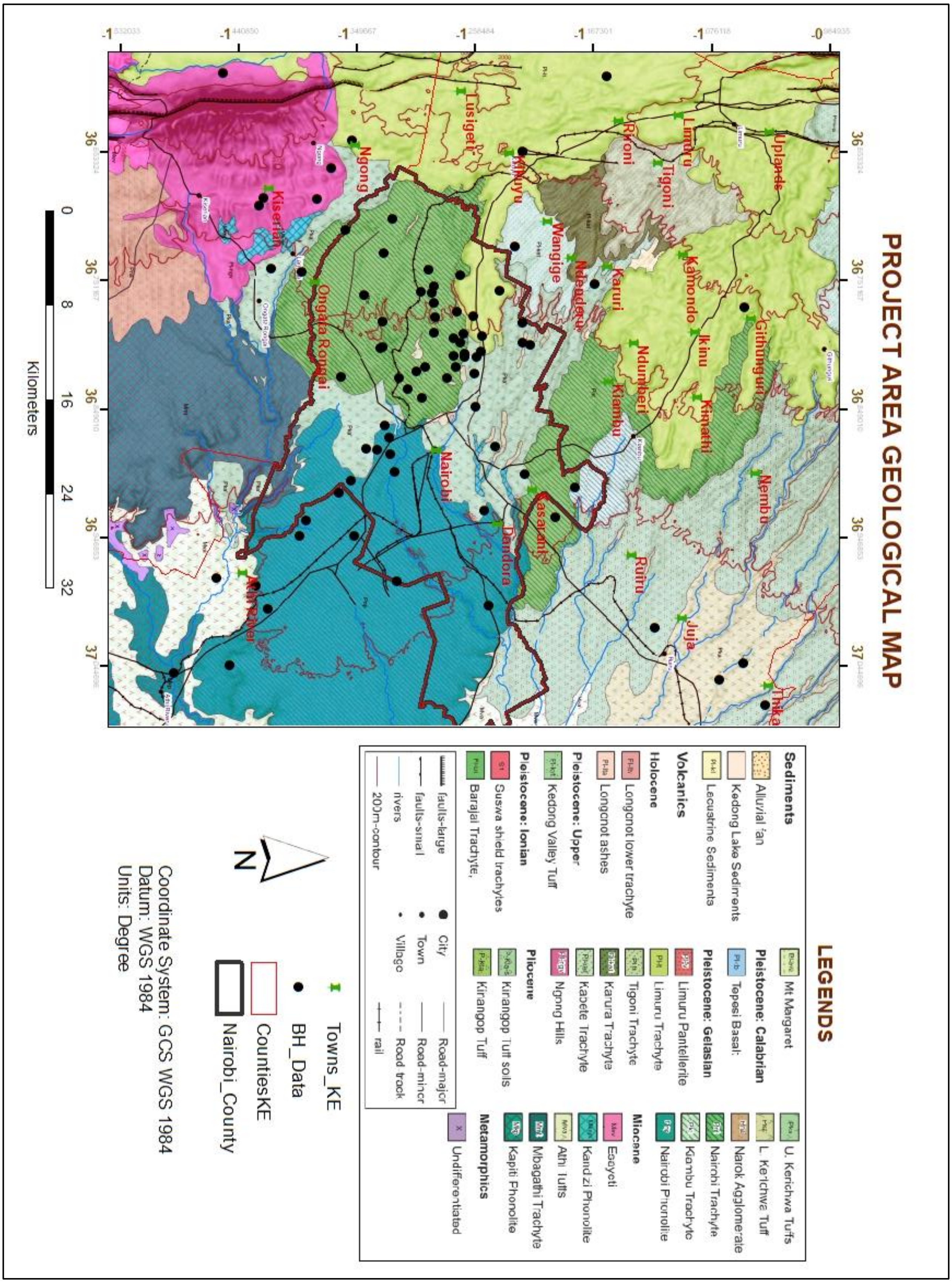


*Figure 1.7: Study area Geological map: Digitized from A. Guth & J. Wood, (2013)*

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

As groundwater flows through various geologic formations, there are various geochemical processes that tend to influence the chemical evolution of the water. Some of these processes include adsorption – desorption, oxidation – reduction and carbonate equilibrium processes (These processes are not within the scope of this project).

## 2.2 Dissolved Constituents of Groundwater

Due to interactions with the atmosphere, soils, bedrocks and the surficial environment, groundwater can dissolve a wide range of elements (Allen, 2001). According to Earle, (1982), groundwater tends to be exposed to a widely dynamic environment regarding geochemistry, it tends to dissolve more of the mineral elements than surface water. Deep groundwater also tends to contain higher concentration of chemicals due to longer time of exposure and contact to various formations that shallow groundwater sources that are theoretically presumed to be younger than the deeper groundwater sources.

Within the dynamic formation prevailing in the project area, silicate rocks dominate the greater percentage of the whole coverage. Silicate rocks are normally stable and don't easily react with the groundwater unlike carbonate rocks (Allen, 2001). The carbonate rocks are major contributors to chemical evolution of groundwater in many areas. The dissolved constituents in groundwater are normally expressed in mg/l for the main constituents while the trace elements are expressed in terms of µg/l or in Molarity terms.

Earle, (2004) tends to classify the mineral components of the groundwater as Major Constituents, including the predominant anions and cations, and Trace elements. The major components include anions like bicarbonates, chloride and Sulphates while the major cations entail sodium, magnesium, calcium, potassium among many others. The concentration of these chemical components and other borehole properties representing the groundwater properties within the study area are given under the appendix section of this report.

## 2.3 Factors affecting groundwater quality

Groundwater quality can either change naturally or through non-natural (Anthropogenic) means. As water infiltrates and percolates through the ground, it gets into contact with various geological formations with numerous chemical components (Dennis, 2002). Anthropogenic induced sources can be easily detected by water taste and/or odor. In summary, the different factors that affect the total groundwater dissolved minerals includes the length of time the water is in contact with the mineralized aquifer formation, the mineral types that make up the aquifer and the chemical condition of the same groundwater which in turn dictates how reactive it can be (Dennis, 2002).

For a break down, Gibbs (1970) proposes several earth processes that tend to influence the surface water quality or groundwater quality. These processes entail rock weathering, which controls the ease of the ionic exchange, atmospheric precipitation that tends to dissolve several elements from the atmosphere thus precipitates compounds that can affect the groundwater quality, evaporation that leads to formation of various salts and crystallization. Acid rain, for instance, is a key source for Al, Be, Mn, Fe and many others for groundwater.

There seems to be a very complex ionic exchange between groundwater and soils as observed by (Hesterberg, 1998). Human disturbance of the natural resources like groundwater aquifers through drilling can also interfere with the water quality due to addition of foreign materials including casings, drilling fluids, gravel packs (Appelo and Postma, 1996). They further noted that pesticides, fertilizers and other agricultural chemicals also play a bigger role in groundwater quality deterioration through vertical fluxation especially in areas having high precipitation, high infiltration and percolation rates and gently sloping regions.

### 2.4 Acceptable limits for groundwater quality parameters

According to WHO (2003), 80 percent of all the diseases found in humans originates from water or because of lack of clean and safe water for consumption. The quality of water once contaminated, is not easy to reverse as huge capital might be needed. To communicate effectively to the legal authorities, law makers or any other water resource management body and concerned members of the public, a water quality index is needed. Dissolved minerals that majorly originates from soils, more specifically, sedimentary formations, pose a greater risk and a major deterioration to the groundwater quality (Devendra, 2014). The guideline for a standard drinking water quality was published by IS: 10500-2012, the major parameters included specific conductance units, sodium adsorption/content and boron concentration.

*Table 2.1: Naturally found substances in groundwater that poses problems in operating wells (After Devendra, 2014)*

| Substance | Types of problems |
|---|---|
| Iron ($Fe^{+2}$,$Fe^{+3}$) | Encrustation, staining of laundry and toilet fixtures |
| Manganese ($Mn^{-2}$) | Encrustation, Staining of laundry and toilet fixtures |
| Silica ($SiO_2$) | Encrustation |
| Chloride ($Cl^-$) | Portability, Corrosiveness |
| Fluoride ($F^-$) | Fluorosis |
| Nitrate ($NO_3^-$) | Methemoglobenemia |
| Sulphate ($So_4^{2-}$) | Portability |
| Dissolved Gases | Corrosiveness |
| Dissolved Oxygen | Corrosiveness |
| Hydrogen Sulphide ($H_2S$) | Corrosiveness |
| Carbon dioxide ($CO_2$) | Corrosiveness |
| Radio Nuclides | Portability |
| Miner Constituents | Portability, Health aspects |
| Calcium and Magnesium ($Ca^{2+}$, $Mg^{2+}$) | Encrustation |

Devendra, (2014) in his research, goes ahead to discuss in detail the various parameters that are used to assess the water quality. A hydrogen Potential (pH) that should lie between 4.4 to 8.5, Turbidity of the groundwater that dictates the total suspended solids should fall between 1 and 5 NTU as the acceptable and permissible limits in that order. TDS is the basically the difference between the total and the suspended solids that are usable in determining the solids that can be filtered from the water. The acceptable and permissible limits are 500 and 2000 mg/l. electrical conductivity as a parameter is the capacity of the electric currents that can be held by water and is solely dependent on the number and the type of ions present within the water media. The permissible limits of a consumable groundwater in terms of Total hardness as another major factor lies between 200 and 600 mg/l.

In terms of the chemistry of a groundwater, a good number of parameters can be used to further assess the quality of a consumable groundwater. The chemical elements include Sulphates, Nitrates, Chloride, Fluoride, Boron, Phosphates, Zinc among other parameters like Chemical Oxygen Demand (COD) and Alkalinity levels. The acceptable limits for these elements are given in table 2.2 below.

*Table 2.2: Physical and chemical properties of tube well water as per IS 10500-2012*

| S.No. | Parameter | Unit | Accept. Limit | Permi. Limit |
|---|---|---|---|---|
| 1 | Colour | Hazen Unit | 5 | 15 |
| 2 | Odour | | Agreeable | Agreeable |
| 3 | pH | | 6.5-8.5 | No relaxation |
| 4 | Turbidity | NTU | 1 | 5 |
| 5 | Total Dissolved Solids | mg/l | 500 | 2000 |
| 6 | Ammonia | mg/l | 0.5 | No relaxation |
| 7 | Boron | mg/l | 0.5 | 1 |
| 8 | Calcium | mg/l | 75 | 200 |
| 9 | Chloride | mg/l | 250 | 1000 |
| 10 | Fluoride | mg/l | 1 | 1.5 |
| 11 | Magnesium | mg/l | 30 | 100 |
| 12 | Nitrate | mg/l | 45 | No relaxation |
| 15 | Total Alkalinity | mg/l | 200 | 600 |
| 16 | Sulphate | mg/l | 200 | 400 |
| 17 | Total Hardness | mg/l | 200 | 600 |
| 18 | Temperature | °C | - | |
| 19 | Sodium | mg/l | - | |
| 21 | Iron | mg/l | 0.3 | No relaxation |
| 22 | Cadmium | mg/l | 0.003 | No relaxation |
| 23 | Chromium | mg/l | 0.05 | No relaxation |
| 24 | Zinc | mg/l | 5 | 15 |
| 25 | Manganese | mg/l | 0.1 | 0.3 |
| 26 | Nickel | mg/l | 0.02 | No relaxation |

Human consumption of these minerals has always been considered highly critical due to their effects on the human health. For this reason, WHO and EU has set out the standards aimed at targeting the best quality possible. Though consumption of these minerals above the limits can result into adverse human health effects, it is not necessarily harmful to consume some of the minerals above the set standards. For toxic chemicals, a maximum permissible limit shown in table 2.3 below should not be exceeded in personal or public water supply.

*Table 2.3: Maximum dissolved constituent limits as per WHO/EU 2003 guideline values*

| Parameter | WHO/ EU Guideline |
|---|---|
| Cations | (mg/l) |
| Iron | 0.2 |
| Manganese | 0.5 |
| Calcium | No Guideline |
| Magnesium | No Guideline |
| Sodium | 200 |
| Potassium | No Guideline |
| Anions | (mg/l) |
| Chloride | 250 |
| Fluoride | 1.5 |
| Nitrate | 50 |
| Nitrite | 0.50 |
| Sulphate | 250 |
| Total Hardness | Desirable: 150-500(mg$CaCO_3$/l) |
| Total Alkalinity | No Guideline(mg$CaCO_3$/l) |
| Physical Parameters | |
| PH | Desirable: 6.5-8.5 |
| Colour | Desirable: 15(mgPt/l) |
| Turbidity | Desirable:< 5(NTU) |
| Permanganate Value | No Guideline(mgO2/l) |
| Conductivity | 250 microS/cm (S/cm) |
| Total Dissolved Solids | No Guideline(mg/l) |
| Free Carbon Dioxide | No Guideline(mg/l) |

## 2.5 Geology and Hydrogeology

### 2.5.1 General Geology

From the geological history keenly crafted by Guth and Wood (2013), the study area is sandwiched between a massive Neoproterozoic basement outcrops to the East and the highly elevated volcanic formation to the West, representing Lukenya and Ngong' hills, respectively. It forms a huge depression right off the eastern edge of the Great Rift Valley. This depression was filled with Cainozoic volcanics and sediments (Old land surfaces and lake sediments).

These sediments and the volcanic sequence above the Neoproterozoic basement system are believed to be younger than the Miocene. The basement system experienced a lot of tectonic disturbances during this time (Miocene) leaving the formation moderately dominated by faults. Saggerson (1991) further describes the geomorphological evolution took place from the Miocene stating that an active volcanic activity through the massive cracks that filled the huge depression that covered the central part of the study area occurred.

Basically, Saggerson (1991) states the successive volcanic formation comprising of deep soils and gravels, dated to Quaternary age, lava flows and pyroclastic: depending on the type of eruption belonging to Cainozoic age and the Archean Neoproterozoic basement made up of the Precambrian gneisses and schists known to belong to the old Mozambique belt system (See attached Geological map on the study area description).

A proper description of the composition of this basement system within the study area is not clear since the thick volcanic succession above the basement system that bears a series of aquifers, named the Nairobi aquifer suite, buries deeply the basement rocks further hindering a proper study. This geologic succession (above the basement rocks) is majorly composed of the Nairobi Phonolite, Nairobi Trachyte and other trachytic series, Kapiti Phonolite, Athi series, Kerichwa Valley and many others.

### 2.5.2 General Hydrogeology

Gevaerts, (1964) documented a proper hydrogeological description of the study area stating largely that the hydrogeology of an area is greatly determined by the type of rocks/type of parent rock, the precipitation pattern which dictates the amount of recharge, the structural features including joints, faults and fractures and lastly the weathering patterns. Massive lava flows rarely contain substantial groundwater due to lack of pore spaces. Geologically, groundwater flows through secondary features such as fractures, fissures, faults, old land surfaces, lake beds and lithological contacts.

The Nairobi aquifer suite has two major aquifer series suggested by Gevaerts (1964), these are the Kerichwa Valley series and the Athi Series. The main aquifer is the Upper Athi Series that is majorly a Lake bed. The lower Athi series suffers a porosity problem thus forms an aquiclude. The Kerichwa Valley series is literally exposed near Karen and Kibera showing little groundwater potential. The Kerichwa valley is majorly ashy tuffs, pumices and highly permeable.

The Nairobi phonolites have also been exposed in Nairobi west area through industrial area up to Embakasi region. It is a pretty hard formation known for creating the basis of the extensive quarrying activity within the area. A patched aquifer occurs above Nairobi Phonolite around Nairobi south area due to minor groundwater accumulation.

### 2.5.3 Groundwater Chemistry

Groundwater flows within the aquifers or weak zones. Due to this process, the water interacts both chemically and biochemically with different geological formations. Since water is a solvent, it dissolves different minerals altering the original chemical composition of the groundwater in various concentrations (Freeze and Cherry, 1979).

Groundwater dissolves minerals in ionic forms making it an electrolyte. The total dissolved ionic content can be determined by the capacity to conduct an injected electric current. This is measured in terms of conductance which is then converted into resistance then to resistivity which is easily interpreted into other uses. This technique forms the basis of the resistivity survey used in most of the hydrogeological surveys (Freeze and Cherry, 1979).

The groundwater quality within Nairobi area has been classified as good in most of the parts (Gevaerts, 1964 and Saggerson, 1991). Except for fluoride that poses a major challenge to the residents, pH, dissolved solids and other dissolved minerals are rarely detected beyond the WHO limits. Higher Sulphate and chloride concentrations have also been detected within the Kapiti phonolites. They are contributed by the intercalated lacustrine sediments.

Recharge rates and groundwater movement are two major factors that tend to influence the groundwater mineral concentration. Higher recharge; majorly experienced on a seasonal basis and good groundwater movement including water table variations, leads to a flashing effect neutralizing the dissolved ionic chemicals.

### 2.6 Aquifer Recharge

Aquifer recharge can either be natural or artificial and refers to a process in which water inters an underground water saturated zone through percolation and infiltration from either precipitation or a surface water source like rivers, lakes or swamps. With respect to the study area, major recharge zones are restricted to the highland in Tigoni, Ngong' and Kikuyu areas (Gevearts, 1964).

Ngong' hills lie to the West of the study area right at the edge of the Great Rift Valley. It is an area heavily dominated by faults presumed to be having a direct connection with the aquifers thus offering a good direct replenishment for the aquifers (Mulwa et al, 2005). High rainfall of about 1200mm per annum, intense drainage and thick vegetation offers even better recharge conditions. Due to heavy rainfall annually received in the greater part of Nairobi area, more aquifer recharge is experienced due to normal infiltration. This creates patched aquifers above resistant formations that has been identified in Nairobi south confined above by the Nairobi Phonolites.

# CHAPTER 3: METHODOLOGY

## 3.1 Methods

### 3.1.1 Desktop studies

This stage involved reviewing of literature work on the study area to get to understand the geology, stratigraphy, hydrogeology (groundwater occurrence, groundwater flow, aquifers and behavior and recharge quality) and geochemistry from already done projects in the study area. Also, hydrogeological cross-sections were studied to understand different formations that forms aquifers within the study area and the kind of formation forming the aquifer at different parts.

### 3.1.2 Data processing

Scientifically, data processing is simply transforming a raw data into a usable form in order to show trends or give a visual reading about the researched subject.

A Digital Elevation Model form the USGS website contains raw elevation values that needs to be reprocessed before use. ArcMap offers a special statistical calculator tool that transforms the raw elevation values into a visually interpretable 2D TIFF data, easily manipulated into other useful forms. The DEM was used to model the elevation data to assist in area physiographical description.

Geology represented in the study area was obtained from a Nairobi area geological analysis done by Wood and Guth, (2013). The data available in an Image format was georeferenced and digitized then overlaid on the project area. The duo further summarized the geological history of the area.

The borehole chemical data and the coordinates drawn from the Ministry of Water and Irrigation were first compiled in an excel format. Before the proper analysis was done, they were first converted into a shapefile that could be read easily by any GIS software. The shapefile data was thus capable of being interpolated in order to show the various concentration levels within the project area.

Some of the area downloaded shapefiles including the Land cover also needed a little preprocessing and a bit of data re arrangement to visually show the targeted information. More appealing color codes were chosen in order to avoid color clash with the represented object.

### 3.1.3 Data analysis

On the analysis of the already collected and complied data, ARC GIS software was used to help in getting to understand how different chemicals behaved at different depths at different regions within the study area.

Generally, the IDW (Inverse Distance Weighted) interpolation is arc tool used in the interpolation of this chemical data. It has been used before being that it tends to assume that things/values close to each other are related more than those far from each other. The tool is programmed to assume that every point's influence diminishes with distance from the local point. The different chemical parameters interpolated at different depths include manganese, calcium, nitrate, iron, magnesium and chloride ions among others.

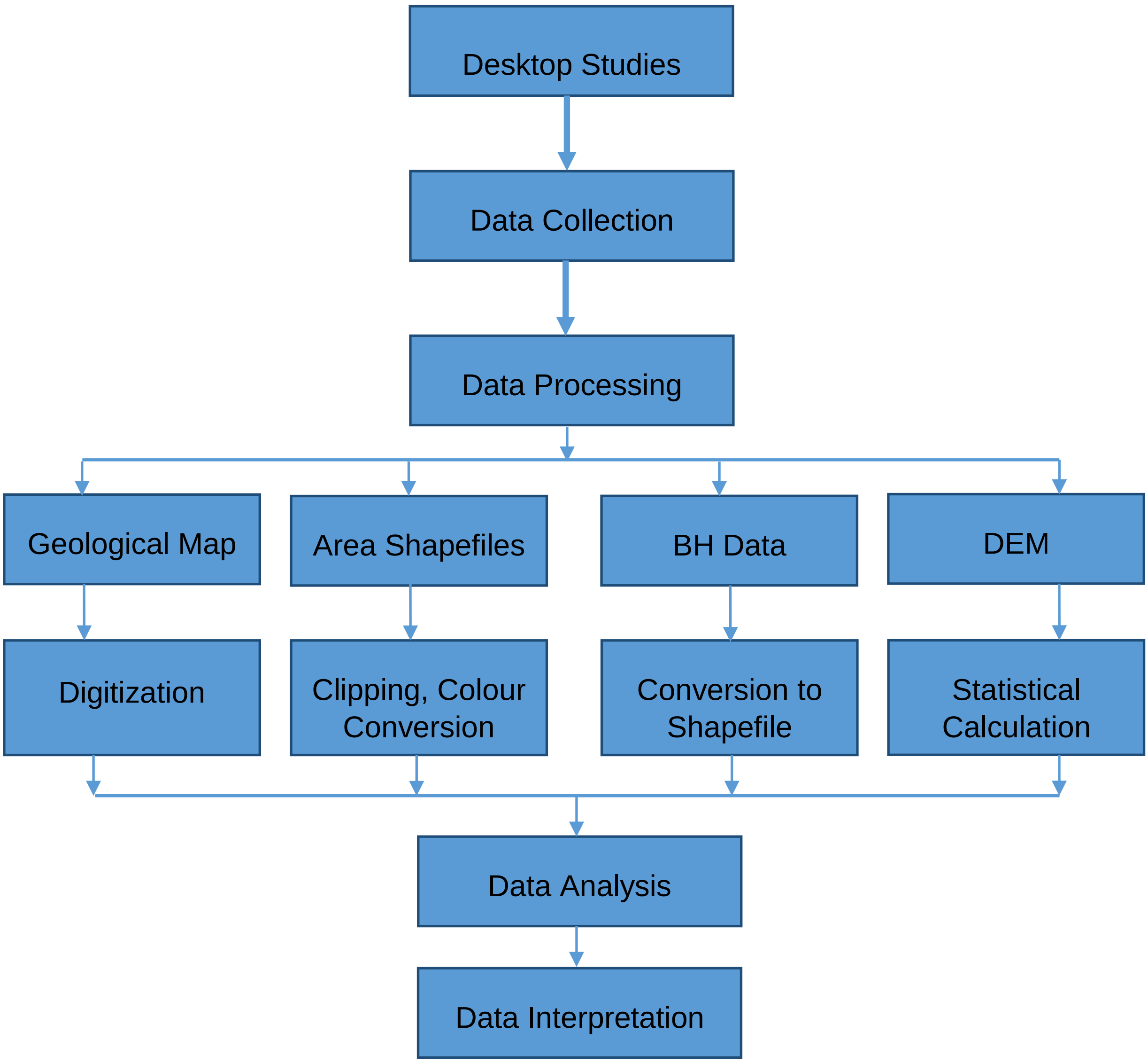


*Figure 3.1: Project methodological summary*

### 3.2 Materials

Since a lot of data was needed for this project, a number of data used were obtained from various sources thus availing them in various formats. For the purposes of the study area description, the Digital Elevation Model is a freely available elevation model data was obtained from the USGS website with a 30m resolution. It is made available in a TIFF format that makes it easy to be registered in a specific coordinate projection.

The geological map used for geological description of the study area was also obtained from the Ministry of Water and Irrigation, Water Resources Department in an IMG format and a 1:125,000 resolution.

Chemically analyzed data was obtained from borehole completion report. Data from a total of 86 boreholes were taken from the ministry of water and irrigation, Water Resources department. The data was compiled and arranged in an excel sheet (Excel Format) putting into consideration parameters such as co-ordinates of the respective boreholes and the different chemical parameters to be studied. The summary of the data used, and the format is as shown in table 3.1 below.

*Table 3.1: Type of data used for the research project*

| DATA | SOURCE | FORMAT | REMARKS |
|---|---|---|---|
| Geological Map | MWI: Water Recourses | IMG | 1:125,000 (Scale) |
| Borehole Data | MWI: Water Recourses | Excel/Shapefile | 86 Boreholes |
| Digital Elevation Model | USGS Website | TIFF | 30m resolution |
| Study area shapefiles | ILRI Website | TIFF | Undefined |

# CHAPTER 4: RESULTS AND DISCUSSION

## 4.1 Results

The Nairobi aquifer suite has been listed as one of the most significant aquifers in Kenya with respect to the quantity of water that can be abstracted and the population it serves. However, the use of groundwater always has a few limiting factors including the poor quality of the groundwater which can be attributed to over concentration of minerals or saline coastal intrusions. Inadequate scientific knowledge on the safe abstraction and occurrence of groundwater is also another limiting factor.

Kenya's groundwater potential, including the shared transboundary aquifers had been estimated to an approximate volume of about 619 million cubic meters (Pavelic et al., 2012). The abstraction rate at the same time was estimated at 7.12 million cubic meters a year. This proves a potential that can serve the nation for about 85 years without recharge. Ministry of Water Development (1992), later backed by Pavelic et al. (2012), safe abstraction, considering the quantity of water that annually recharge into these aquifers, was estimated at about 190 million cubic meters a year. The quantity of water to be abstracted annually varies from one aquifer to another due to varied water potential and recharge quantity: generally aquifer dynamics.

With this regard to individual aquifer exploitation, some aquifers are considered over-abstracted depending on the water demand in relation to the quantity of recharge. Over-abstraction normally comes with associated water quality and water level reduction problems which can lead to permanent destruction of the aquifer and Nairobi aquifer suite has been listed as one of the aquifers facing this problem. The aquifer, from the previously discussed literature, is composed of well layered volcanics alternated with minor Old Land Surfaces composed of sediments and Lake Materials. The chemical characteristics of the groundwater quality within this area is thus dictated by the chemical composition of the existing volcanic rocks that originated from the eastern flanks of the East African Rift Valley.

The East African Rift Valley volcanics are known for high mineral concentrations. A better example that has been found to be way above the maximum permissible level by the World Health organization (WHO) is Fluoride in a number of secluded areas as shown in the interpolated maps discussed in the following subtitles with a concentration reading up to 30mg/L. The Maximum permissible Fluoride levels for human consumption is normally 1.5mg/L. This problem is experienced throughout the East African Rift in which Lake Naivasha seems to be leading with the highest Fluoride concentration level among other chemicals. For this reason, human ingested fluoride health issues are prevalent in these three East African Countries: Kenya, Tanzania and Ethiopia. Apart from the leaching processes, evaporation and thermal springs can further increase these minerals' concentrations depending on the prevailing environmental conditions within a particular setting and this explains why Ethiopia has the most affected areas.

This project tries to classify these aquifers with high concern to their chemical composition from borehole chemical analysis data. Specific chemical discussion on those found above the WHO permissible limits, their source, human health problems and lateral extent in form of the interpolated maps is also included in the discussion.

#### 4.1.1 General Chemical concentrations

The radionuclide contaminants for some of the radioactive minerals or continuous chemical release or spill into the soil, not necessarily a water body, creates neither a point nor non – point pollution source but normally end up into the aquifers below them through infiltration and percolation of periodic surface water capable of generating a toxic plume. Leaching and thermal deposition are just some of the natural processes capable of completely transforming the groundwater quality of a specific aquifer.

Borehole drilling for groundwater exploitation process normally targets the main aquifer for maximum groundwater exploitation and to achieve the highest yield. For this reason, most of the boreholes do abstract water from two or more aquifers in order to yield the most water. Thus, the water quality is also influenced by the chemistry of all the aquifers that contributes to the yield of the borehole. The individual chemical concentration within the study area is thus as given below.

##### 4.1.1.1 Fluoride

Fluoride concentration within the Nairobi aquifer suites is solely through a natural process. The Nairobi aquifer suite is a purely volcanic aquifer suite in which the groundwater normally occurs between the interbedded layers described as the Old Land Surfaces and weathered zones. The water infiltration or percolation into these aquifers is through faults, fractures, fissures or through a loosely consolidated/weathered zone. This water movement, geologically, takes a long time to physically observe the effects. During this time, several chemical processes take place as the infiltrated zones tend to chemically achieve a reaction equilibrium forming other chemicals. On the other hand, Fluorine is leached and physically transported along with the recharge water into the main aquifers thus increasing Fluoride concentration. Apart from leaching effects, Thermal gases also play a big role in Fluoride deposition thus giving a proper reason why Fluoride concentration is much higher within the rift itself mainly around Lake Naivasha and other areas due these combined processes: Leaching and Thermal gases effects.

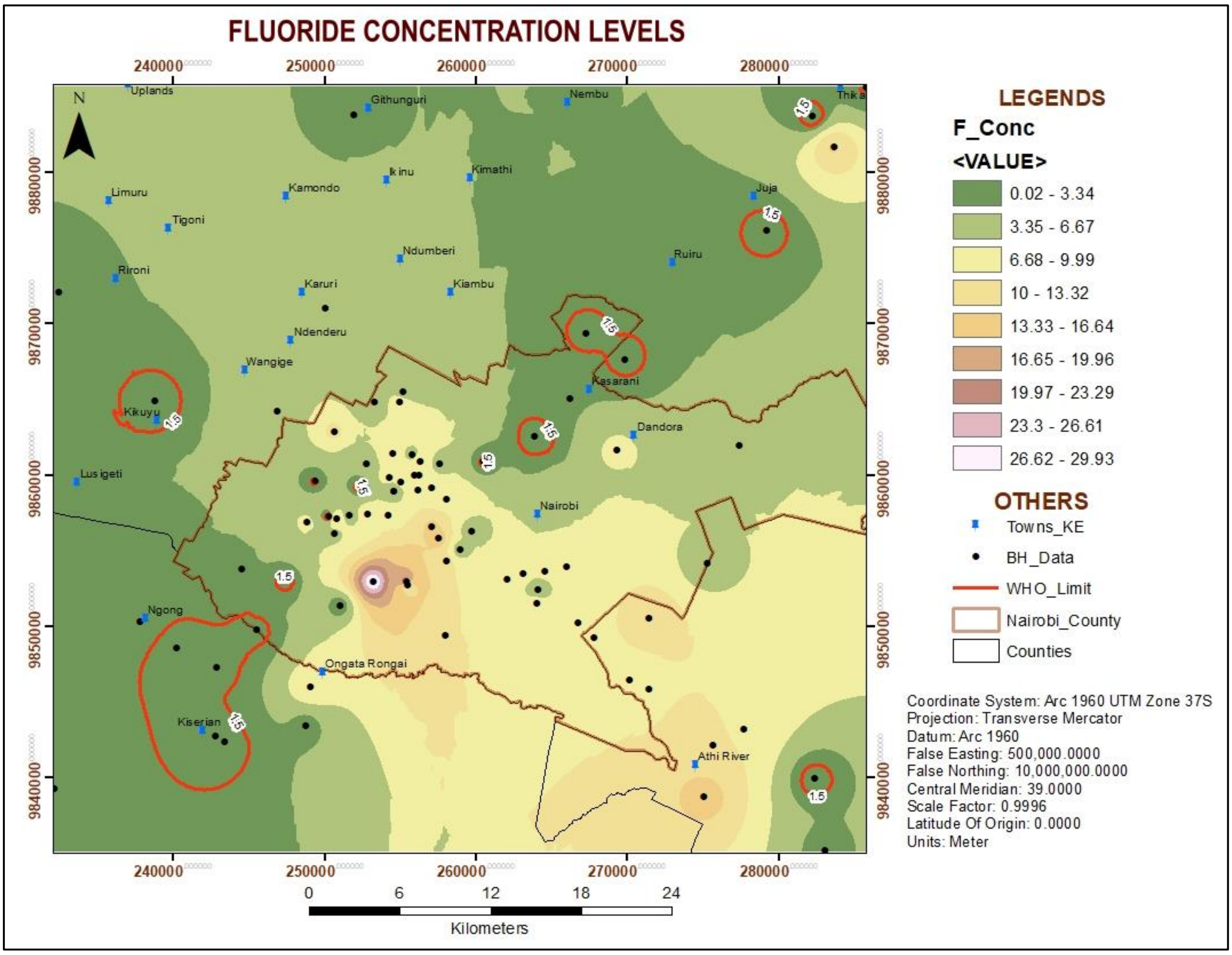


*Figure 4.1: Fluoride concentration levels in Nairobi and its Environments*

Easy movement of Fluorine from the volcanic rocks makes the chemical more concentrated in some parts of the area than others. From figure 4.1 above, a perfect representation of Fluoride concentration and Fluorine movement is represented showing an accurate alignment to the orientation and groundwater movement within this aquifer suite. The groundwater movement is generally from west to east with the aquifer suite being dammed by the impermeable Precambrian formation known to be the basement system to the east. Highest Fluoride concentration is these expected in these eastern parts of the aquifer.

The immediate interpolation map above outlines very few safe regions from Fluoride whose concentration fall below the maximum permissible limit as recommended by the World health Organization (WHO) which is 1.5mg/l. These regions include Kikuyu town, Kiserian town to some parts of Ngong' Township, secluded and patched points within Nairobi County: Githurai, and few points near Thika, Juja and Mua Hills. The rest of the areas are above the WHO limit to a tune of about 95 percent of the area under study.

Generally, the northern and the western parts of the project area shows a lower Fluoride concentration being the major recharge area to the aquifer suite as compared to the eastern aquiferous region. Langata area has recently recorded the highest Fluoride level of about 26mg/l and of course showing a continuous higher concentration to the eastern Athi River areas.

#### 4.1.1.1.1 Fluoride Risks

Excessive use of Fluoride above the healthy permissible limits comes with a lot of serious health risk issues. Some of which include:

1. Exposure to Fluoride during childhood, specifically for children below 6years or continual exposure to individuals above the 6years of age for a longer time normally tend to develop some white streaks on the teeth enamel which can later express itself as discoloration, a condition known to be **Dental Fluorosis**: from the effects of Fluoride. Feeding of infants from formula milk made from Fluoride water can also result into the same condition in equal measure. It is thus advisable to breastfeed and prevent the infants from using toothpastes and mouthwash products.
2. Skeleton fluorosis is basically a condition that hardens the skeletal bones making them even stiffer and non-flexible or just less elastic. This normally comes with a number of complications as the bones become thicker with more bone tissue accumulation that can result into fractures in little strain. It can also lead to impaired joint movements.
3. A more related to the bone strength condition is about the thyroid problems. This condition impairs secretion of vital hormones that can lead to depletion of calcium

within the bone structure and higher calcium concentration in the blood stream. Low calcium concentration in bones can cause fracture problems.

4. Further exposure of Fluoride to infant babies from after birth to about 12 years of age can also reduce the child's cognitive ability thus registering a lower IQ. Due to this, Fluoride was thus classified together with a number of arsenics i.e. lead.

Apart from these main health problems associated with Fluoride, other risks include skin complications, arterial calcification due to increased calcium in blood that results into high blood pressure and eventually heart failure, reproductive problems in women and perhaps bone cancer.

#### 4.1.1.2 Iron and Manganese

Iron and Manganese are two major metals that are normally detected as components during groundwater chemical analysis. Among all the metals found naturally within the earth's crust, Iron is the second most abundant with the most abundant being Aluminum. Just like some other minerals, Iron can also the dissolved by infiltrating and percolating surface water through different soils and rocks with different concentrations of Ironic deposits. Iron normally behaves differently depending on the chemical properties of the dissolving solvent. In most of the cases, the pH (Potential of Hydrogen) of the dissolving agent plays a critical role in Ironic behavior in that particular system.

Iron generally has a stable range of pH – Eh being a transition element in any aqueous solution. Any condition outside this range can to either a reduction or oxygenation of the same with both resulting into different products/compounds with varied physical and chemical characteristics.  This reaction has been termed as redox. In most of the affected areas, Iron confesses itself immediately after exposure of the groundwater to oxygen which immediately turns reddish proving formation of Iron oxides normally referred to as rust. This is the reason why most borehole waters turn red during abstraction from a borehole within the highly affected zones.

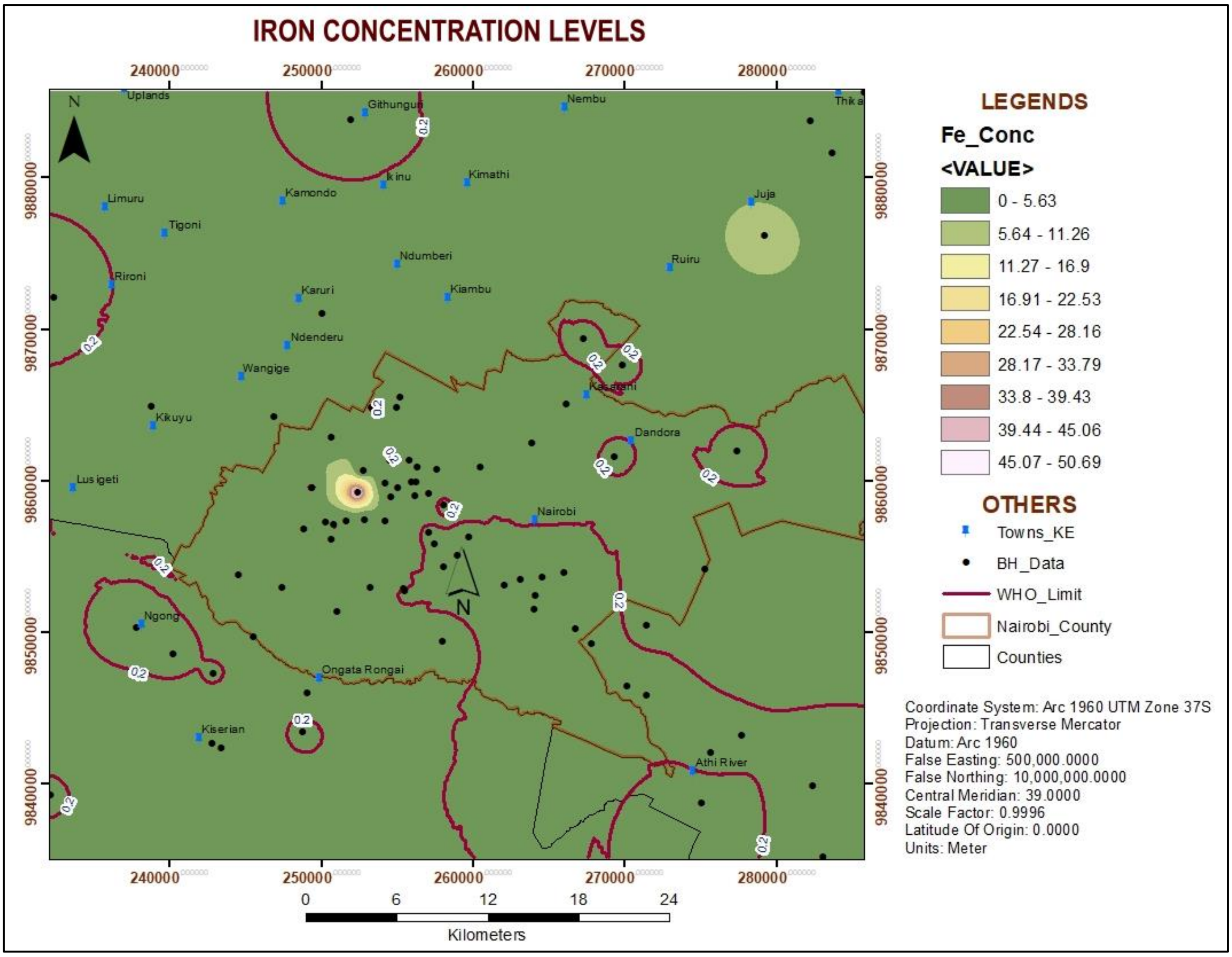


*Figure 4.2: Iron concentration levels in Nairobi and its environments*

It is also important to note that Iron can exist in two forms, as $Fe^{2+}$ or as $Fe^{3+}$ depending on the level of dissolved oxygen in the water. $Fe^{2+}$ is formed when oxygen concentration is below 1mg/L, a less reddish substance above which $Fe^{3+}$ is formed as a result of the continual exposure to dissolved oxygen in the water.

Figure 4.2 above provides a properly interpolated map regarding Ironic concertation levels within the area. Generally, most of the areas are affected with a number of secluded areas considered safe from iron being around Ngong' town, most parts of Dandora, parts of Rironi area towards Limuru and Githurai near Kasarani area. The highest concentration has been reported near Kilimani area towards Kikuyu recording a concentration to a tune of 7.9mg/L taking into account the acceptable limit of about 0.2mg/L as shown in the immediate map above, this value is subjected to an increase in adults and expectant mothers.

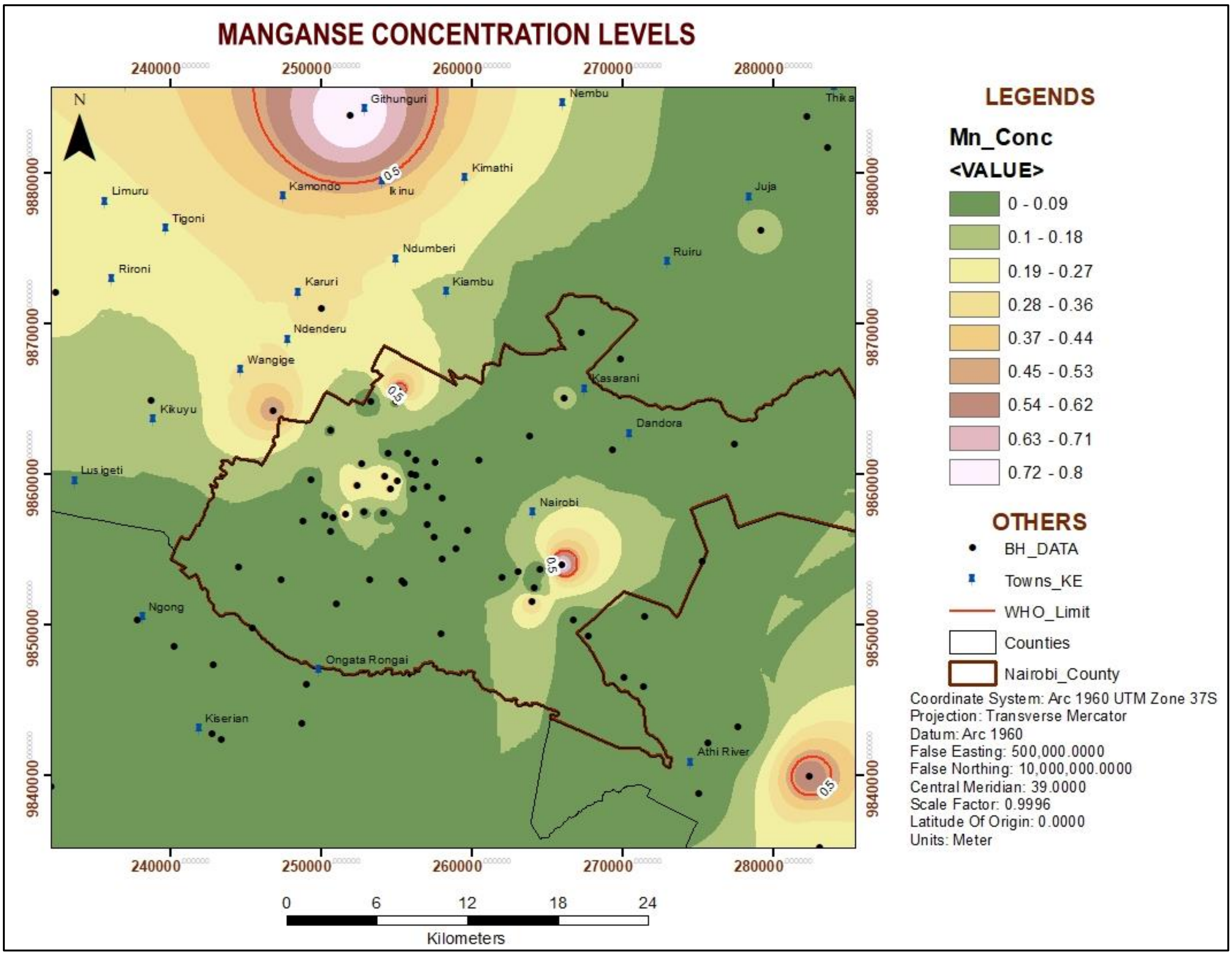


*Figure 4.3: Manganese concentration levels in Nairobi and its environments*

On the other hand, manganese is generally abundant and is naturally occurring in the earth's crust. Just like iron, manganese presence in groundwater is also controlled by the pH variations and oxidation – reduction reactions as water seeps, infiltrates and percolates through various geological formations. Manganese occurrence can also be described as ubiquitous thus can be found in soils, sediments and surface water apart from the groundwater. Manganese is a stable element in oxygen depleted water or in anaerobic conditions/systems. The concentration of this element is again dependent on the flow paths, recharge water chemistry and residence time apart from the lithological factors.

The Manganese standards as contoured in the map above is around 0.5 mg/l as set by the WHO and EU. Most of the area under study is generally safe proving a less manganese deposits within the geological structure of the study area except for secluded regions like Githunguri and Wangige, few points within Nairobi town and around Athi River.

#### 4.1.1.2.1 Iron Risks

Common stomach upsets are regular when iron is taken in large quantities. Expectant mothers can take in iron to a tune of about 120mg in a day while a normal adult person can take in a quantity of about 60mg. a genetic condition called hemochromatosis encourages even more absorption of iron than the normal people into the bloodstream resulting into an iron overload in people suffering from the condition. The long-term effect of this can be over accumulation of iron in many body organs including liver, pancreas and heart resulting into a vital failures and increased risk of cancers.

#### 4.1.1.2.2 Manganese side effects

Whereas manganese helps in accumulation of iron in the body that greatly fights Anemia, it's over accumulation can again course Anemia though it's one of the minerals that can rarely lack or over accumulate in a human body. Impaired cognitive ability can be observed in infants or teens in case of lack or too much manganese. Over accumulation into the Central Nervous System can also cause the mentioned birth defects. Several other risks come with a very low blood sugar sensitivity, impaired reproduction, significant changes in digestions and hormonal imbalances.

Lack of sufficient manganese in a body can worsen premenstrual syndrome (PMS) symptoms in viable women accompanied by low immunity and frequent sickness mostly for expectant women.

### 4.1.1.3 Sodium

Sodium is an odorless, highly soluble chemical element naturally found in groundwater. Apart from being odorless, sodium can be tasted under high concentrations of above 200mg/L by many people. It is one element that can be found in all the groundwater sources but for different concentration levels depending on the prevailing geology and the formation method. There are various sources of elevated sodium concentrations in groundwater which includes sodium bearing rocks and erosion of sodium salt evaporites deposits. Salt water from the oceans is majorly composed of sodium, this salt water can intrude into the underground water sources or aquifers increasing its concentration in these underground water storage sources within the coastal areas.

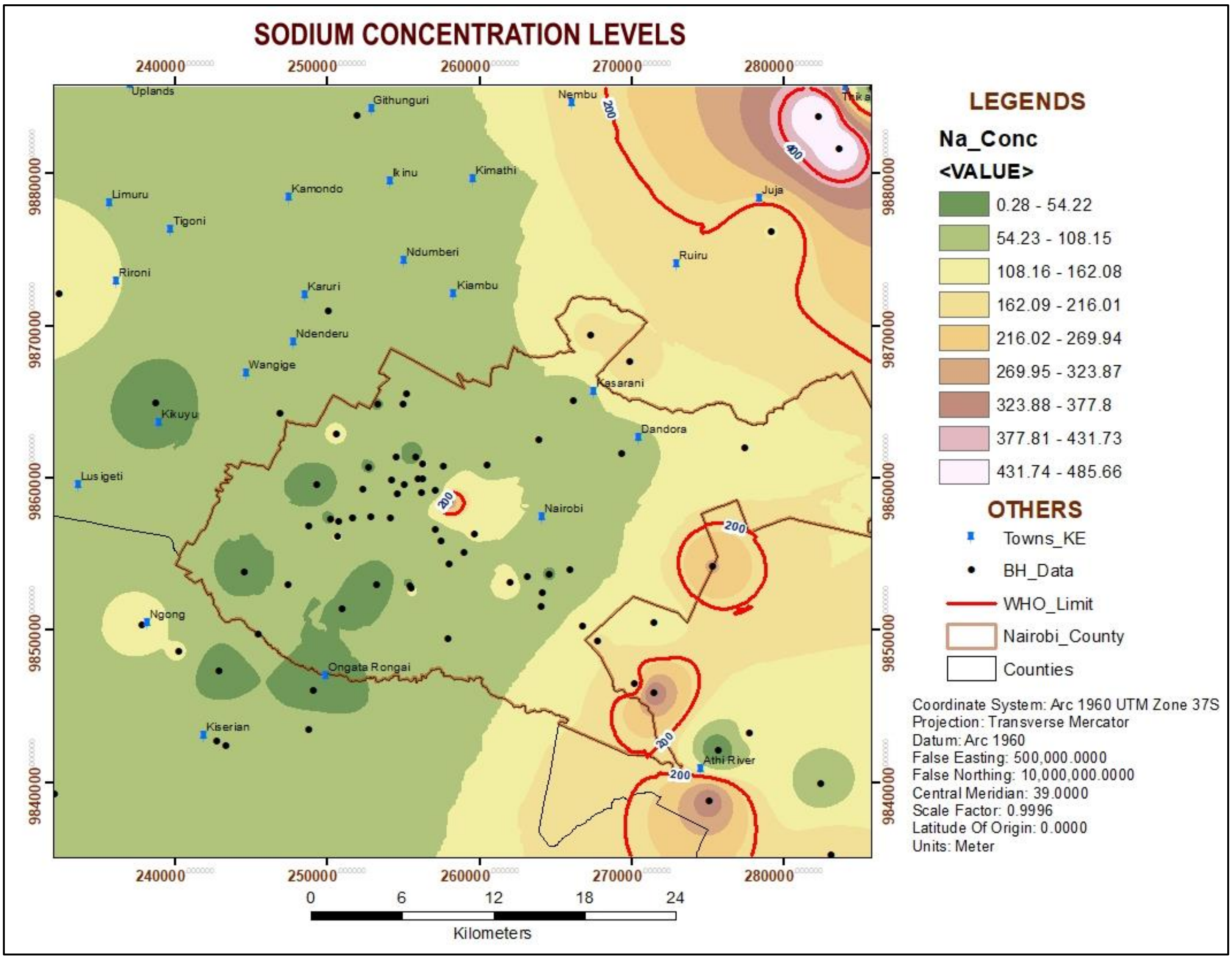


*Figure 4.4: Sodium concentration levels in Nairobi and its environments*

A larger population in the coastal region depends on shallow wells for fresh water, these wells are at risk of salt water intrusions resulting into elevated sodium concentrations. Sodium can also get into the groundwater through infiltration of surface water having dissolved a road salt. Other sources of sodium are chemicals normally used in irrigation, pollution agents including sewage effluent and leaching from sodium rich soils.

From figure 4.4 above, high sodium concentrations are observed on the eastern part of the area under study which of course can be attributed to the leaching effect related to the underground water flow generally from the eastern flanks of the rift to the eastern part as specified in the study area. The World Health Organization permissible limits is about 200mg/L. This value is surpassed in a number of secluded points within the study area including the northern and southern sections of Athi River, a zone from Thika extending to Juja area as shown in the immediate map above and a secluded point within Nairobi town.

These high sodium values are restricted on the eastern zone with the western hilly areas having concentration values of below 108mg/L.

#### 4.1.1.3.1 Sodium Risks

Though the essentiality of sodium in any balanced diet is undebatable, very high sodium concentrations can also cause stomach cancer and high blood pressure if not keenly monitored. Most of the kidney related diseases are attributed to high sodium levels in the blood stream. On the other hand, as more sodium accumulates in one's body, the body systems tend to retain more water in order to dilute the rising sodium levels. This in turn, increases the volume of the retained body fluid meaning more blood in the system. Since the blood has to be circulated throughout the body, the heart tends to overwork, a condition possibly resulting into a heart failure. This is a type of disease known as cardiovascular disease.

#### 4.1.1.4 Chloride

Chloride occurs in groundwater sources with accompanying cations forming compounds of Sodium, Potassium and Calcium. The tastable threshold of chloride in water is fully dependent on the accompanying cations. It can be dissolved in groundwater from various sources, some of which include precipitation and rock - water interactions among others. Chloride as a precipitate or as a solid – dry deposit, mostly around the coastal areas, originated from the volcanic gases and the marine aerosols. Due to this, huge chloride values are normally tested around these coastal regions and almost to a 0.1mg/L within the mid continental regions.

Apart from the sea water intrusion, common in most of the coastal regions, extreme chloride in ground or surface water can be as a result of major anthropogenic sources such as road de – icing salts in most of the temperate zones, massive use of industrially manufactured fertilizers (inorganic), subsurface landfill leachates from disposal of most of the cleaning products and food, effluents from huge septic tanks and treatment plants due to the bigger population solely dependent on these services. Water treatment through chlorination can also result into an increased chloride concentration, a situation highly prevailing within the study area. Other known anthropogenic sources are industrial wastes, irrigation drainage and livestock wastes including animal feeds and urine.

According to Feth, (1981), ocean water is the highly mineralized surface water source with chloride concentration to a tune of 19,000 mg/L. This results to the highest concentration of chloride and sodium ions in the atmosphere above the oceans due to atmospheric deposition, specifically, wet deposition. The figure 4.5 below shows chloride general concentration within the study area. Higher concentrations are spotted few kilometers south west of Thika and even higher concentrations within Athi River and its environments. Sagggerson, (1991) noted high chloride concentrations in aquifers intercalated within the Kapiti phonolites and is expected to have originated from the lacustrine sediments and not from the Kapiti phonolites. These higher levels are detected as shown from the immediate map below right from boreholes that abstract water directly from the lacustrine sediments near Athi River.

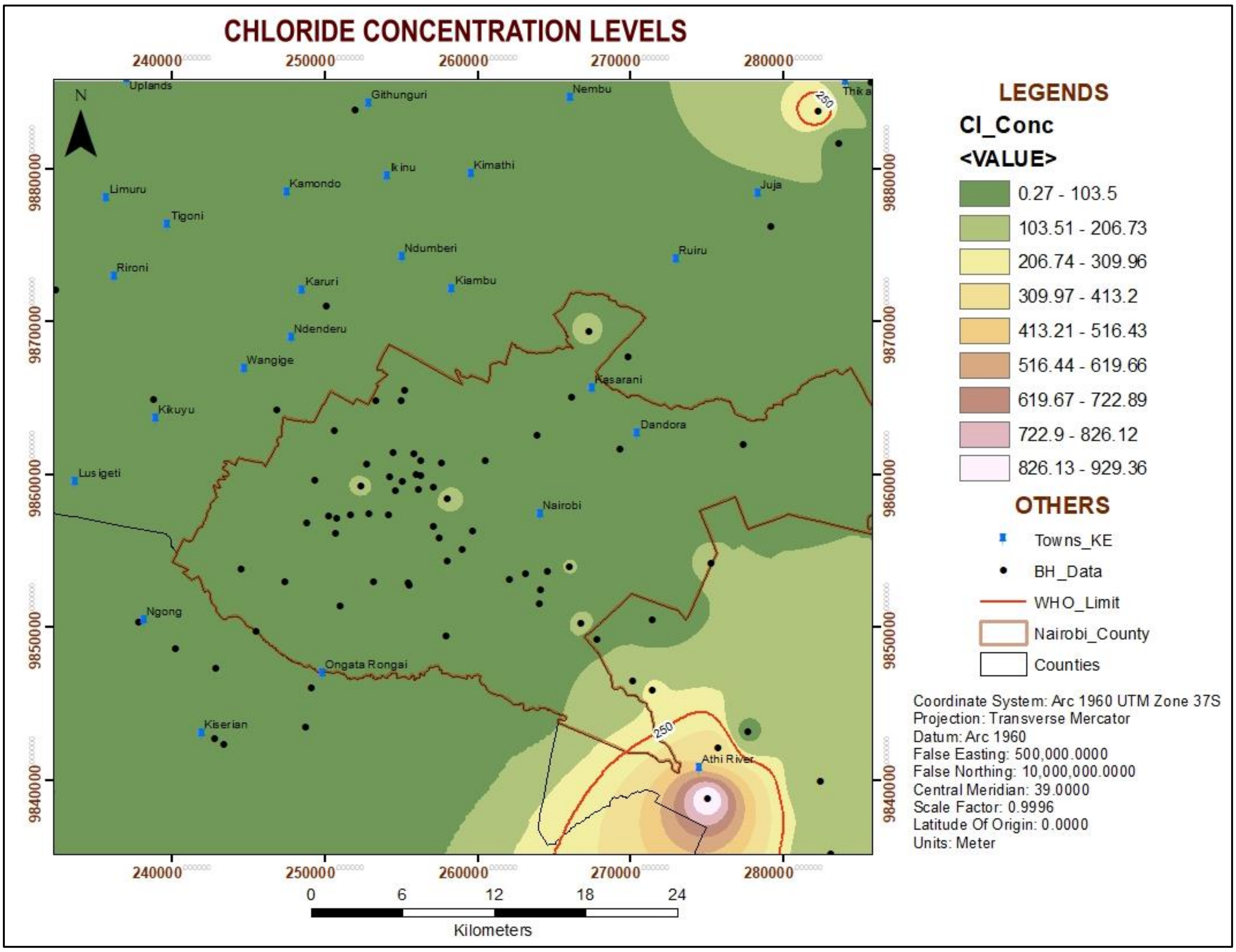


*Figure 4.5: Chloride concentration levels in Nairobi and its environments*

#### 4.1.1.4.1 Chloride Risks

In both the audio, visual and written media, chloride compounds (majorly sodium chloride) has been reported as a health hazard and a huge population ended up cutting it off completely which is even a bigger health risk as most of them ended up weakening their skeletal structure. The most consumed chloride compound is the known rock salt, usually sodium chloride used as a food flavor. Right proportion is advised in food in order to develop strong bones.

Since chloride is responsible for maintaining the body pH, very low chloride levels can result into a condition known as Alkalosis (a condition that develop in the body when acid levels drop too low and the body simultaneously loses substantial potassium through urine). This condition can be detected through low blood pressure and general body weakness as major symptoms. Lack or loss of these two minerals (chloride and potassium) can also lead to lose of muscle function control ability resulting into poor functioning muscle control in all related functions including swallowing, breathing and general body movements which if not addressed can lead to death on a long term.

#### 4.1.1.5 Nitrate

Nitrate originates from nitrogen which is the most abundant element in the atmosphere with nearly 80% of the air we breathe. This gaseous nitrogen finds its way into the soils and eventually into the groundwater and is found in various forms including $N_2$, $N_2O$, NO, $NO_2$, $NH_3$ through the nitrogen cycle. These listed gases do react readily with rain water to form Nitrate and ammonium ions in solution forms that finds their way into the groundwater after forming part of the substantial soil layer thus can be detected in wells and boreholes in excessive concentrations.

Nitrate sources in the atmosphere are as a result of various processes including lightning, photochemical oxidation majorly within the stratosphere, ammonium oxidation and microbial reactions within the troposphere apart from fossil fuel combustion. Many scientific studies have pointed groundwater deterioration as a result of high nitrate levels majorly out of anthropogenic sources. Maximum contaminant levels have significantly been exceeded majorly in aquifers lying below agricultural dominated watersheds. The natural nitrogen fixation into the soil is a natural process with a self-correction mechanism and requires special conditions in order to take place and in minimal quantities. Human activities including earlier mentioned active irrigation, human (animal) waste disposal, food industrial waste and some of the polyresin facilities.

The figure 4.6 below shows Nitrate distribution and concentration levels within Nairobi and its environments. The WHO acceptable and permissible Nitrate levels is around 50mg/L, a figure that triples the maximum detectable concentration levels within the study area with the highest concentration not exceeding 14.0mg/L.

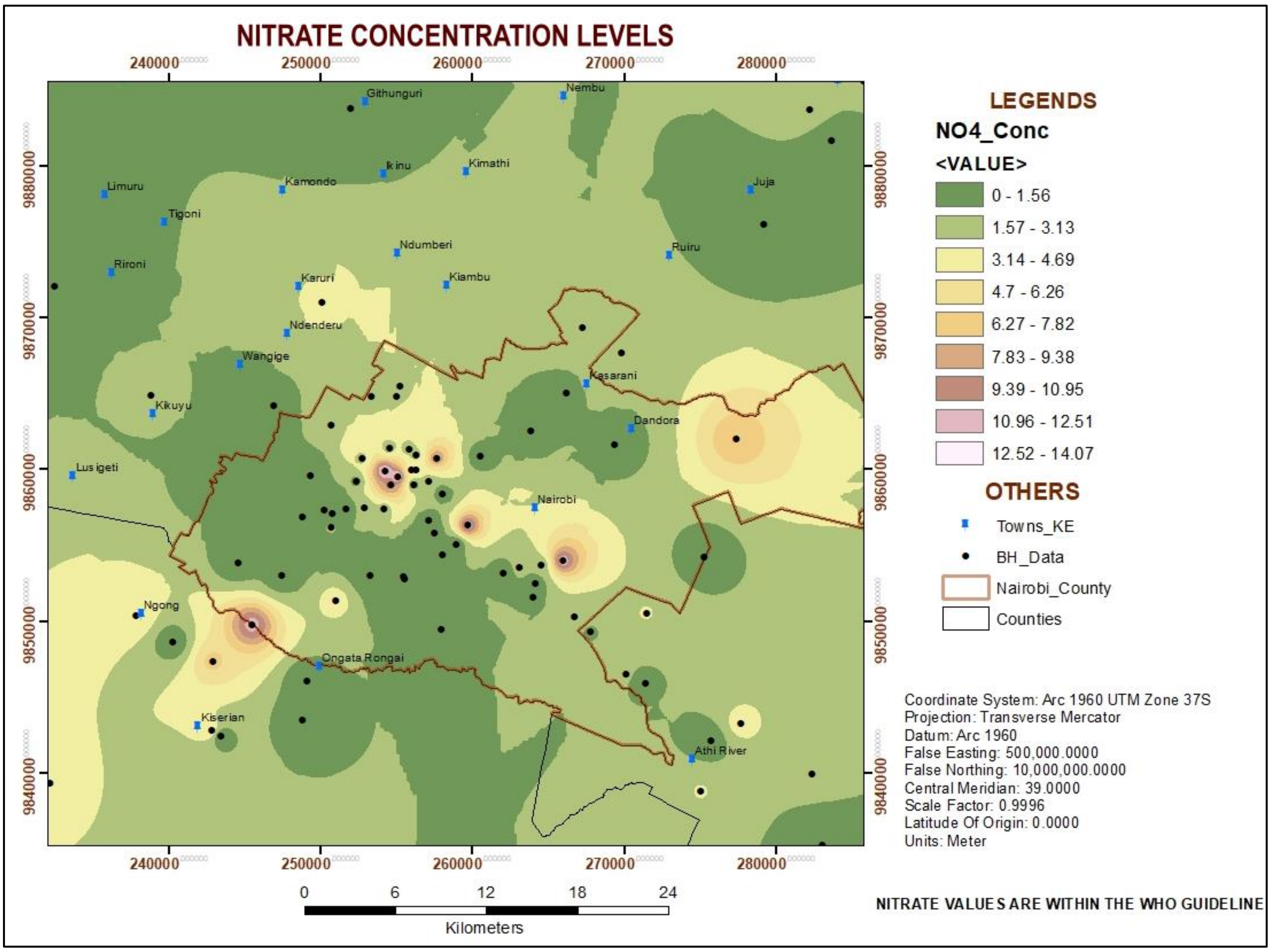


*Figure 4.6: Nitrate concentration levels in Nairobi and its environments*

Serious Nitrate side effects are not expected within and around the project area. Nitrogen already fixed into the soil through nitrogen fixing bacteria or any other process can be converted back into the atmosphere in an elemental form through denitrification, a process that takes place in the soil and involves chemical reduction of Nitrates. Ammonium is one of the compounds that can be easily oxidized into Nitrates through a nitrification process. The nitrogen in the ammonium ion is thus released back into the atmosphere in gaseous elemental form.

#### 4.1.1.6 Sulfate

This is a chemical mainly found in air, soils and water (both ground and surface). Due to its high solubility, it readily dissolves to form part of the both the ground and surface water sources. It has been detected in high concentrations majorly in surface water sources. Fossil fuel combustion releases substantial amount of sulfur into the atmosphere which later gets oxidized to form sulfates and eventually gets deposited through precipitation or dry deposition into the ground. Sulfate is known to be slightly mobile thus source tracing through groundwater becomes difficult because of this mobility.

The behavior of sulfur in groundwater is not uniform due to its presence in a variety of oxidation forms. There are so many sources of sulfate apart from fossil fuel combustion. One of the natural geological sources include gypsum. This a sulfide mineral that can be oxidized in the presence of oxygen to form sulfates during the mining activity. Before active mining were adapted, important source of sulfate was massive atmospheric fallout. Other sources of sulfur include decomposition of organic materials, agricultural fertilizers and other natural sources such as volcanic activity.

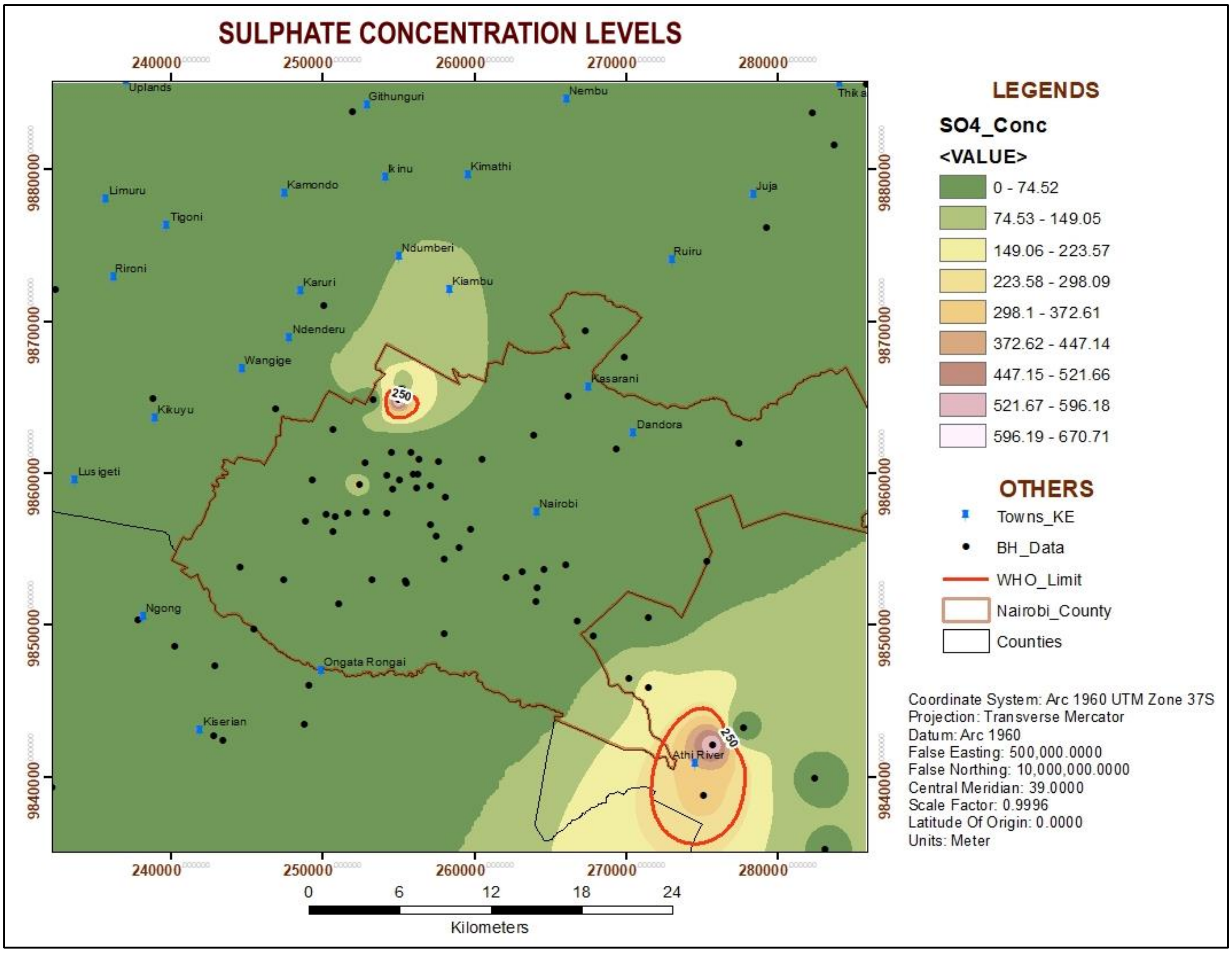


*Figure 4.7: sulfate concentration levels in Nairobi and its environments*

Sulfate distribution within the study area is generally restricted to the south eastern side of the project area around Athi River as shown in immediate map above (figure 4.7). Its mobility can thus be visualized bearing in mind the groundwater movement within the project location. The aquifer is recharged from the north western part and is expected to be transmitted towards the south eastern area around Athi River where the aquifer is laterally confined. Higher concentrations around Athi River is thus expected due to the higher sulfate mobility.

#### 4.1.1.6.1 Sulfur side effects

Sulfur has been reviewed as a safe substance when applied on the skin on a short term up to about 8 months for products with sulfur concentrations of about 10%. Above this period, some individuals might begin showing an allergic reaction that might make the skin extremely dry. Enough evidence is still needed to prove whether taking sulfur by mouth is dangerous, but it has been observed to cause lots of diarrhea when taken directly through the mouth.

### 4.1.2 Individual Aquifer Analysis

In order to accurately analyze the individual aquifers within the Nairobi aquifer suite, specific chemical data has to be utilized. The general hydrogeology of the Nairobi area was massively and accurately mapped by Gevaerts, 1964 and Saggerson, 1991. The data collected from the Ministry of Water: Water Resources Department shows that a number of variables including Total dissolved solids, Total Hardness, Alkalinity, Chlorides, Sulfates and other chemicals were within the WHO human consumption limits except for Fluoride content which is in excess of the maximum permissible limits of 1.5ppm within a very large area. This data has worsened over time in that a number of chemicals are continuously increasing in content within these aquifers, a condition that has been thoroughly monitored and sources suggested from both natural and anthropogenic regarding the Geology of Nairobi area and population grown, not forgetting the activities that comes with the growth.

From the literature (**CHAPTER TWO**), Sagggerson, (1991) gives a hint about higher concentrations of both sulfate and chloride in water from the lake sediments intercalated within/above the Kapiti Phonolites. It is believed that the chemicals are derived from the lacustrine sediments rather than the phonolites, a conclusion that was made after detailed chemical analysis of the phonolitic formation known to occur above the Basement System. These chemicals show a wide variation in concentrations majorly due to recharge variations among other factors. Recharge water leaches soluble minerals or due to rise in water table, the chemicals can easily increase the concentrations in less concentrated zones or dilute a highly mineralized zone as a result of the interaction.

The Nairobi aquifer suite is a compilation of a regionally multi-layered aquifers between the volcanic flows that originated from the Southern Aberdares, Kikuyu Escarpments and Ngong' Hills dipping gently above the ancient Athi lake basin (a pre-tertiary formation) being terminated by the resistant Basement System around the eastern Lukenya Hills.

Initially, all the aquifers within this suite were productive right from Kerichwa Valley series which is almost entirely on the surface in most parts including Karen area. There is a patched aquifer above the Nairobi phonolite which is also characterized by less productivity in most areas. The main aquifers thus being the Athi Series: specifically, the

Upper Athi aquifer being the most productive due to its high confined nature and high transmissivity and storage capacity properties. The Middle Athi series is characterized by a lot of clays that blocks the free water movement thus becoming less productive. The Lower Athi series has also been highly investigated and described as an aquiclude with very minimal transmissivity properties thus cannot sustain a productive borehole for long. The lake sediments intercalated within the Kapiti phonolites and below the Kapiti phonolitic formation right above the basement system is also a very productive aquifer confined by the phonolitic formation and the highly resistant basement system. This aquifer is widened further by the active weathering of the upper contact between the basement complex and the aquifer itself making the metamorphic formation to be a little productive at the top zone.

The immediate short description above proves that the Nairobi population at this time depends on the two main aquifers: Upper Athi Series and the Aquifer between the Kapiti Phonolites and the basement system being that the formerly highly productive Kerichwa Valley Aquifer got depleted and rendered unproductive. The following chemical data was obtained from boreholes that specifically or majorly abstract water from the aquifers in question in order to minimize some of the errors.

#### 4.1.2.1 Kapiti Phonolite and Basement contact Aquifer

The Kapiti phonolite came as a series of eruptions that covered a very irregular and highly eroded surface above the major metamorphic Basement formation thus intercalating a number of the sediment layers that are currently productive. This is a main aquifer and sustains almost 90 percent of the boreholes within the eastern zone right from Syokimau area through Athi River almost up to Lukenya hills extending to areas of Isinya.

Syokimau area shows a complex unexpected basement anomaly as shown in the immediate figure below. A resistant basement dome is predominant in this area and has led to a high number of dry boreholes around this area. The boreholes done a few kilometers west of this dome are productive depending on the distance from the dome itself facing the recharge direction. The Nairobi phonolite is exposed at the top followed by an Upper Athi series then the Lower Athi Series that is underlain by the Kapiti phonolitic series then the Basement system. From the old test boreholes shown in the immediate figure below, dry boreholes are restricted to the eastern side of the dome where the recharge water is completely blocked by the unexpected dome shaped formation. The chemical analysis is not inclusive of the chemicals without the WHO (World Health

Organization) or Local acceptable/permissible limits due to their zero effect on human health.

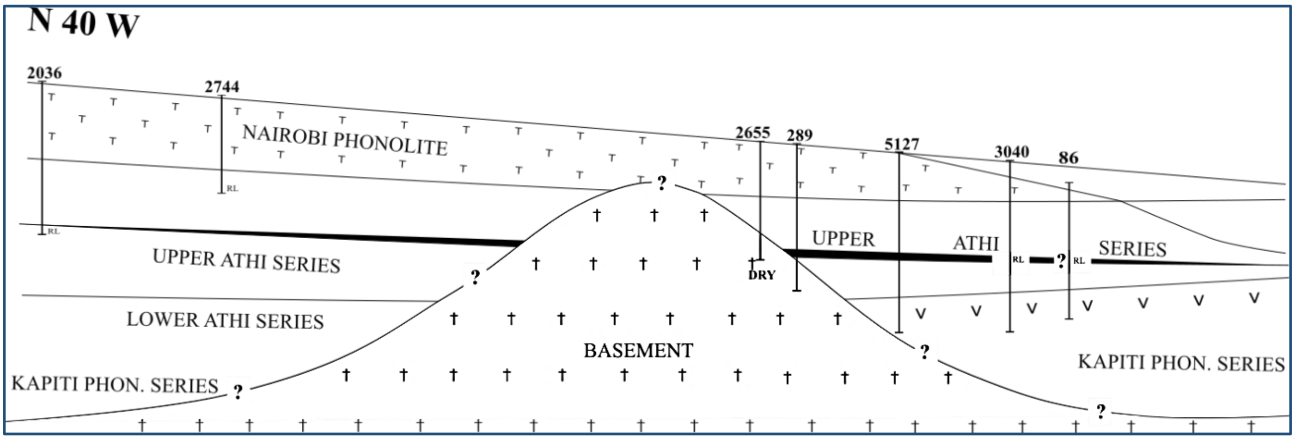


*Figure 4.8: Syokimau Mozambiquan Basement dome cross-section (Adapted from Gevaerts, 1964)*

Three sampled boreholes plotted in figure 4.9 below abstract water majorly from this aquifer (Contact between basement and the Kapiti series). The boreholes selected had the needed chemical analysis enough to compile the discussed data below. The chemical properties of the selected boreholes are represented in the immediate table below.

*Table 4.1: Sampled boreholes chemical properties for the Kapiti – Basement contact aquifer*

| | **C 16021** | **C 20914** | **C 22329** | **Avg.** | **WHO Guideline** |
|---|---|---|---|---|---|
| **Chloride** | 45 | 75 | 70 | 63.33 | 250 |
| **Sulphate** | 350 | 31.7 | 10 | 130.57 | 250 |
| **Nitrate** | **ND** | 0.38 | 2.3 | 0.89 | 50 |
| **Fluoride** | 13.3 | 9 | 11.6 | 11.30 | 1.5 |
| **Sodium** | 105.7 | 186.53 | 117.3 | 136.51 | 200 |
| **Manganese** | **ND** | 0.01 | 0.022 | 0.01 | 0.5 |
| **Iron** | 0.2 | 0.01 | 0.1 | 0.10 | 0.2 |
| **Calcium** | **ND** | **ND** | **ND** | - | **NO GUIDELINE** |

*Table 4.2: Sampled boreholes properties for the Kapiti – Basement contact aquifer*

| BH. No | Name | TD(m) | WSL(m) | WRL(m) | Q($m^3$/hr) | PWL(m) |
|---|---|---|---|---|---|---|
| **C 16021** | Syokimau (Kenya) | 220 | 200 | 124.5 | 9.0 | 132.67 |
| **C 20914** | Syokimau (Machakos) | 200 | 152 | 108.99 | 19.3 | 121.15 |
| **C 22329** | Mlolongo | 243 | 129 | 114.45 | 18.0 | 160.62 |

All the three boreholes have been drilled up to the basement system with the main water strike levels in each case being 129m, 152m and 200m for C 22329, C 20914 and C 16021 respectively. The borehole depths also range from 200m to 243m with C 22329 being the deepest and C 20914 being the shallow borehole among the three. Attached borehole log for C 20914 indicates a weathered biotite gneiss grading to fresh at the bottom of the well with an aquiferous layer being at the top around 164m

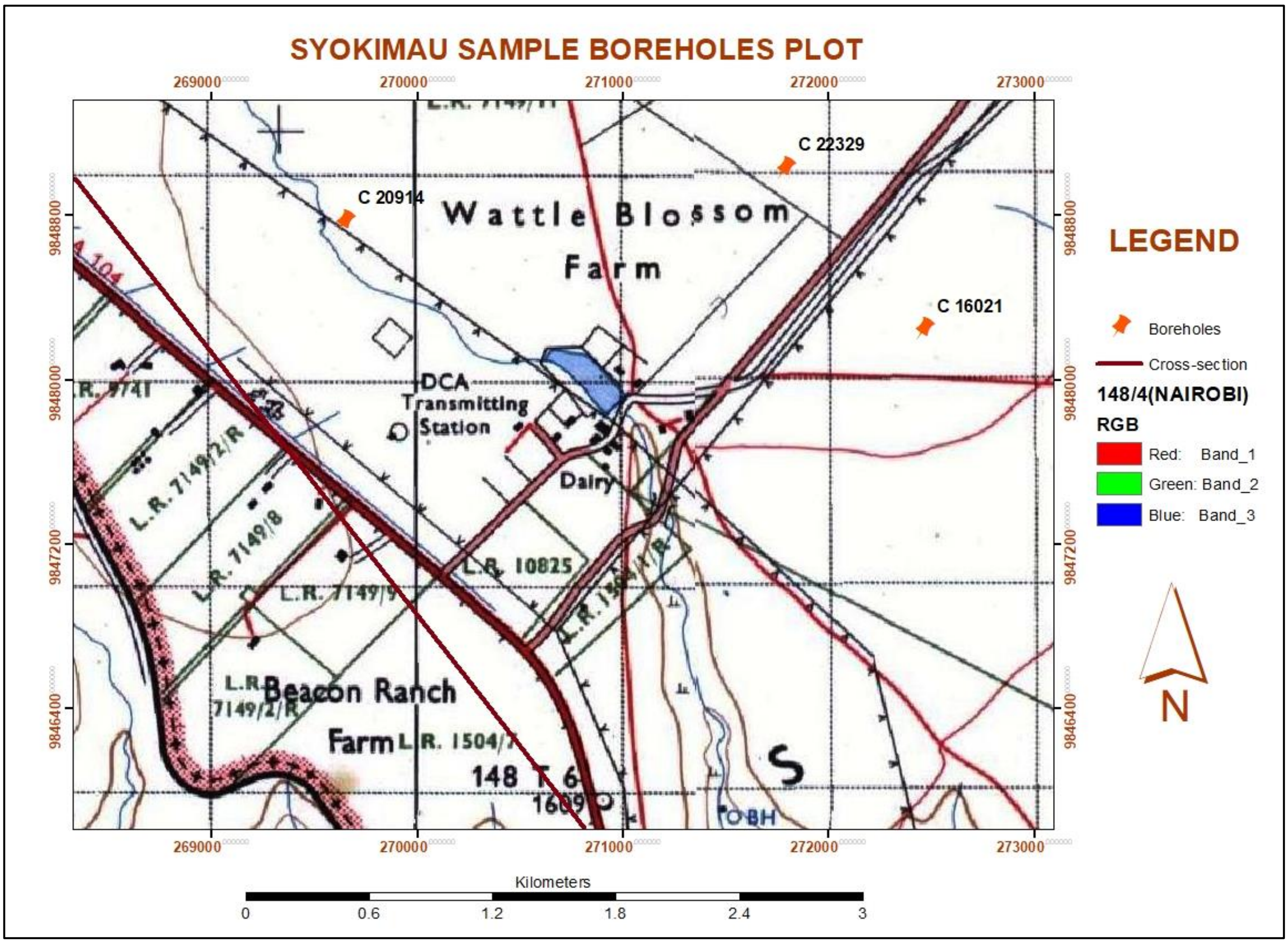


*Figure 4.9: Syokimau boreholes sample plot (Topo sheet number 148/4: Nairobi)*

Chloride concentrations as observed from figure 4.10 to be way below the WHO and local authority guideline with the highest and the lowest being 75mg/l and 45mg/l respectively averaging at 63.33mg/l. chloride side effects are thus not expected for boreholes abstracting most of their water from this aquifer.

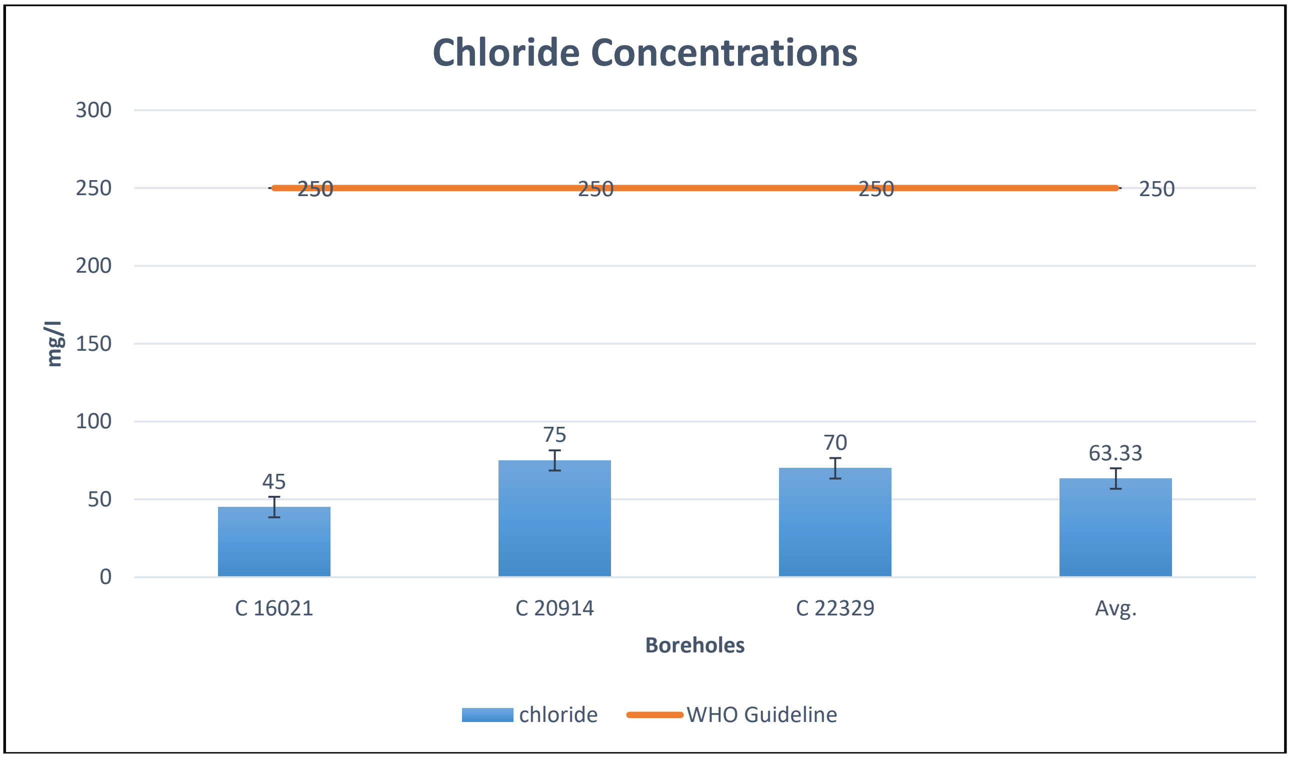


*Figure 4.10: Kapiti Phonolite – Basement contact Aquifer Chloride concentrations*

Sulphates (Sulfate) is averagely below the WHO Guideline but secluded areas have concentrations way above the 250mg/l limit as shown for borehole C 16021 below. This is a representation of the secluded high Sulphate zones shown in figure 4.11 below. Excessive consumptions are thus expected in some areas for borehole utilizing this aquifer.

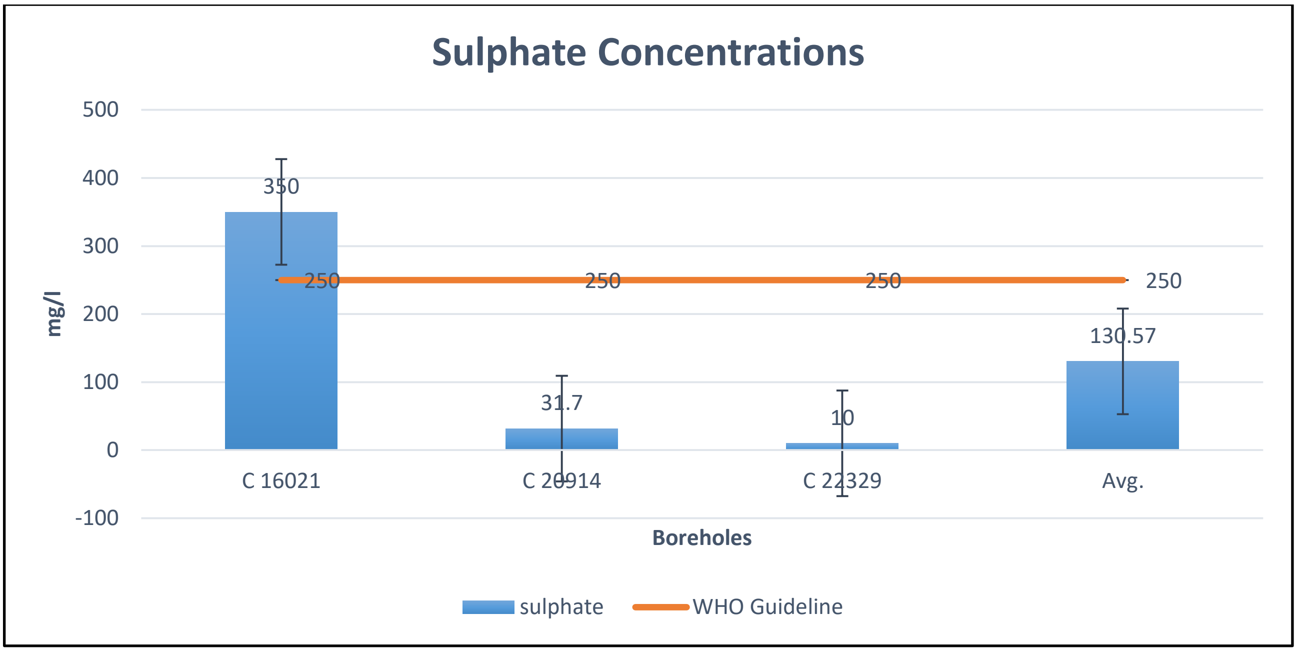


*Figure 4.11: Kapiti Phonolite – Basement contact Aquifer Sulphate concentrations*

Fluoride has been the major water quality problem for most boreholes in the Athi Basin. High concentrations followed by worse side effects contribute more for human health deterioration for those that solely depend on the borehole water. Most of the previous studies, as discussed earlier hints at a sole source being the intercalated lake sediments within and below the Kapiti phonolites. Borehole C 16021 has the highest concentration of about 13.3mg/l with the three boreholes averaging at 11.30mg/l.

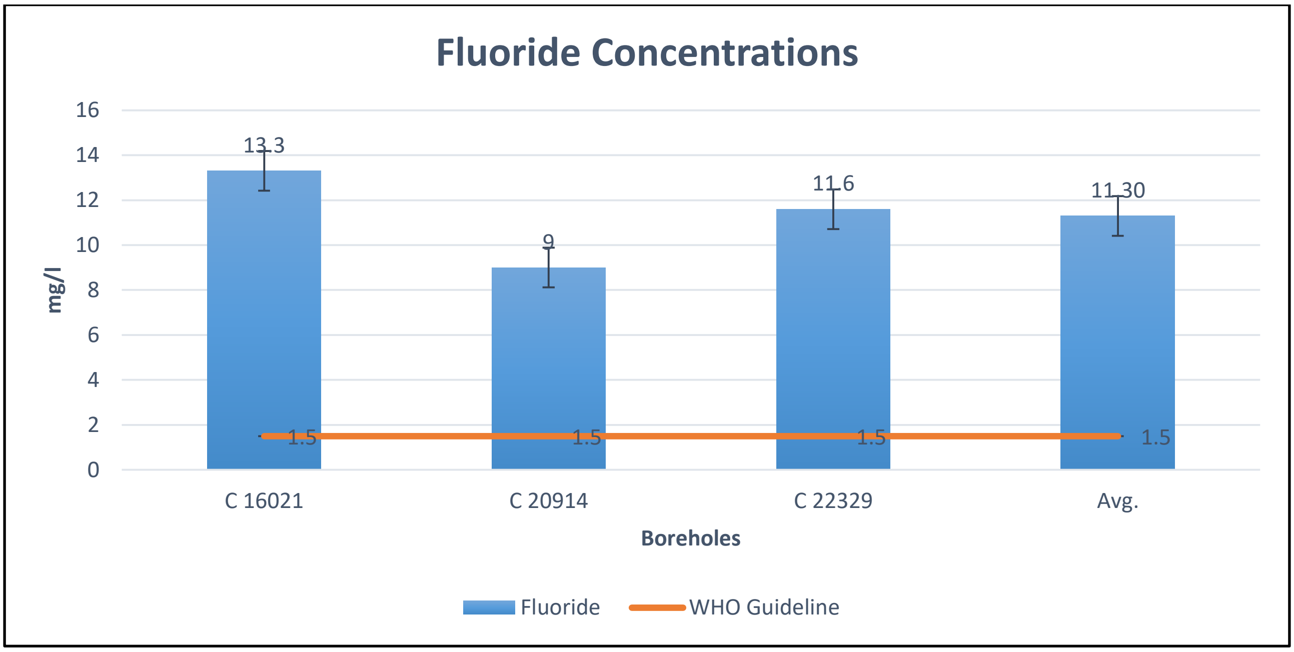


*Figure 4.12: Kapiti Phonolite – Basement contact Aquifer Fluoride concentrations*

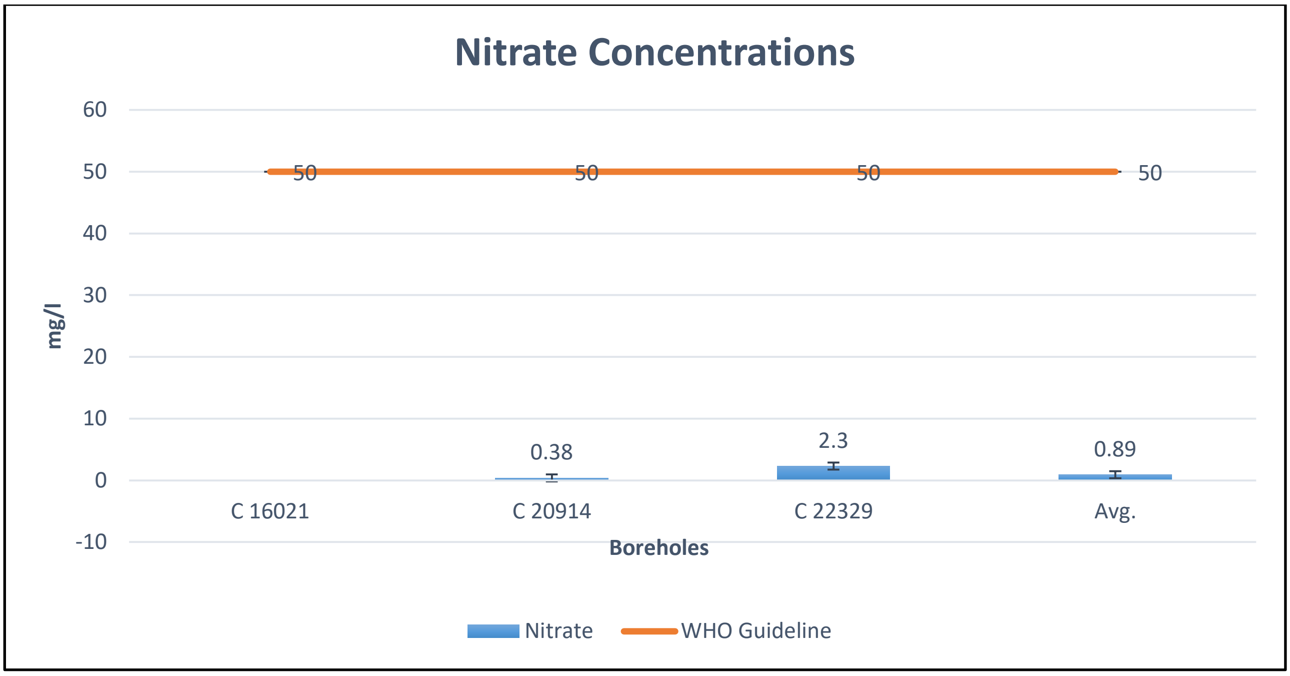


*Figure 4.13: Kapiti Phonolite – Basement contact Aquifer Nitrate concentrations*

Figure 4.13 above illustrates nitrate concentration within the aquifer in question. Though nitrates have very minimal side effects, its concentration within this aquifer is way below the acceptable/permissible limits with the highest concentration being for borehole number C 22329 with 2.3mg/l: 25 times less than the WHO limits.

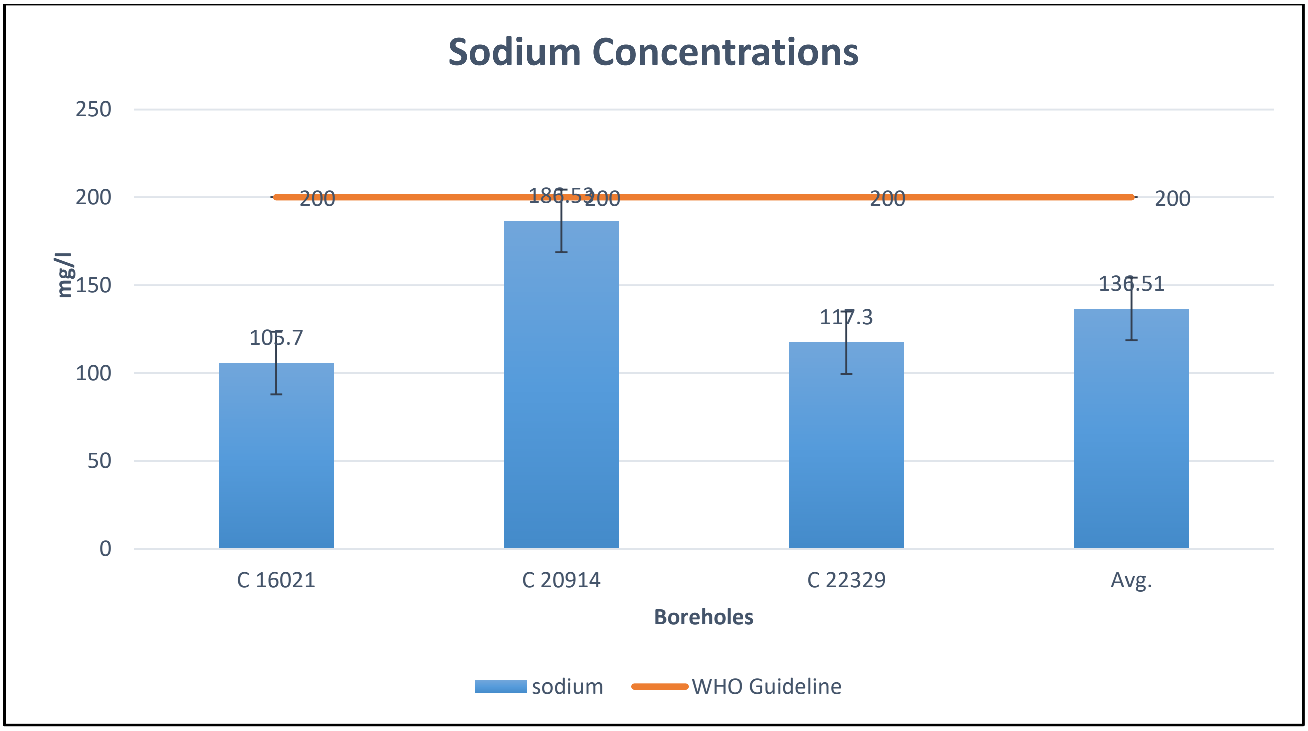


*Figure 4.14: Kapiti Phonolite – Basement contact Aquifer Sodium concentrations*

Sodium concentrations for the three sampled boreholes average at 136.51mg/l with the highest being at 186.53mg/l for borehole C 20914. This the right proportion regarding the optimum levels required by the human body for healthier stronger bones. From figure 4.14 showing the general sodium distribution, higher concentrations are expected to the Far East and north east of the current site beginning from Juja to Thika area. These are zones that are currently, due to the depletion of the upper aquifers, abstract water from these deeper aquifers. Thika area having a very simple with the Upper Athi series at the top followed by the Middle and the Lower Athi tuffeceous series with the Kapiti phonolite and Basement system at the bottom.

According to the Geology of the Basement system and the Kapiti phonolites, iron is one of the minerals that are least expected in this aquifer apart from the Nitrates and Manganese. The highest concentration detected for both the sampled boreholes is at the optimum permissible limit which stated at 0.2mg/l with the lowest being detected below 0.01mg/l. The general Iron concentrations shows very high levels around Dagoretti area towards Wangige and Kikuyu regions: areas whose upper aquifers are highly productive and don't go beyond the Upper Athi Series due to drilling related challenges.

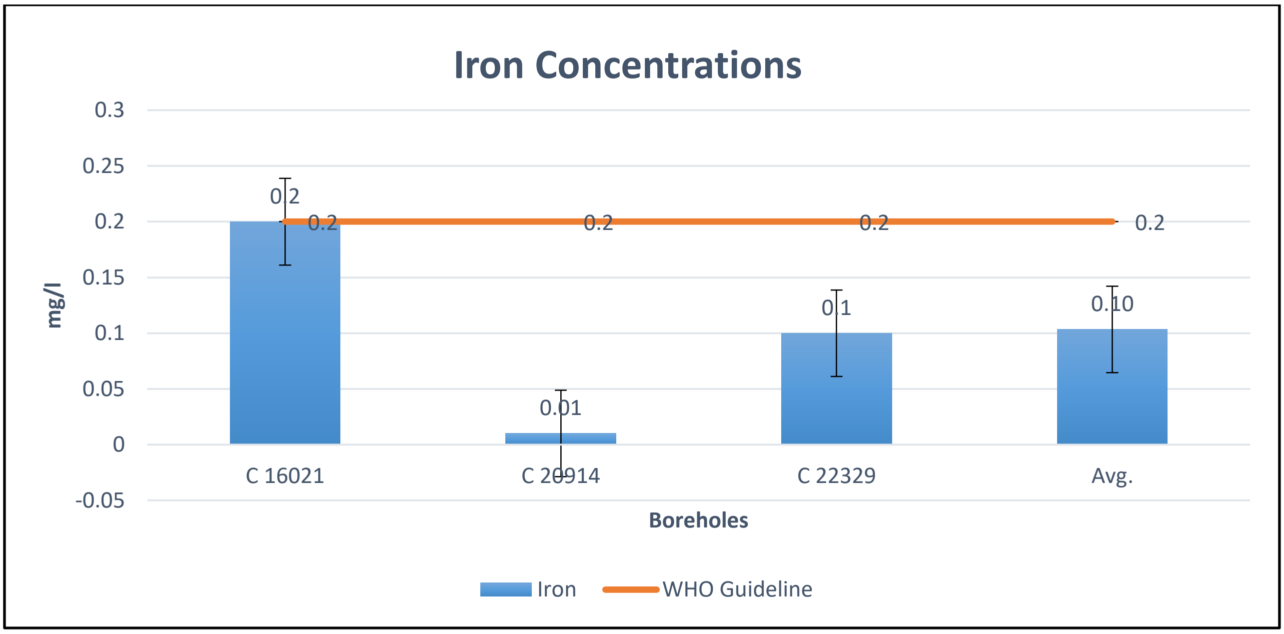


*Figure 4.15: Kapiti Phonolite – Basement contact Aquifer Iron concentrations*

Manganese is part of the chemicals that is needed is very small quantities in a human body to an optimum of about 0.5mg/l. the chemical data from the sampled boreholes hardly go past the 0.022mg/l mark detected at borehole C 22329. Since it's not a basic mineral in the body, normal consumption of a borehole water can in this region is enough to obtain the required levels.

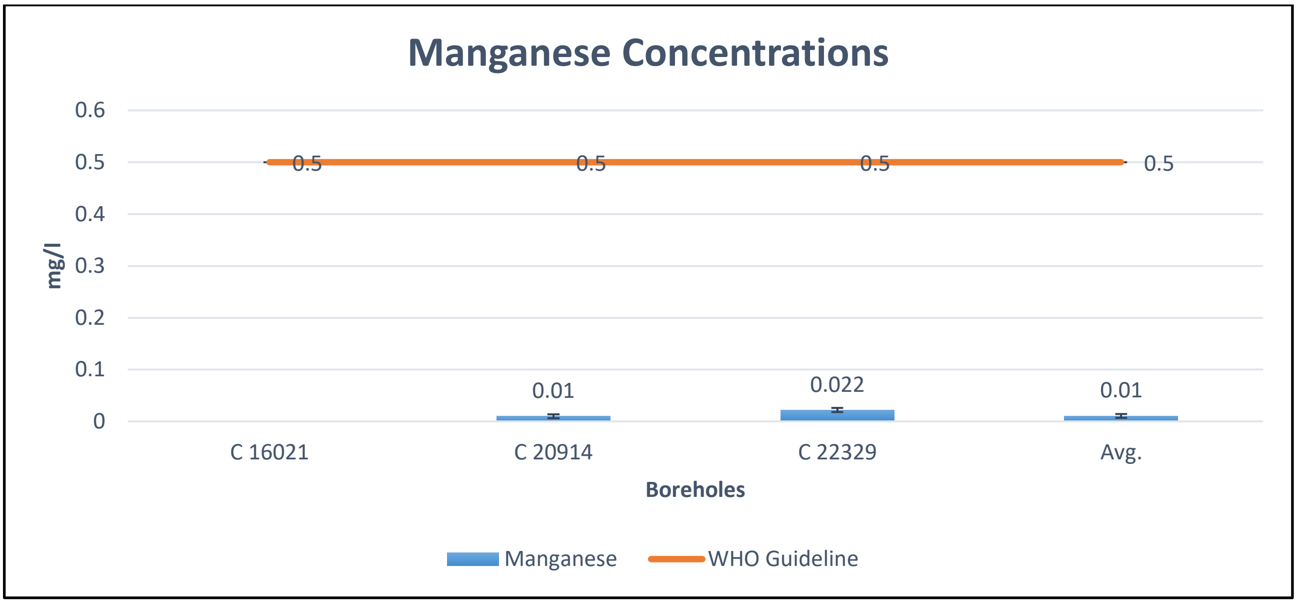


*Figure 4.16: Kapiti Phonolite – Basement contact Aquifer Iron concentrations*

#### 4.1.2.2 Lower Athi series

This comprises of the lowest beds within the Athi series and is essentially composed of fine grained tuffs and majorly bentonite clays together with mild scoriaceous agglomerates and gneiss flakes. Previously, economic investigations of the bentonite clays, characteristic of the Lower Athi series, a chemical investigation was carried out as mentioned by Saggerson, E. P., (1991).

*Table 4.3: Chemical analysis of bentonite clay: Sample taken near Athi River (Adapted from Saggerson, 1991)*

| | Sample 307 | WHO Guideline |
|---|---|---|
| **Chloride** | Not Tested | 250 |
| **Sulphate** | Not Detected | 250 |
| **Nitrate** | Not Tested | 50 |
| **Fluoride** | Not Tested | 1.5 |
| **Sodium** | 3.00 | 200 |
| **Manganese** | Not Detected | 0.5 |
| **Iron** | Not Detected | 0.2 |

Due to the clayed nature that forms the major component of the Lower Athi Series, it hardly sustains a borehole. Geologically, the layer thins to the eastern part of the study area gaining more grip on the Kapiti phonolites. Bentonites are characterized by good binding properties thus reducing groundwater movement within this layer almost to zero transmissivity. Boreholes done within this western edge of the Lukenya hills has to be drilled past the Kapiti phonolites in order to abstract water at the contact zone between the Mozambiquan basement system and the Kapiti phonolites.

#### 4.1.2.3 Middle Athi Series

Although the upper contact of the Athi tuffs (Upper Athi Series) and the Nairobi phonolite is exposed to the south eastern part of the study area, the lower contact (Lower Athi series) is barely exposed sandwiching the Middle Athi series. Occasionally, bentonitic clays are encountered beginning about 20meters below the base of the Nairobi phonolites. This is characteristic of the little clays often encountered within the Upper Athi series. Generally, the Upper Athi series entails lots of sandy sediments, tuffs: some of which are well welded and a bit of clays. Due to the interception of the Mbagathi trachyte into this formation, lots of these lavas might be found within the Upper Athi series together with stray basaltic components as exposed near Utawala area: Nairobi. The Middle Athi on the other hand is highly characterized by basaltic flows, basaltic sands and conglomerates.

In order to obtain a borehole with direct connection to this aquifer, geological controls were highly considered. A stretch right from Thika town through Mogumoini up to Mukurwe was considered ideal. The area portrays a simple geology having a thin unproductive layer of the Upper Athi series at the top to a maximum depth of about 50meters as shown in the Figure 4.17 below. This is immediately underlain by the productive Middle Athi series (Highly productive at the bottom) and terminates at depths below 200meters. Boreholes C 1601 and C 1650 are drilled to 200m and 143m respectively abstracting water from the main aquifer within the Middle Athi series. In this area, boreholes done to a maximum of 250meters solely depend on the Middle Athi series. A single borehole data was sampled for a detailed chemical analysis of the Middle Athi since a bigger population depend on the same aquifer.

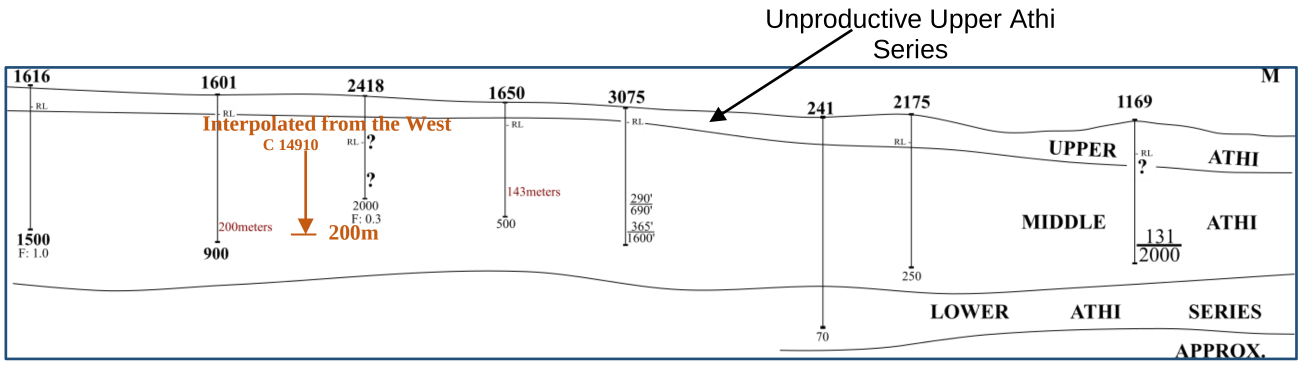


*Figure 4.17: Thika – Mugumoini geological cross-section (Adapted from Gevaerts, 1964)*

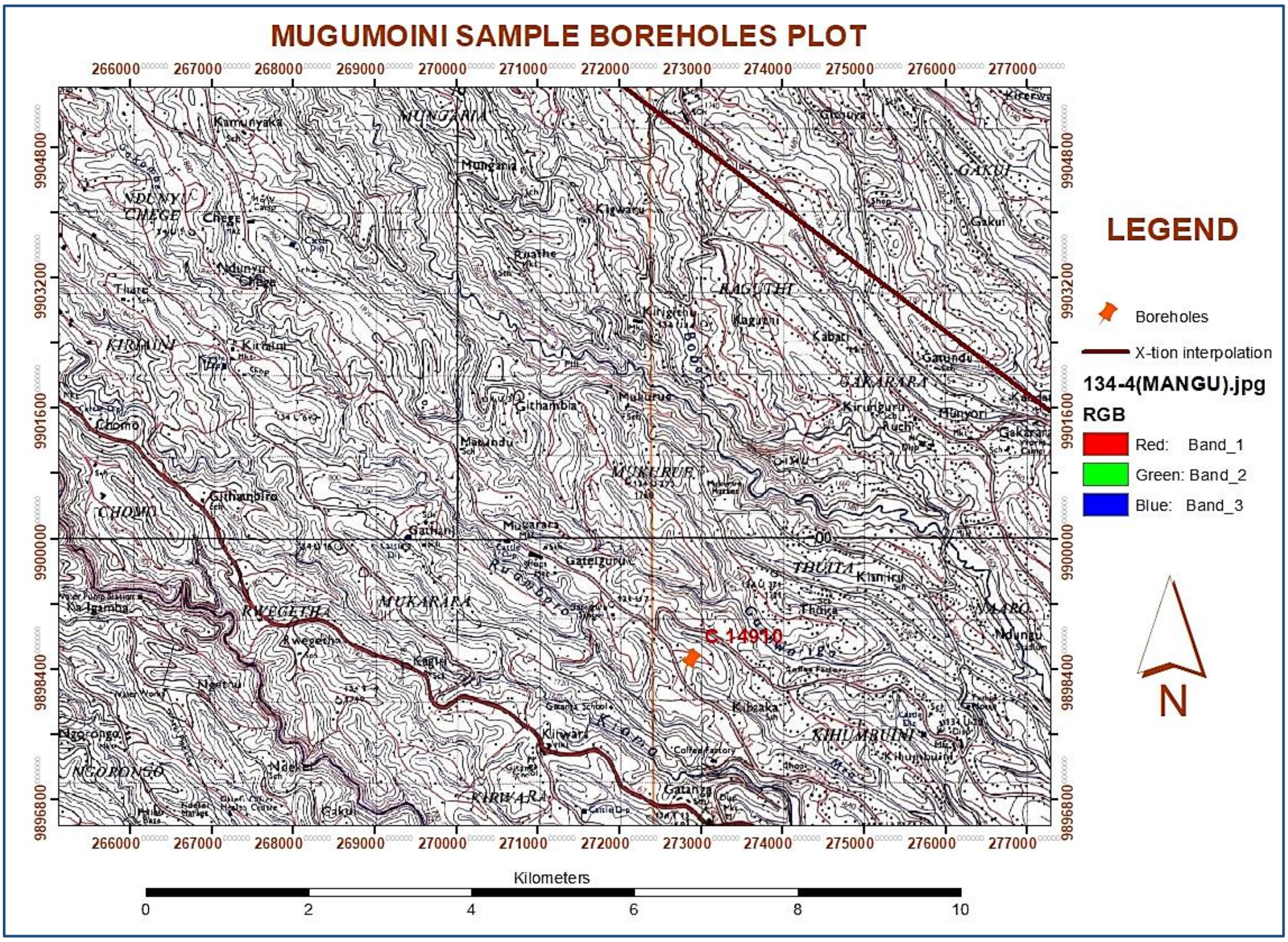


*Figure 4.18: Mugumoini sample borehole plot (Topo sheet No: 134/4, Mangu)*

The sample borehole is a few kilometers from the northern interpolated cross section line but due to the geological nature of the region, which is characterized by regionally layered volcanic flows, the geological arrangement shown in the cross-section is expected to remain the same (with a slight deviation) over a wide area. The borehole is plotted on the cross section in order to obtain a visual depth comparison with other boreholes.

*Table 4.4: Sample borehole properties*

| BH. No | Locality | TD (m) | WSL (m) | WRL (m) | PWL (m) | Q (m3/hr) |
|---|---|---|---|---|---|---|
| **C 14910** | Kibaaka | 200 | 195-198 | 77.58 | 146.45 | 12.0 |

The sample borehole from the immediate table above has a main aquifer from 195m – 198m. This a good indication of a productive aquifer within the Middle Athi series to a tune of about 12 cubic meters per hour. Graphical correlation is thus not possible due to a single data source. The chemical analysis regarding the specific minerals in question is give in table 4.5 below.

*Table 4.5: Sample borehole chemical data*

| | C 14910 | WHO Guideline |
|---|---|---|
| **Chloride** | 20 | 250 |
| **Sulphate** | 4 | 250 |
| **Nitrate** | **ND** | 50 |
| **Fluoride** | 2.2 | 1.5 |
| **Sodium** | 5.4 | 200 |
| **Manganese** | 0.005 | 0.5 |
| **Iron** | 0.1 | 0.2 |

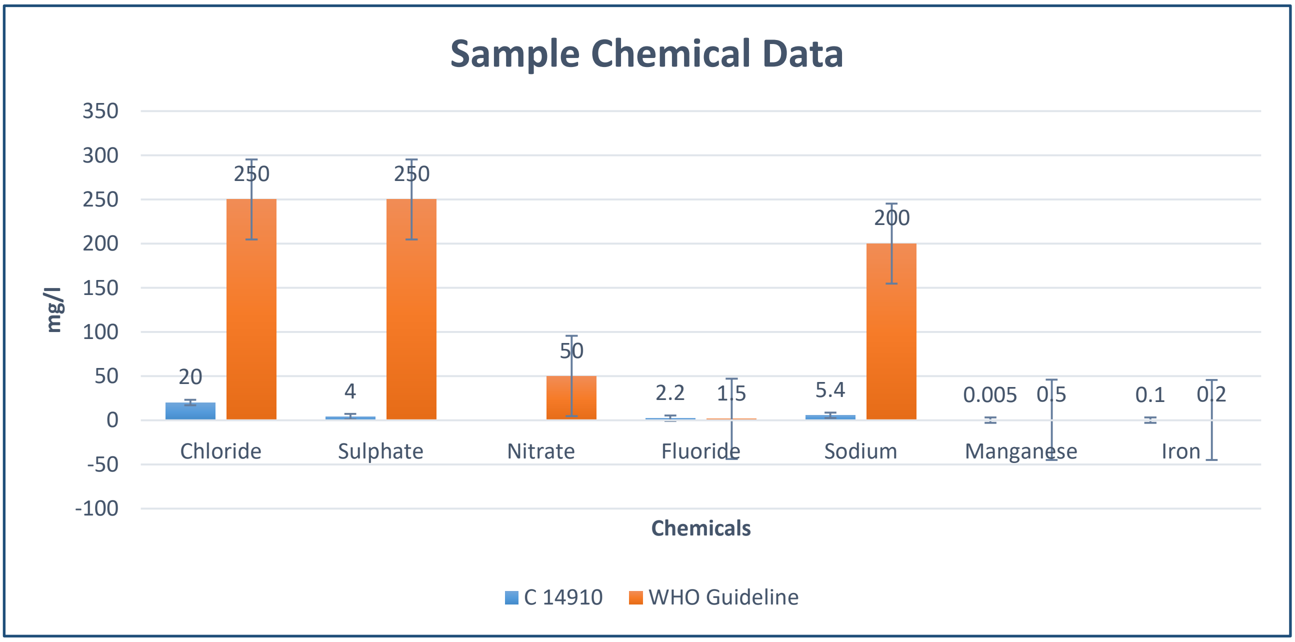


*Figure 4.19: Sample chemical data (Borehole Number C 14910)*

The graphical presentation above (Figure 4.19) shows a good quality water sample apart from a uniform Fluoride high levels previously detected in other aquifers. Chloride, Sulphate, manganese and sodium levels are detected way below the maximum permissible limits with nitrates not being detected at all. Iron is also detected at half concentration and Fluoride at 0.7mg/l more than the maximum permissible/acceptable guideline.

#### 4.1.2.4 Upper Athi Series aquifer

The Upper Athi series is part of the famous Athi tuffs. It's a tufaceous layer majorly characterized by huge accumulation of lake beds of tertiary to Pleistocene origin according to Shackleton, (1945) lying between Nairobi and Kapiti phonolites. This formation is, at some point divided into two by the Mbagathi trachyte thus semi-confining the Upper Athi series that lie below it. The upper part of the Upper Athi Series obtains its recharge directly from the Mbagathi River. Due to high incidence of fractures that strike in a north - south direction, the Upper Athi tufaceous formation is a good aquifer as a result of higher transmissivity and an excellent recharge from the western highlands.

In order to analyze its detailed chemical data, a number of boreholes were sampled from Karen – Langata area. This region has a very simple geology that shows a very thin Kerichwa Valley tuff series at the top (nonproductive) followed by the Nairobi trachyte then the first layer of the Upper Athi series. The Mbagathi trachyte follows then below it is another huge Upper Athi Series formation as shown in the figure 4.20 below. The data as per the sampled boreholes are as shown Table 4.6 below.

*Table 4.6: Sampled boreholes chemical properties for the Upper Athi Series aquifer*

| | **C 21878** | **C 14179** | **C 14288** | **Avg.** | **WHO Guideline** |
|---|---|---|---|---|---|
| **Chloride** | 10 | 12 | 15 | 12.33 | 250 |
| **Sulphate** | 3 | 31.89 | 1.5 | 12.13 | 250 |
| **Nitrate** | 0.5 | 0.5 | **ND** | 0.33 | 50 |
| **Fluoride** | 2.69 | 1.85 | 1.5 | 2.01 | 1.5 |
| **Sodium** | 25.37 | 71 | 61 | 52.46 | 200 |
| **Manganese** | 0.3 | 0.01 | **ND** | 0.10 | 0.5 |
| **Iron** | **ND** | 0.07 | 0.007 | 0.03 | 0.2 |
| **Calcium** | 1.9 | 7.2 | 8.0 | 5.7 | NO GUIDELINE |

*Table 4.7: Sampled boreholes properties for the Upper Athi Series aquifer*

| BH. No | Locality | TD(m) | WSL(m) | WRL(m) | Q($m^3$/hr) | PWL(m) |
|---|---|---|---|---|---|---|
| **C 21878** | Lang'ata | 310 | 220,302 | 187.56 | 25.98 | 240.11 |
| **C 14179** | Lang'ata | 300 | 250 | 117.4 | 6.12 | 194.20 |
| **C 14288** | Lang'ata | 192 | 162,180 | 116.6 | 150.5 | 150.50 |

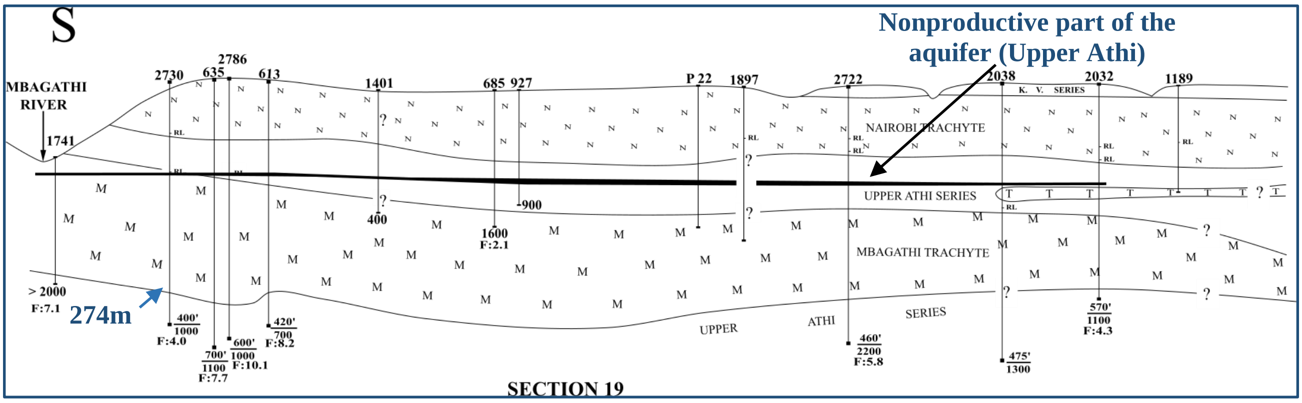


*Figure 4.20: Karen - Langata Geological cross-section showing the major aquifers (Adapted from Gevaerts, 1964)*

Currently, the only production aquifers in Karen – Langata area are those that lie below the Mbagathi trachyte. A bigger part of the Upper Athi series is also not productive enough to sustain a borehole. Three boreholes were sampled to fully analyze the chemical composition of the Upper Athi series.

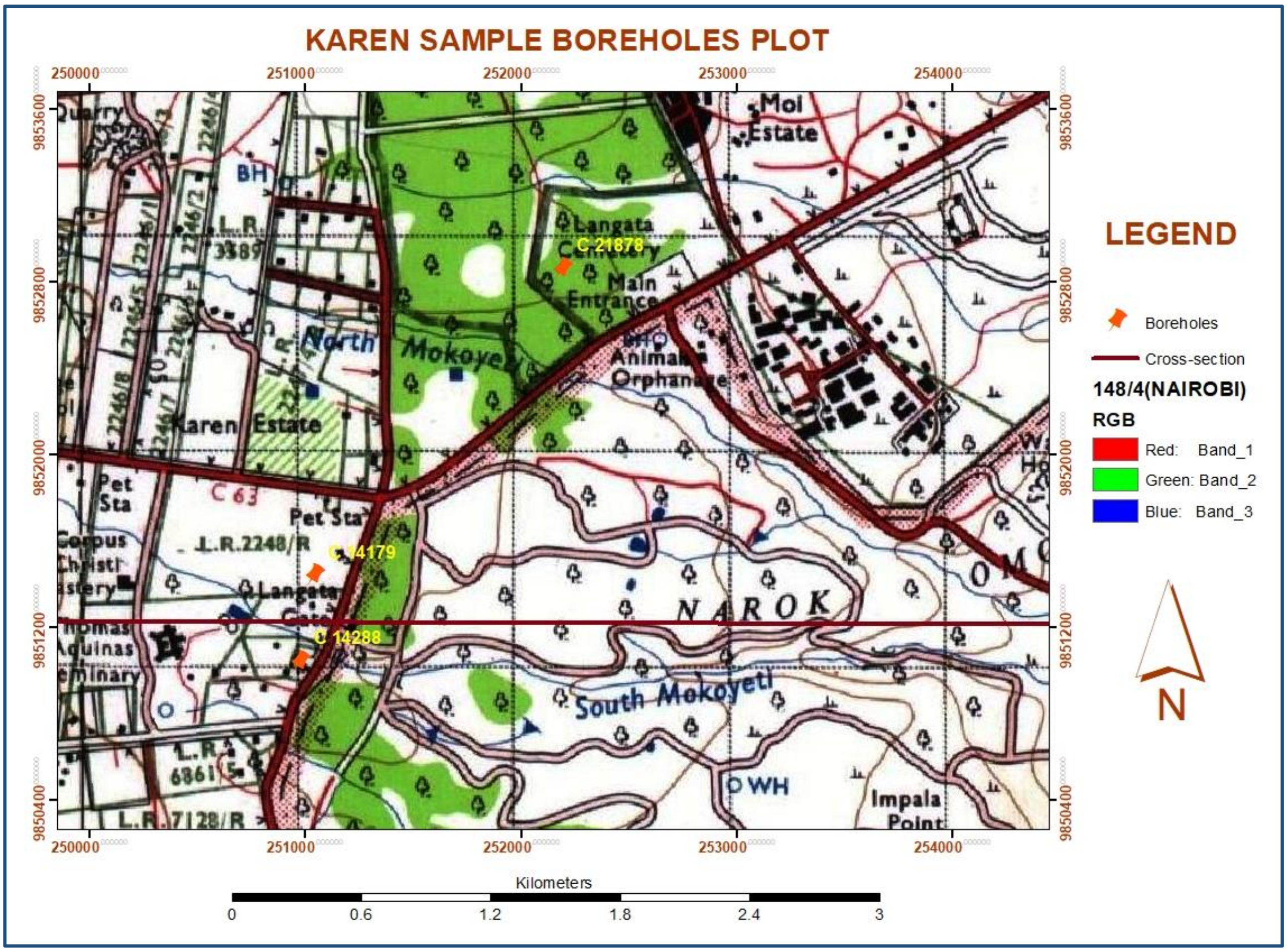


*Figure 4.21: Karen-Langata boreholes sample plot (Topo sheet number 148/4: Nairobi)*

These boreholes are some of the recently drilled wells and strictly do not obtain their recharge water from any upper aquifer. The boreholes used were C 14288, C 14179 and C 21878. The Middle Athi series is encountered in this area at very great depths that only a few powerful drilling rigs can drill. Drilling becomes even more difficult due to the loose sediments that characterize this formation thus preventing further penetration.

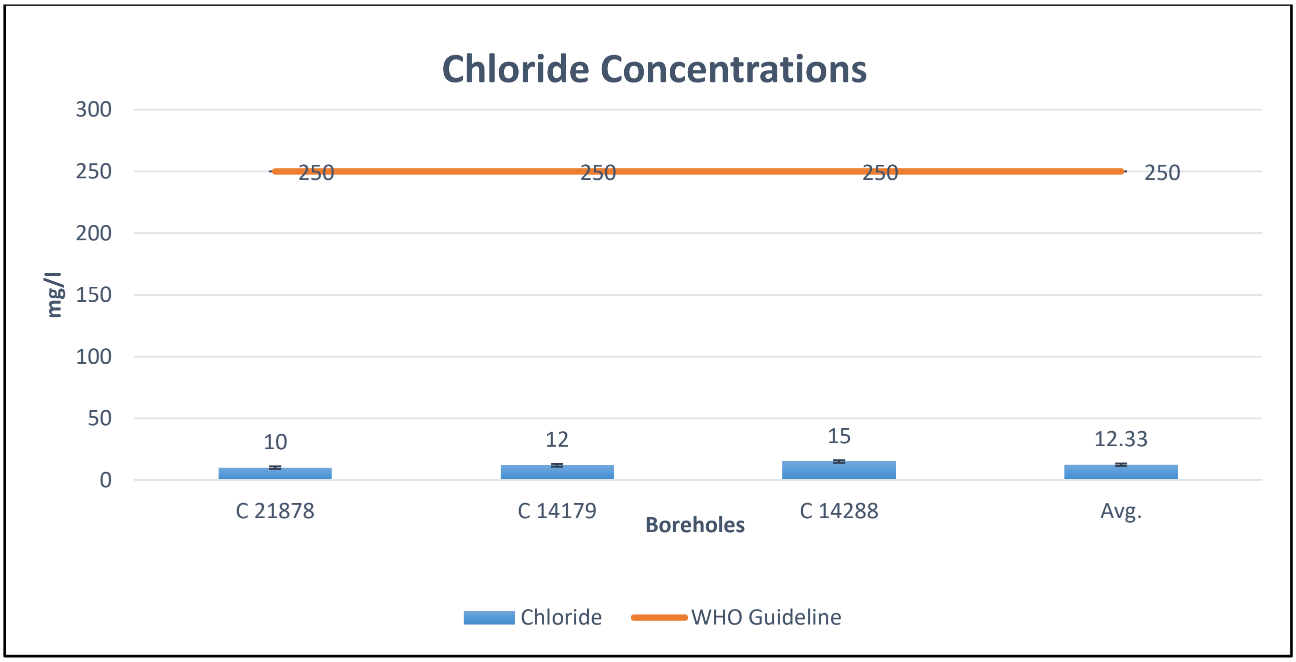


*Figure 4.22: Upper Athi Series Aquifer Chloride concentrations*

Chloride levels within the Upper Athi aquifer as shown in the above immediate illustration is way lower than the WHO permissible limit which is about 250mg/l. The three sampled boreholes show uniformity in all the values proving a bit of accuracy and concentration consistency within the aquifer. Chloride concentrations thus average at about 12.33mg/l with the lowest detected being about 10mg/l for borehole C 21878.

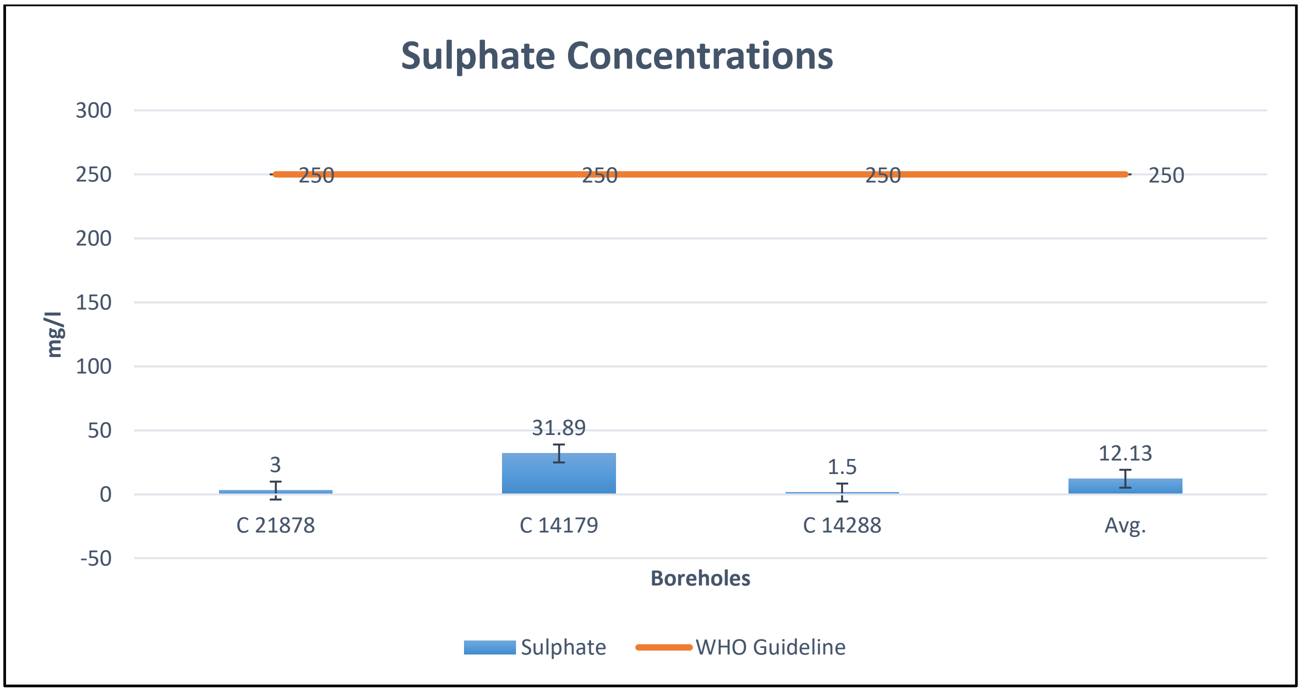


*Figure 4.23: Upper Athi Series Aquifer Sulphate concentrations*

The highest detected Sulphate concentration within the Upper Athi series lies at 31.89mg/l with the lowest being 1.5mg/l for C 14179 and C14288 respectively bearing in mind the maximum permissible/acceptable limit is 250mg/l. This is way below the guideline.

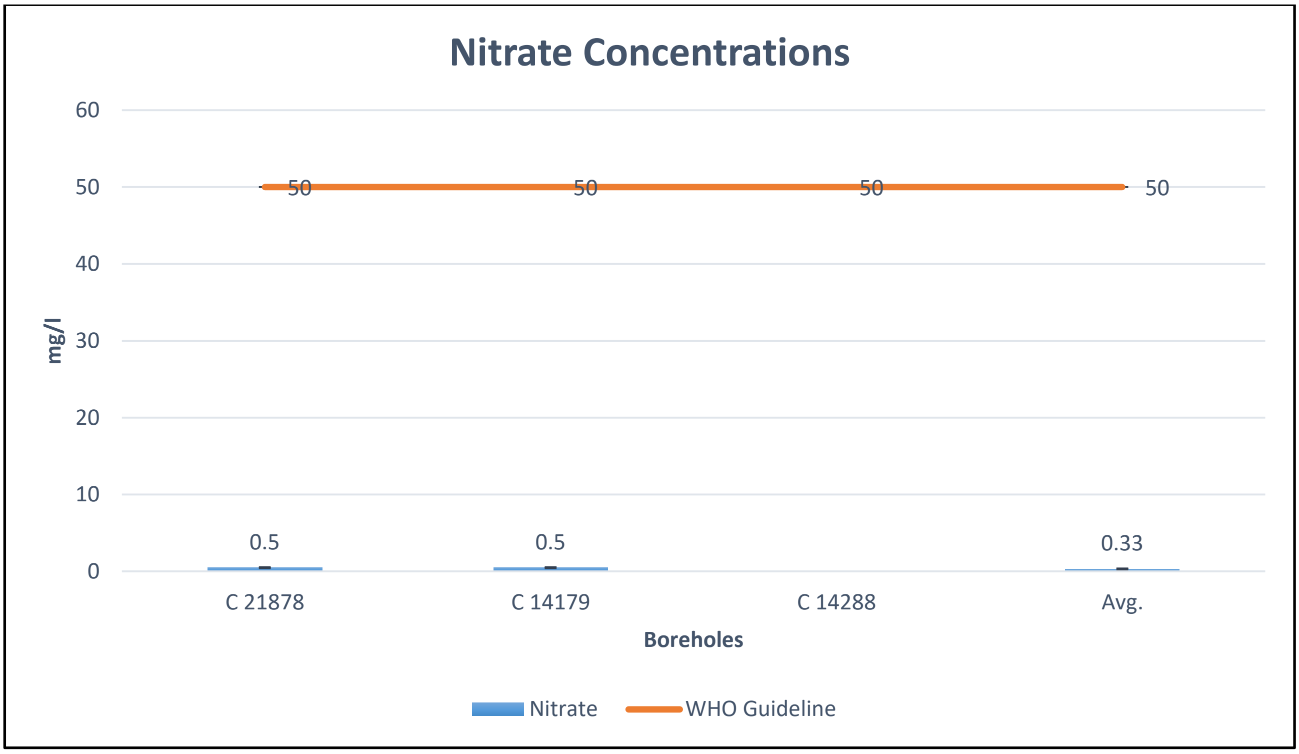


*Figure 4.24: Upper Athi Series Aquifer Nitrate concentrations*

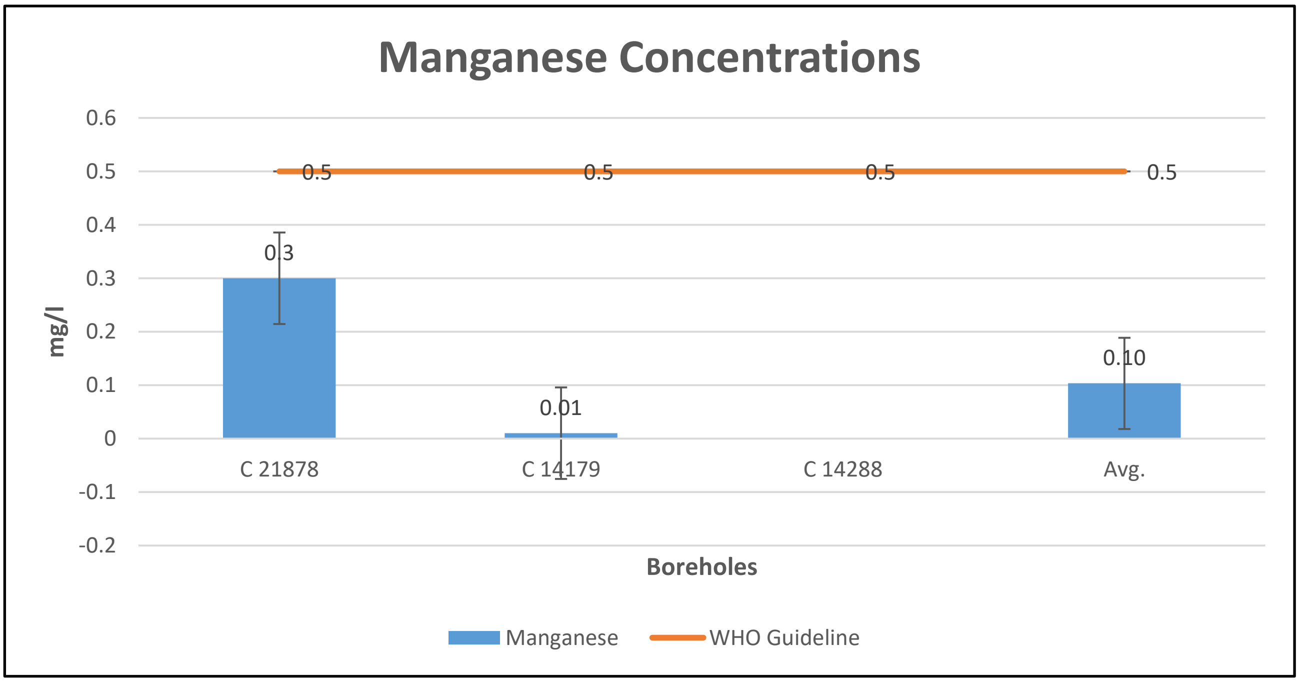


*Figure 4.25: Upper Athi Series Aquifer Manganese concentrations*

Nitrate concentrations within the Upper Athi series is almost to a non-detectable level with both the boreholes C 21878 and C 14179 falling below 1.0mg/l and averaging at 0.33mg/l and not detectable at all at borehole number C 14288 which is also void of any detectable Manganese. The maximum permissible limit Manganese is about 0.5mg/l, the highest detectable limit from all the sampled boreholes is at 0.3mg/l and averages at 0.10mg/l.

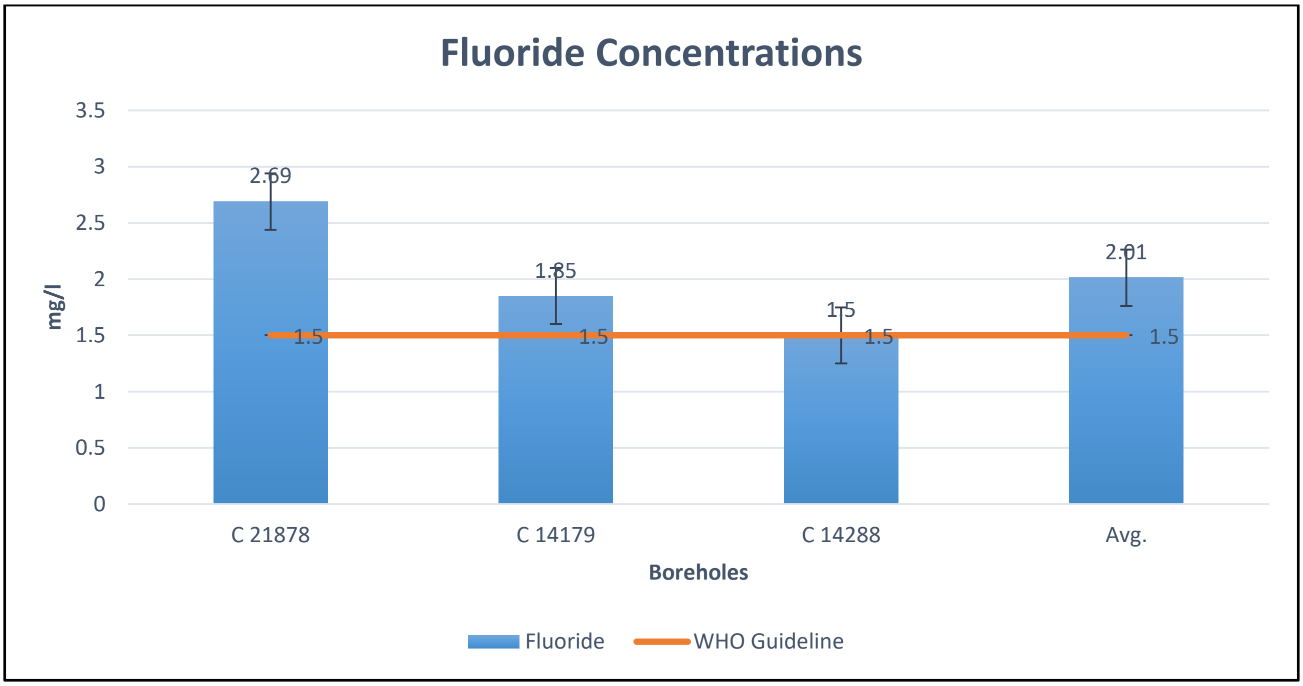


*Figure 4.26: Upper Athi Series Aquifer Fluoride concentrations*

As one of the most critical minerals under this study, it can be noted that the average Fluoride concentrations in this aquifer is still above the permissible limit by the WHO. Slight concentration above the permitted limit can cause adverse negative human health effects. In this aquifer, none of the samples fell below the required consumable levels.

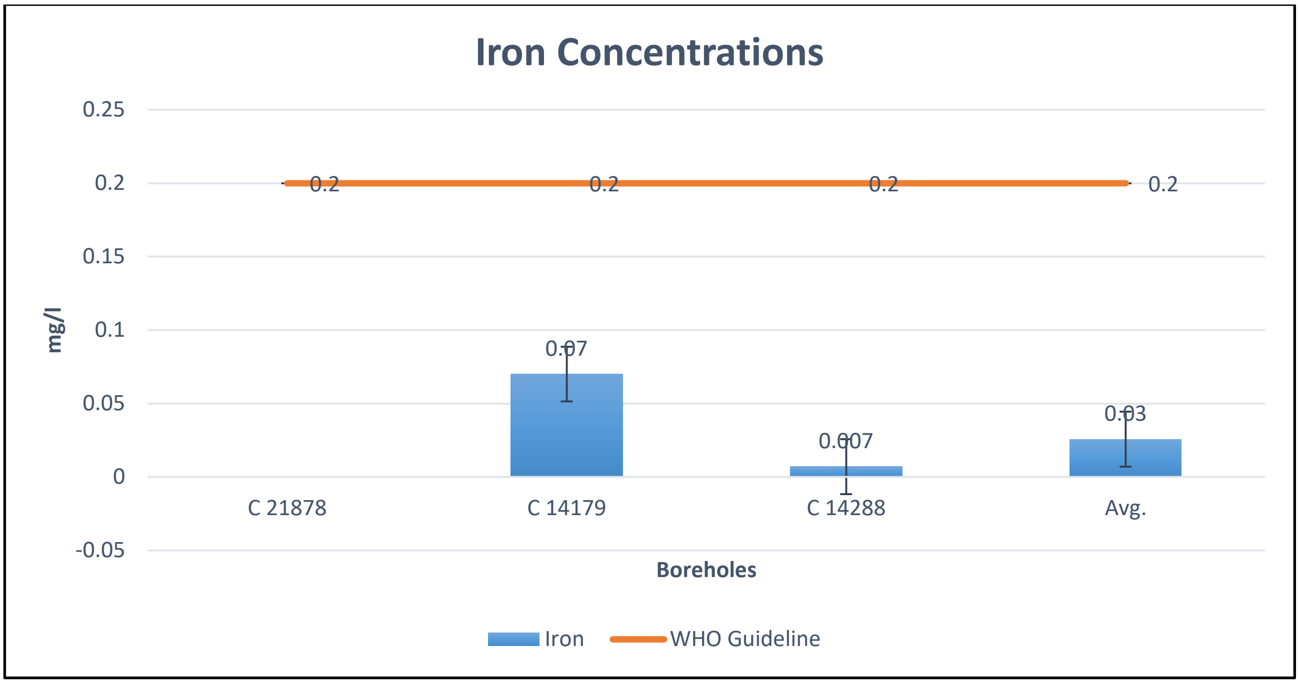


*Figure 4.27: Upper Athi Series Aquifer Iron concentrations*

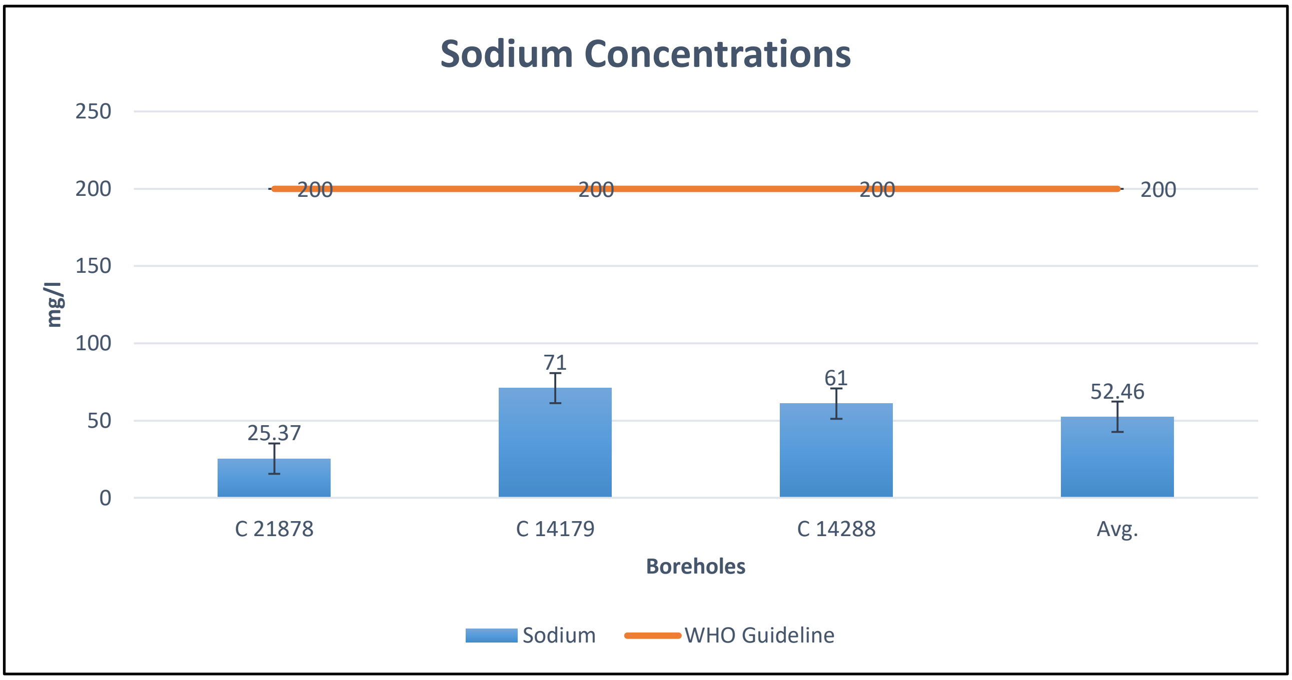


*Figure 4.28: Upper Athi Series Aquifer Sodium concentrations*

Both Iron and sodium levels fall below the acceptable limits. Since sodium play a bigger role in the human body, it's required in higher quantities with a maximum permissible limit being about 200mg/l. The average sodium concentrations as shown in the above graphical representation (Figure 4.28) falls at 52.46mg/l. Iron is also detected in very small quantities in this aquifer though it has been detected in other regions with slightly higher concentrations proving a point source or regionally restricted to the western highlands.

#### 4.1.2.5 Kerichwa Valley series

The Kerichwa Valley series, widely spread in Nairobi region and its environs, is a tufaceous formation locally referred to as Nairobi building stone. It is fine grained with an indistinct banding. It is also divided into three: Upper, Middle and Lower Kerichwa valley tuffs. The tuffs, which at some points well welded and reworked, consists of flaky pumiceous layers with thickly bedded impermeable strata. Most of the impermeable layers are highly weathered resulting to higher levels of sandy deposits that forms the best aquifers within this formation. Just like the Athi series, other geological formations are often encountered within the Kerichwa Valley series some of which include the Karura Quartz trachyte mainly encountered around Wangige area, Karura trachyte and Kabete trachyte.

Kerichwa Valley (KV) series can be traced from Ondiri swamp, source of its recharge water and terminates around Karen –Langata area. Previous investigations and drilling logs analysis have repeatedly pointed out the deteriorating nature of this aquifer over a wider area. The aquifer is still productive in a few areas towards the recharge zones though its transmissivity property has been rendered too low for a standard aquifer thus cannot sustain a borehole. So far, older boreholes that depended on the Kerichwa Valley aquifer have dried up in most of the parts. The chemical analysis for these older boreholes is not available to enable us to tabulate the true character of this aquifer regarding its chemistry. Numerous recent boreholes with well analyzed chemistry abstract water from deeper aquifers.

## 4.2 Discussion

This discussion gives a detailed account of analyzed different sets of data from various sources including aerial photographs, borehole data and most importantly the chemical analysis. This is to chemically characterize the individual aquifers in terms of their chemistry with depth within this aquifer suite.

The study area delineation and proper description was fully dependent on the online data that were readily provided by the USGS free satellite image data source. From the digital elevation model (DEM), surface projections could be easily processed into a proper 2D or 3D elevation models. Flow directions and flow accumulations led to a proper Athi watershed and drainage models that gave hint to the groundwater movement. Apart from the satellite images, chemical data gathered for a sample of boreholes from the Ministry of Water data center for representation of the general mineral distribution and specific graphical aquifer analysis showed a unique trend that gives a proper solution/explanation to the earlier advanced theoretical suggestions and interpolations about various sources of different critical chemicals like sodium, iron and fluoride.

Usually, groundwater flows within the aquifers or weak zones as clearly stated under the Literature. Due to this process, the water interacts both chemically and biochemically with different geological formations but since water is a good solvent, it dissolves different minerals altering the original chemical composition of the groundwater in various concentrations depending on time of exposure and the quantity of the mineral deposits. Groundwater dissolves minerals in ionic forms making it an electrolyte. The total dissolved ionic content can be determined by the capacity to conduct an injected electric current. This is measured in terms of conductance which is then converted into resistance then to resistivity which is easily interpreted into other uses. This technique forms the basis of the resistivity survey used in most of the hydrogeological surveys as widely discussed by Freeze and Cherry, (1979).

The Nairobi aquifer suite is a compilation of a regionally multi-layered aquifers as described earlier, that occurs between the volcanic flows that originated from the Southern Aberdares, Kikuyu Escarpments and Ngong' Hills dipping gently above the ancient Athi lake basin (a pre-tertiary formation) being terminated by a foundation of a highly folded and resistant Basement System around the eastern Lukenya Hills and ends with an alkaline volcanic activity at the top.

Apart from Chalcedony: abundant in Nairobi National park, minerals like carbon from Kedong' valley, limestone near Kiambu, Montmoriollonitic clays of the Athi series, diatomite at Gicheru, ferric rete within Nairobi municipality and other numerous mineral deposits found in small quantities play a huge role in molding the chemistry of water that lies within the Nairobi aquifer suite. Generally, recharge rates and groundwater movement are two major factors that tend to influence the groundwater mineral concentration as higher recharge, majorly experienced on a seasonal basis and good groundwater movement including water table variations leads to a flashing effect thus neutralizing the dissolved ionic components.

The groundwater quality within Nairobi area has been classified as good in most of the parts by (Gevaerts, 1964; Saggerson, 1991), except for fluoride that poses a major challenge to the residents. Others like pH, dissolved solids and other dissolved minerals are rarely detected beyond the WHO limits. Higher Sulphate and chloride concentrations have also been detected within the Kapiti phonolites contributed by the intercalated lacustrine sediments. This can be observed from the results shown in the previous chapter.

This dissertation focuses mainly on seven key minerals: Fluoride, Calcium, Manganese, Iron, Sodium, Calcium, Nitrates and Sulphates. The rest of the minerals left out under this thesis are either non-significant in the human body, has no WHO guideline or is an anthropogenically induced heavy metal making it out of the scope of this dissertation since the project is confined within natural geological controls. The general distribution of the chemicals in question shows surprisingly an expected trend according to the theoretical behavior of various chemicals under this study. Fluoride is one of the chemicals that have been extensively discussed in various previous works with every paper trying to insinuate its source. From figure 4.1 (General distribution of fluoride) shows a gradual and steady easterly increase in concentration to values way above the 1.5mg/l WHO guideline. This unique increment is directly related to the direction of the groundwater flow from areas of Kikuyu and Limuru to Industrial area and Athi River areas.

Borehole chemical data sampling for this project was categorized according to the use and the objective to be achieved. After the definition of the study area extent, general borehole data was obtained in order to visualize the general distribution and concentration of the different chemicals under study. Specific borehole data was obtained for specific aquifer characterization, for boreholes that currently abstract water from specific aquifers ensuring minimal recharge from the upper aquifers. Cross-sections are attached showing different stratigraphic layering of various geological formations where different aquifers could be accessed with maximum accuracy.

Extreme fluoride levels as analyzed, tabulated and represented in graphical format in figure 4.12 above is sampled from The Basement – Kapiti phonolite series aquifer characterized by intercalated lake sediments near Mozambiquan basement dome around Syokimau area. Apart from the Kapiti lake sediments, Fluoride is also detected above the acceptable limit in both the Upper and Middle Athi series shown in figures 4.26 and 4.19. The Athi series is widely known to be characterized with tuffs and lakes beds. The presence of sodium in a number of these aquifers: Athi series and Kapiti series gives a new angle to the source of the highly concentrated fluoride within these specific aquifers. High fluoride concentration has previously been linked to high/moderate sodium content as shown in figure 4.14 and potential of hydrogen against low calcite concentrations. Calcium is not detectable in Kapiti aquifer but has very low values within the Upper Athi series.

As sodium rich geological formations weathers: typical in highly aquiferous formation, pH increases thus initiates carbon (IV) oxide dissolution increasing hydrogen carbonate and carbonates concentration in the solution. This condition leads to formation of Fluorite which if saturated, reduces further concentration of calcium ions thus oversaturation of Fluorite is achieved. Fluoride is highly soluble in water thus increasing its mobility through groundwater movement. A situation that explains fully the reasons behind over saturations of fluoride to the eastern part of the study area towards which groundwater moves. The reaction process can be summarized in three equations as shown below.

$2Na(AlSi_3)O_8 + 2H^+ + 9H_2O \longrightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 4H_4SiO_4$……….……… (1)

$CaCO_3 \longleftrightarrow Ca^{2+} + CO_3^{2-}$ ……………………………..………………………… (2)

$CaF_2 \longleftrightarrow Ca^{2+} + 2F^-$………………………………………………………….... (3)

It is thus viable to conclude that a medium created in both the Athi series aquifers (Upper and Middle Athi) and Basement – Kapiti series aquifer leads to even more synthesis of the fluorite ions within the aquifers as can be proven by very high levels of sodium in these aquifers that comprises mainly of Lake Beds and intercalated Lake Sediments.

A keen look at figure 4.2 and figure 4.3, showing the general distribution of Iron and Manganese respectively, a gradual decrease of these minerals that normally occur together is seen towards the direction of the groundwater flow. Theoretically, Iron and Manganese is known for their immobile nature thus highly concentrated against the groundwater flow. Apart from iron, manganese has almost a negligible concentration that hardly exceed the WHO guideline in both the Athi series and the Kapiti series aquifers.

Some of the recent deposits as illustrated in the Geology of Nairobi are the red beds, varicolored, Argillaceous and tufaceous beds. Major components of this formation include clay and sandy clays (red and brown colored) which are associated with Iron formations due to their silica content. In a volcanic terrain, basalts have been noted as highly associated with Iron since it's formed under rapid cooling of Magnesium and Iron rich lava. Several reports for boreholes from Kikuyu area have pointed out high level of iron for some boreholes in this area with a number suggesting a deeper source. Most of the boreholes that has been badly affected in this area have depths greater than 200meters. East of Ondiri swamp lies a deeply seated Upper Ngong Basalt at approximately 200meters below ground level as shown in figure 4.29 below. Above the basalt is a thin layer of an Old Land Surface formed after a partial deposition of various argillaceous sediments. This might be a likely source for Iron in most of the boreholes around this area as observed from the geological cross-section through Ondiri swamp, Kikuyu area.

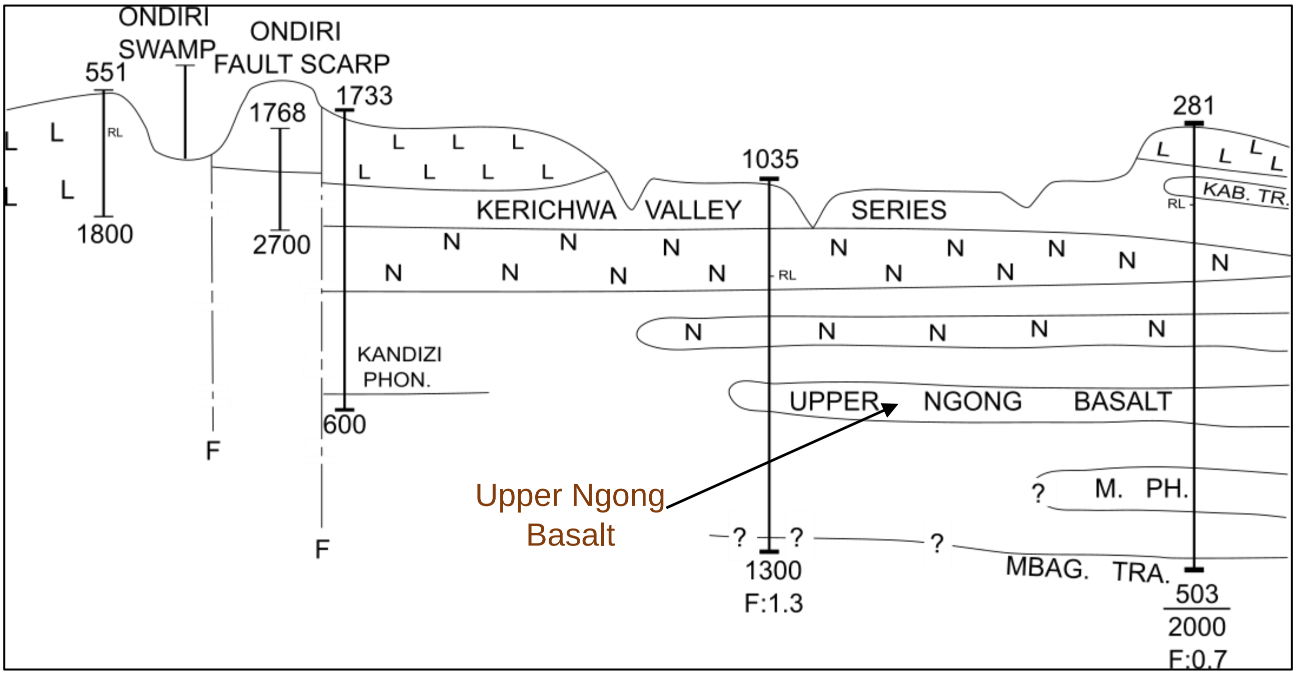


*Figure 4.29: Ondiri swamp – Kikuyu area geological cross-section (Adapted from Gevaerts, 1964)*

Kerichwa Valley Series was for some time one of the most productive aquifers within this aquifer suite but due to its minimal extent, it became unproductive as more boreholes were drilled abstracting water from the aquifer. This resulted into more abstraction than the recharge and transmissivity levels thus damaging the aquifer. For this reason, most of the recent boreholes with properly analyzed chemical data abstracting specifically from the Kerichwa valley aquifer is missing. Its unproductive nature again makes it useless and of no economic importance leave alone any health risk that it might pose to human health. The Lower Athi series is also known to be a typical clay formation. Clay deposits are good confining layers for water that lies below or above it. Efforts to obtain a good chemical data was not successful since the formation is deep seated and is not productive.

## CHAPTER 5: CONCLUSION AND RECOMMENDATION

### 5.1 Conclusion

Interpretation and analysis of borehole data was purely a conceptual process aided by various computer programs that could interpolate and modify the data into a graphical model that could give out a simple and an attractive visual representation of what really lies within the aquifers. The methodology employed for this project is thus satisfactory having resulted into a uniform and reliable results that conforms to the previous works done.

A discussion of different minerals under this study gives a proper understanding on both the negative and positive impacts after a long-term consumption. Different minerals have different consumption limits that when exceeded or less consumed can result into serious side effects.

For this study, a number of chemicals are considered critical and are discussed for specific aquifers in the previous chapter. Some of these include: Fluoride, Sodium, Chloride, Iron, Nitrates, Sulphates and Manganese. Since the scope of this study is confined on the critical chemical analysis with direct influence to human health, other factors/chemicals are considered non-significant having no maximum permissible limits. These include Free Carbon dioxide, Permanganate Value, Total Dissolved Solids, Total Alkalinity, Potassium, Magnesium and Calcium. These minerals therefore, have no significant impact on human health.

It could be suggested like it has always been done in most of the previous works but with different interpolated models (under the results chapter) for each mineral in question proves without doubt that fluoride, that has been highly critical for human health in this region due to its high concentrations can be traced to different layers of lake beds and sediments within the tufaceous aquifers (Upper Athi, Middle Athi and Kapiti). Fluoride is generally high in the above mentioned aquifers but with keen analysis of the general distribution interpolation maps, a unique trend is observed in that its concentration increases towards the direction of the groundwater flow: which is expected due to its highly mobile nature. This has resulted to high concentrations in Athi River and Kitengela areas than Karen and Kikuyu regions.

Unlike fluoride, Iron and Manganese that has been detected in both the Athi series and the Kapiti aquifers: though below the optimum required levels do increase in concentration against the groundwater flow direction. This is attributed to low mobility and poor dispersion of these minerals that seem to have a point source to the north western part of the study area: reportedly around Kikuyu area. Optimum groundwater utilization is limited by the high concentration of a number of key minerals in major aquifers. Safer regions as delineated by this study can be towards the North Eastern areas. Generally, minerals that were detected above the WHO guideline are Fluoride, Sulphate and Iron in a number of aquifers.

## 5.2 Recommendation

In order to ensure safe consumption/utilization of groundwater in Nairobi and its environments, proper chemical analysis should be done with high level of accuracy in order to advice accordingly incase the borehole water isn't fit for human consumption. The Water Resources Authority (WRA) has so far been charged to do this. Strict implementation of this process is lacking as boreholes with extremely high fluoride content is left for clients' personal use.

Apart from the main minerals discussed in this dissertation, the WRA (Water Resources Authority) should be able to track the presence of heavy minerals in any borehole water sample they receive from the Nairobi aquifer suite. The water might be declared to be perfect for consumption yet has very high heavy metal content like lead and other minerals. A case that has been observed in most of the estates around the densely populated Nairobi city. High water demand prevails within Nairobi and its environments. For this reason, Nairobi County has so far proposed borehole drilling to supplement the current water supply. It is thus advisable to drill the boreholes on the North Eastern part of the study area where higher concentrations were not detected for key minerals that can deteriorate human health.

There is need to address the identified gaps on the chemical data availability for the Kerichwa Valley Series and the Lower Athi Series in areas that they could possibly be productive. Enhanced monitoring of the mobile chemical elements such as Fluoride and Sulphate in the existing boreholes for guidance on current use and future planning is necessary.

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# APPENDICES

## APPENDIX I: Chemical Data for selected boreholes

| BH NO | DEPTH | LOCALITY | Y-COORD | X COORD | Na | Cl | F | Fe | Ca | SO4 | NO4 | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22022 | 298 | Kileleshwa | 9859877 | 254232 | 72.9 | 50 | 8.4 | 1.12 | 0 | 10 | 14.3 | 0.3 |
| 21976 | 205 | Enoomatathian | 9847325 | 242845 | 3.24 | 17 | 0.35 | 0.15 | 3.24 | 11 | 6.7 | 0.003 |
| 21980 | 310 | UpperHill | 9855829 | 257484 | 71.8 | 1.9 | 16.25 | 0.16 | 1.39 | 1 | 0.7 | 0.07 |
| 22114 | 212 | Roysambu | 9865049 | 266178 | 78.3 | 30 | 3.3 | 0.26 | 12 | 1 | 1.2 | 0.1 |
| 21985 | 184 | Kiserian | 9842733 | 242757 | 73 | 65 | 0.8 | 1.57 | 60.8 | 6.51 | 4.71 | 0.01 |
| 22112 | 335 | Kilimani | 9857366 | 254182 | 81.2 | 30 | 10 | 1.3 | 0 | 8 | 2.1 | 0.04 |
| 21986 | 185 | Lukenya | 9839918 | 282413 | 70.7 | 114.7 | 0.58 | 0.04 | 22.4 | 40 | 2.1 | 0.6 |
| 22110 | 282 | Juja | 9883757 | 282255 | 487.8 | 300 | 0.5 | 0.28 | 6 | 1 | 2.9 | 0.04 |
| 21987 | 250 | Ngochi, Githunguri | 9883831 | 251961 | 56.7 | 0.8 | 2.44 | 0.07 | 29.61 | 0 | 0.2 | 0.8 |
| 22109 | 280 | Lang'ata | 9852729 | 255506 | 168.2 | 40 | 5 | 0.15 | 2 | 1 | 1.1 | 0.009 |
| 21988 | 260 | Pipeline | 9853955 | 265970 | 70.8 | 115 | 8.14 | 0 | 1.14 | 15 | 12 | 0.8 |
| 21992 | 282 | Parklands | 9861346 | 255796 | 0 | 20 | 4.2 | 0.2 | 50 | 40 | 1.9 | 0.01 |
| 21993 | 220 | Kilimani | 9876188 | 279199 | 160 | 60 | 0.9 | 7.9 | 15 | 25 | 0 | 0.1 |
| 21994 | 210 | Baba Dogo | 9860885 | 260498 | 95 | 9 | 1.2 | 1.3 | 0 | 3 | 0 | 0 |
| 21940 | 253 | Parklands | 9860744 | 257621 | 94.3 | 40 | 4 | 0.2 | 24 | 14 | 10.2 | 0.1 |
| 21995 | 300 | Kitisuru | 9859238 | 252364 | 90 | 190 | 0 | 52 | 75 | 170 | 0.9 | 0.3 |
| 21941 | 231 | Westlands | 9865505 | 255188 | 53.2 | 40 | 3 | 1.6 | 16 | 3 | 2.66 | 0.67 |
| 21966 | 223 | Baba Dogo | 9862534 | 263879 | 92 | 8 | 0 | 1.2 | 0 | 3 | 0 | 0 |
| 21944 | 296 | Highridge | 9860925 | 256282 | 130.4 | 40 | 11.6 | 0.2 | 4 | 3 | 2.2 | 0 |
| 21997 | 250 | South B | 9855066 | 258953 | 60 | 51 | 4.2 | 0.11 | 53 | 18 | 0.02 | 0.01 |
| 21945 | 283 | Kitisuru | 9862883 | 250629 | 124.8 | 30 | 11 | 0.25 | 8 | 2 | 2.21 | 0.08 |
| 21946 | 300 | Kiambaa | 9871014 | 250070 | 82.3 | 30 | 6.5 | 0.3 | 16 | 13 | 3.5 | 0.3 |
| 22001 | 198 | Syokimau | 9849246 | 267782 | 172.9 | 90 | 10 | 0.02 | 4 | 28 | 1.4 | 0 |
| 21947 | 307 | Highridge | 9860711 | 252744 | 48.3 | 20 | 4 | 0.08 | 4 | 1 | 2.6 | 0.16 |
| 22003 | 220 | Roysambu | 9869373 | 267280 | 172.1 | 120 | 1 | 0.1 | 40 | 18 | 2.8 | 0 |
| 21948 | 253 | Kikuyu | 9864913 | 238752 | 32.4 | 30 | 0.5 | 0.3 | 8 | 0 | 2.2 | 0.1 |
| 22004 | 285 | Upper Parklands | 9859955 | 256272 | 91.7 | 20 | 8 | 0.7 | 0 | 4 | 4.5 | 0 |
| 22006 | 250 | Imara Daima | 9853640 | 264552 | 39 | 44 | 7.19 | 0.15 | 1.71 | 9 | 1.9 | 0 |
| 21949 | 286 | Highridge | 9859966 | 255969 | 64.9 | 50 | 10 | 0.3 | 8 | 56 | 3.1 | 0.007 |
| 22007 | 205 | Lukenya | 9835194 | 283087 | 200 | 127 | 2.47 | 0.05 | 25.12 | 61 | 0.1 | 0.2 |
| 21950 | 300 | Spring Valley | 9861405 | 254495 | 54.6 | 40 | 10 | 0.03 | 0 | 1 | 1.77 | 0.03 |
| 21957 | 270 | Embakasi | 9850276 | 266748 | 114.7 | 120 | 10 | 0.18 | 8 | 0 | 2.21 | 0.02 |
| 22131 | 204 | Utawala | 9861630 | 269339 | 82 | 8 | 7.55 | 0.13 | 0.8 | 0.66 | <0.01 | 0.01 |
| 22132 | 310 | Lang'ata | 9852962 | 253209 | 0 | 25 | 30 | 0.3 | 2.002 | 1 | 0.2 | 0.089 |
| 22117 | 300 | Thika | 9881661 | 283655 | 472 | 65 | 13.62 | 0.3 | 12 | 55.29 | <0.01 | 0.01 |
| 22044 | 123 | Ruai | 9861976 | 277414 | 133.1 | 38 | 6.22 | <0.01 | 10.4 | 8.86 | 7.34 | 0.01 |
| 22119 | 165 | Athi River | 9854170 | 275301 | 274 | 113 | 4.52 | 1.5 | 2.4 | 22.57 | 0.06 | 0.04 |
| 22140 | 250 | Embakasi | 9856290 | 259696 | 116 | 92 | 4.2 | 0.01 | 29 | 5 | 12 | 0.003 |
| 22024 | 198 | Oloolua Ridge | 9849752 | 245464 | 84.2 | 40 | 0.8 | 0.3 | 20 | 2.9 | 11.7 | 0.04 |
| 22159 | 250 | Lavington | 9857287 | 250228 | 36 | 12 | 0.2 | 1 | 9.6 | 2.31 | <0.01 | 0.08 |
| 22164 | 300 | Kitisuru | 9864837 | 254986 | 64.1 | 40 | 10 | 0.3 | 12 | 690 | 2.9 | 0.01 |
| 22023 | 303 | Kileleshwa | 9857448 | 252863 | 51.7 | 20 | 9.8 | 0.3 | 4 | 2 | 1.7 | 0.06 |
| 22022 | 298 | Kileleshwa | 9859538 | 255059 | 72.9 | 50 | 8.4 | 1.12 | 0 | 10 | 14.3 | 0.3 |
| 22170 | 150 | Thika | 9885618 | 285786 | 46.8 | 40 | 1.4 | 0.23 | 24 | 1 | 2 | 0 |
| 21181 | 282 | Highridge | 9864835 | 253302 | 52.2 | 70 | 3.3 | 0.13 | 16 | 0 | 2.3 | 0 |
| 22184 | 244 | Ngara | 9859186 | 257077 | 41.2 | 30 | 8.3 | 0.3 | 0 | 0 | 1.7 | 0 |
| 22315 | 285 | Athi River | 9838766 | 275082 | 361.7 | 930 | 15 | 0.6 | 16 | 320 | 3.2 | 0.04 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22316 | 242 | Syokimau | 9850518 | 271458 | 121.4 | 8 | 13.3 | 0.3 | 0 | 2 | 3.2 | 0.04 |
| 22188 | 305 | Lavington | 9857357 | 251636 | 49 | 7 | 4.35 | 0.43 | 1.6 | 3.89 | 0.07 | 0.27 |
| 22317 | 153 | Kahawa Wendani | 9867660 | 269856 | 189.4 | 40 | 1 | 0.09 | 32 | 1 | 2.7 | 0.024 |
| 22189 | 325 | UpperHill | 9856606 | 257095 | 94 | 11 | 14.55 | <0.01 | 2.4 | 4.89 | <0.01 | 0.01 |
| 22319 | 300 | Karen | 9851361 | 250991 | 52.4 | 40 | 1.5 | 0.23 | 4 | 1 | 4.1 | 0.017 |
| 22321 | 300 | Lang'ata | 9864219 | 246862 | 100 | 7 | 3.97 | 0.59 | 2.04 | 1 | 0.1 | 0.5 |
| 21435 | 241 | Embakasi | 9852442 | 264135 | 110 | 54 | 4.6 | 0.02 | 50 | 19 | 0.02 | 0 |
| 21262 | 216 | Embakasi | 9851520 | 264020 | 71.9 | 8 | 7.95 | 0.07 | 1.77 | 23 | 1.1 | 0.4 |
| 22241 | 195 | Lang'ata | 9853492 | 263109 | 84.3 | 60 | 7.5 | 0.01 | 4 | 0 | 2.1 | 0.09 |
| 22243 | 232 | Athi River | 9843202 | 277700 | 112.7 | 60 | 8 | 0.2 | 8 | 0 | 3.8 | 0.003 |
| 22014 | 284 | Athi River | 9846461 | 270141 | 168.2 | 180 | 8 | 0.03 | 8 | 112 | 1.6 | 0.01 |
| 22296 | 200 | Ngong | 9839264 | 232092 | 68 | 64 | 2.27 | 0.167 | 26.4 | 6.26 | 3.32 | 0.01 |
| 22135 | 310 | Karen | 9853007 | 247390 | 57 | 8 | 0.85 | 0.23 | 7.2 | 3.54 | <0.01 | 0.01 |
| 22134 | 215 | Athi River | 9842116 | 275693 | 0 | 360 | 13 | 0.03 | 6.006 | 590 | 0.3 | 0.019 |
| 22133 | 310 | Lang'ata | 9852930 | 255415 | 0 | 30 | 26.2 | 0.24 | 1.201 | 1 | 0.3 | 0.037 |
| 22116 | 220 | Karen | 9853794 | 244514 | 36 | 9 | 2.92 | 0.4 | 14.4 | 1.6 | <0.01 | 0.01 |
| 21687 | 250 | Ngong | 9842371 | 243370 | 105 | 20 | 1.1 | 1.3 | 9 | 7 | 0 | 0 |
| 13170 | 240 | Riruta | 9856862 | 248803 | 58 | 7 | 7.5 | 0.27 | 1.6 | 7.6 | 0 | 0.01 |
| 13843 | 230 | Ngong | 9848570 | 240232 | 114 | 25 | 0.8 | 0.01 | 28 | 5 | 0 | 0 |
| 13732 | 222 | Kandisi | 9846032 | 249068 | 6.1 | 40 | 10 | 0.6 | 16 | 30 | 0 | 0.06 |
| 4909 | 300 | Ndeiya | 9872080 | 232379 | 150 | 13 | 2.6 | 0.1 | 4.2 | 4.8 | 0 | 0.2 |
| 19970 | 300 | Lang'ata | 9857110 | 250773 | 98.8 | 17 | 13 | <0.01 | 1.6 | 4.46 | 0.1 | 0.01 |
| 11019 | 101 | Kangemi | 9859587 | 249324 | 8.7 | 0 | 1.3 | 0.01 | 2.4 | 7 | 0 | 0.05 |
| 19948 | 270 | Chiromo | 9859008 | 256155 | 72.5 | 10 | 9.2 | 2.53 | 1.6 | <0.3 | 0.24 | 0.01 |
| 12785 | 204 | Ongata Rongai | 9843446 | 248745 | 94.6 | 22 | 2.4 | 0.03 | 20 | 39 | 0 | 0.01 |
| 19913 | 250 | Nairobi West | 9854320 | 258019 | 94.5 | 16 | 11.04 | <0.01 | 2.4 | 2.86 | 0.8 | 0.01 |
| 19961 | 280 | Lang'ata | 9849411 | 257947 | 87.3 | 21 | 10 | 0.45 | 4 | 3.14 | 0.75 | 0.01 |
| 18550 | 119 | Mlolongo | 9845890 | 271433 | 381 | 220 | 10 | <0.01 | 0 | 188 | 1.2 | 0.01 |
| 17991 | 182 | Embakasi | 9853128 | 262041 | 142 | 65 | 7.6 | 0.03 | 8.8 | 28.9 | <0.01 | 0.01 |
| 14610 | 300 | Lang'ata | 9856168 | 250669 | 119.9 | 32 | 6 | 0.281 | 3.2 | 20 | 1.9 | 0.025 |
| 10626 | 167 | Ngong | 9850331 | 237821 | 137 | 64 | 2.3 | 0 | 13 | 11.3 | 4.4 | 0 |
| 14852 | 175.8 | Westlands | 9858969 | 254607 | 49.9 | 60 | 1.7 | 0.72 | 27.2 | 24 | 10 | 0.309 |
| 22043 | 282 | Starehe | 9858403 | 258030 | 344 | 207 | 8.99 | <0.01 | 6.4 | 0 | 0 | 0.01 |

## APPENDIX II: BOREHOLE LOGS

he Chief Executive **Officer**
Vater Resources Management Authority
.O. Box 45250 – 00100
AIROBI

Form: WRMA 004
Catchment: ATHI CATCHMENT AREA
WRMA ID: WRMA/40/01195
File: WRMA/40/MRG/4CB/10427/G

*Drillers Log*

Borehole No. **C- XXX**

| FROM (M) | TO (M) | DRILLING RATE (M/Hr) | DESCRIPTION OF THE PENETRATED FORMATION |
|---|---|---|---|
| 0 | 10 | | Red soils |
| 10 | 28 | | Clay soils |
| 28 | 38 | | Moderately fractured tuff |
| 38 | 56 | | Clay soils |
| 56 | 78 | | Welded tuff |
| 78 | 88 | | Compact / fractured upper Athi tuff |
| 88 | 100 | | Fracture / phonolite sediments |
| 100 | 150 | | Tuff sediments |
| 150 | 170 | | Weathered ponolites |
| 170 | 200 | | Decomposed/ fractured phonolites |

(Geologist's log on attached sheets)
Remarks or additional information on Driller's log, or on sketch of Borehole.

.............................................................................................
.............................................................................................
.............................................................................................
.............................................................................................
.............................................................................................
.......................................................

Total depth 200m

(Sketch include: - depth and changes of hole diameter, casing positions, manner of casing (of different diam.) connections, and casing connection to screen, depths of screen or slotted casing lengths, how casing is closed at bottom, formation caving zones, and any other pertinent information)

Page 4

Continuation ...

# HYDRO WATER BOREHOLE GEOLOGS

| | |
|---|---|
| *Location:* | Syokimau Area Machakos District |
| *Borehole No:* | WRMA/ACB/8235 |
| *Drilling Started:* | 3/11/2010 |
| *Drilling Completed:* | 6/11/2010 |

| DEPTH (M) | | DESCRIPTION |
|---|---|---|
| 0-2 | - | Black Cotton Soil |
| 2-4 | - | Decomposed Tuffs |
| 4-10 | - | Weathered tuffs |
| 10-18 | - | Weathered phonolites |
| 18-32 | - | Fractured phonolites |
| 32-50 | - | Moderately weathered Phonolites |
| 50-54 | - | Old land surface deposits |
| 54-60 | - | Brownish weathered tuffs |
| 60-64 | - | Greyish weathered tuffs |
| 64-74 | - | Blackish Weathered tuffs |
| 74-86 | - | Brownish weathered tuffs |
| 86-102 | - | Greyish weathered tuffs (Moist) |
| 102-120 | - | Athi series sediments |
| 120-154 | - | Highly weathered tuffeceous phonolites |
| 154-164 | - | Weathered tuffs ( aquiferous) |
| 164-174 | - | Weathered quartzo feldsphartic gneisses |
| 174-200 | - | Slightly weathered biotite gneisses grading to fresh |

**Total Drilled Depth:** **200mgl**

## APPENDIX III: SPECIFIC BOREHOLE CHEMICAL DATA

### Borehole C14288

REPUBLIC OF KENYA

MINISTRY OF HEALTH

GOVERNMENT CHEMIST'S DEPARTMENT

Telephone: 725806/7
P.O Box 20753
NAIROBI KENYA

**REPORT ON CHEMICAL ANALYSIS WATER**

Report Reference : P/WAT/VOL. 1/2004/341
Laboratory Sample No. W341/2004
Sender : Living Water Intl. Box 50839 NBI.
Source : Borehole-Langata.

Date: 14/10/2004
Date Received :08/10/2004
Date Sample Taken :

**RESULTS**

PHYSICAL TESTS

Colour : Less 5(Hazen Units)
Deposit : None
Taste : -
pH : 7.5

Turbidity : Clear (J.T.U)
Oduor : Not offensive(T.O.N)
Electrical Conductivity at 25°C (micro mhos/cm³)340.0

CHEMICAL TESTS

| | mg/1(ppm) | me/1 |
|---|---|---|
| Total Alkalinity as $CaCO_3$ | 150.0 | |
| Phemolphthalein ($CO_3$) = | 15.0 | |
| Methly Orange ($HCO_3$)- | 135.0 | |
| Chloride (Cl)- | 15.0 | |
| Sulphate ($SO_4$)= | 1.5 | |
| Nitrate ($NO_3$)- | Nil | |
| Nitrite ($NO_2$)- | Nil | |
| Fluoride (F)- | 1.5 | |
| Total Anions | | |
| Sodium (Na) + | 61.0 | |
| Potassium (K) + | 13.3 | |
| Calcium (Ca) ++ | 8.0 | |
| Magnesium (Mg)++ | 1.2 | |
| Iron (Total) (Fe) +++ | 0.007 | |
| Manganese (Mn)++ | Nil | |
| Ammonia-Free & Saline ($NH_4$)+ | 0.1 | |
| Ammonia-Albuminoid ($NH_4$)+ | Nil | |
| (Pb Cu Zn) | - | |
| Total Cations | | |

| | | | |
|---|---|---|---|
| Carbonate Hardness as ($CaCO_3$) | .. .. .. | 60.0 |
| Non-Carbonate Hardness as ($CaCO_3$) | .. .. .. | Nil |
| Total Hardness as ($CaCO_3$) | .. .. .. .. | 60.0 |
| Free Carbon Dioxide | .. .. .. .. | 12.0 |
| Silica ($SiO_2$) | .. .. .. .. .. .. | 50.0 |
| Oxygen absorbed. 4 hr. at 27°C (P.V.) | .. .. .. .. | 0.3 |
| Total Dissolved Solids, residue dried at 180°C | .. .. | 395.0 |

REMARKS: Moderately soft and neutral water that is well mineralized. The Fluoride and Iron levels exceed the WHO maximum guideline limit of 1.5ppm and 0.3ppm respectively for drinking water. Treatment to lower these levels to within the WHO limits is recommended.

**Borehole C20914**

# REPUBLIC OF KENYA

## MINISTRY OF WATER AND IRRIGATION

### Central Water Testing Laboratories

Tel No. (020) 553834, 553665
P.O. Box 30521-00100,
NAIROBI.

## PHYSICAL/CHEMICAL WATER ANALYSIS REPORT

Sample No..........1724............................................
Source.. B/H Syokimau Machakos.
Purpose of Sampling........Domestic............................

Date of Sampling ...10– 12 – 10.................
Date Received........15 – 12 – 10.................
Submitted by....Hydro Water well................
Address..................................................

| PARAMETERS | UNIT | RESULTS | REMARKS |
|---|---|---|---|
| pH | Ph Scale | 8.53 | |
| Colour | mgPt/l | <5.0 | |
| Turbidity | N.T.U. | 2.0 | |
| Permanganate Value (20 min. boiling) | $mgO_2/l$ | <0.4 | |
| Conductivity (25$^0$ C) | µS/cm | 828 | |
| Iron | mg/l | <0.01 | |
| Manganese | mg/l | <0.01 | |
| Calcium | mg/l | Nil | |
| Magnesium | mg/l | 1.94 | |
| Sodium | mg/l | 186.53 | |
| Potassium | mg/l | 0.4 | |
| Total Hardness | $mgCaCO_3/l$ | 8.0 | |
| Total Alkalinity | $mgCaCO_3/l$ | 248 | |
| Chloride | mg/l | 75 | |
| Fluoride | mg/l | 9.0 | |
| Nitrate | mgN/l | 0.38 | |
| Nitrite | mgN/l | <0.01 | |
| Ammonia | mgN/l | - | |
| Total Nitrogen | mgN/l | - | |
| Sulphate | mg/l | 31.7 | |
| Orthophosphate | mg/l | - | |
| Total Suspended Solids | mg/l | - | |
| Free Carbon Dioxide | mg/l | Nil | |
| Dissolved Oxygen | $mgO_2/l$ | - | |
| Total Dissolved Solids | mg/l | 513.4 | |
| Others | | | |

**COMMENTS**

**The water has high Fluoride content. Defluoridation or mixing with water of low Fluoride content is recommended to achieve the KEBS/WHO Standard of 1.5 mg/l. Other parameters are satisfactory.**

## Borehole C22329

MINISTRY OF HEALTH

Mobile: 0714 995000
Wireless: 020-2336300, 020-2336216, 020-2336214
Telephone: +254-20-2725806/7,
and +254-20-2725873/4 (four lines)
Fax: +254-20-2717567
E-mail: gchemist@wananchi.com
govchem@health.go.ke
when replying please quote
Ref. No. P/WAT/VOL.I/17/18/41
and date

GOVERNMENT CHEMIST'S DEPARTMENT
P.O. Box 20753-00202, KNH
NAIROBI

15th September, 2017 ......20......

# REPORT ON CHEMICAL ANALYSIS OF WATER

**Laboratory sample No** 53/17/18 **Date Received:** 6/9/17

**Sender:** Spar Drilling Co. Ltd
P. O. Box 40590 NAIROBI **Date sample taken**

**Source:-Borehole:** **(Mlolongo)**

**PHYSICAL TESTS**

| | | | | | |
|---|---|---|---|---|---|
| Colour: | - | (Hazen Units) | Turbidity | Clear | (J.T.U.'s) |
| Deposit | None | | Odour: | None | (T.O.N) |
| Taste | - | | | | |
| pH: | 10.0 | | Electrical Conductivity at 25 °c (microsiemens/cm) | 645.0 | |

**CHEMICAL TESTS**

| | Results *mg/l(ppm)* | *Max guideline value mg/l(ppm)* |
|---|---|---|
| Total Alkalinity as $CaCO_3$ | 340.0 | 500.0 |
| Phenolphthalein ($CO_3$) = | 100.0 | |
| Methyl Orange ($HCO_3$) | 240.0 | |
| Chloride (Cl)- | 70.0 | 250.0 |
| Sulphate ($SO_4$)= | 10.0 | 250.0 |
| Nitrate ($NO_3$)- | 2.3 | |
| Nitrite ($NO_2$)- | 0.016 | 3.0 |
| Fluoride (F)- | 11.6 | 1.5 |
| Total Anions | | |

**P.T.O**

| | Results mg/l(ppm) | Max guideline value mg/l(ppm) |
|---|---|---|
| Sodium (Na)+ | 117.3 | 200.0 |
| Potassium (K)+ | 9.4 | - |
| Calcium (Ca)++ | Not detected | - |
| Magnesium (Mg)++ | Not detected | - |
| Iron (Total) (Fe)+++ | 0.1 | 0.3 |
| Manganese (Mn)++ | 0.022 | 0.5 |
| Ammonia-Free & Saline (N) | | |
| Ammonia-Albuminoid (N) | - | |
| Total Cations | | |
| Carbonate Hardness as ($CaCO_3$) | Not detected | - |
| Non-Carbonate hardness as ($CaCO_3$) | Nil | - |
| Total Hardness as ($CaCO_3$) | Not detected | 500.0 |
| Free Carbon Dioxide | - | - |
| Silica ($SiO_2$) | 66.0 | - |
| Oxygen absorbed. 4 hr. at 27°C(P.V.) | 0.4 | 1.0 |
| Total Dissolved Solids, residue dried at 180°C | 450.0 | 1000.0 |
| **Optional Parameters (done on request)** | | |
| Lead ($Pb^{2+}$) | | |
| Copper ($Cu^{2+}$) | | |
| Zinc ($Zn^{2+}$) | | |

**REMARKS:**

**Very soft and alkaline water that is well mineralized.**
**The fluoride level is above the WHO maximum guideline value of 1.5 ppm for drinking water. The pH is also out of the guideline range of 6.5-8.5**
**Treatment to lower the fluoride level as well as to adjust the pH accordingly is recommended.**

**Borehole C 16021**

REPUBLIC OF KENYA

MINISTRY OF HEALTH

GOVERNMENT CHEMIST DEPARTMENT

Telephone: 725806/7
P.O. Box 20753
Nairobi, KENYA

# REPORT ON CHEMICAL ANALYSIS OF WATER

Report Reference No: P/WAT/VOL.I/2008/2
Laboratory Sample No. W2/08
Sender: Indepth Water Services, Box 74152 Nairobi

Date:
Date Received: 11/1/08
Date Sample Taken:

Syokimau MACHAKOS

## RESULTS

### PHYSICAL TESTS

Colour: < 5 (Hazen Units)
Deposit: None
Taste: _
pH: 8.5

Turbidity: Clear (J.T.U.'s)
Odour: None (T.O.N.)
Electrical Conductivity at 25° C (micro mhos/cm) 716.0

### CHEMICAL TESTS

| | *Results mg/1(ppm)* | *Max. Guideline Value mg/I (ppm)* | *me/1* |
|---|---|---|---|
| Total Alkalinity as $CaCO_3$...... | 285.0 | 500.0 | |
| Phenolphthalein $(CO)_3$ = ...... | 45.0 | – | |
| Methyl Orange $(HCO_3)$- ....... | 2400 | – | |
| Chloride (Cl)- .................. | 45.0 | 250.0 | |
| Sulphate $(SO_4)$= ............... | 350 | 250.0 | |
| Nitrate $(NO_3)$ .................. | Not detected | 50.0 | |
| Nitrite $(NO_2)$- .................. | 0.003 | 3.0 | |
| Fluoride (F)- .................... | 13.3 | 1.5 | |
| Total Anions............... | | | |
| Sodium (Na)+ .................. | 105.7 | 200.0 | |
| Potassium (K)+ ................ | 21.3 | – | |
| Calcium (Ca)++ ................ | Not detected | – | |
| Magnesium (Mg)++............ | Not detected | – | |
| Iron (Total) (Fe)+++............ | 0.2 | 0.3 | |
| Manganese (Mn)++ ............ | Not detected | 0.4 | |
| Ammonia-Free and Saline (N).. | – | – | |
| Ammonia-Albuminoid (N) ...... | – | – | |
| Total Cations............... | | | |

| | Results mg/1(ppm) | Max.guideline value mg/I (ppm) |
|---|---|---|
| Carbonate Hardness as ($CaCO_3$)................ | Not detected | — |
| Non-Carbonate hardness as ($CaCO_3$)........... | NIL | — |
| Total Hardness as ($CaCO_3$)...................... | Not detected | 500.0 |
| Free Carbon Dioxide ............................ | — | — |
| Silica ($SiO_2$)........................................ | 40.0 | — |
| Oxygen absorbed. 4 hr. at 27°C(P.V.)........... | 0.1 | 1.0 |
| Total Dissolved Solids, residue dried at 180°C. | 494.0 | 1500.0 |

**Optional Parameters (done on request)**

| | | |
|---|---|---|
| Lead ($Pb^{2+}$)........................................ | | |
| Copper ($Cu^{2+}$).................................... | | |
| Zinc ($Zn^{2+}$)........................................ | | |
| Phosphate ($PO_4^{3-}$)................................ | | |

**REMARKS:**

Very soft and alkaline water that is well mineralized. The Fluoride level exceeds the WHO maximum guideline value of 1.5ppm for drinking water.

Treatment to lower this level is recommended.

## Borehole C 21120

| | | |
|---|---|---|
| | **WATER RESOURCES MANAGEMENT AUTHORITY** | |
| | **TITLE:** Water Sample analytical certificate-physical chemical results | **REF NO:** F/9/1/29 |
| | | **ISSUE NO:** 23 |
| | **DEPARTMENT:** Technical | **REV. NO:** 20 |
| | **ISSUED BY:** DTCM | **DATE OF ISSUE:** 19/05/14 |
| | **AUTHORISED BY:** TCM | **PAGE:** 1 OF 2 |

SERIAL NO.........
Name of Customer:
Purpose of Sampling...Domestic.......................
Date Sampled...13/05/14.............................
Source..............B/Hole.............................

Sample No...2233.......................
Address... ..........................
County...Nairobi.............................
Date Received...12/05/14.....................
Date Compiled...19/05/14

| PARAMETERS | UNIT | RESULTS | WHO STANDARDS | KEBS(KS 459-1:2007)STANDARDS |
|---|---|---|---|---|
| pH | pH Scale | 7.75 | 6.5-8.5 | 6.5-8.5 |
| Colour | mgPt/l | 5 | Max 15 | Max 15 |
| Turbidity | N.T.U. | 5 | Max 5 | Max 5 |
| Conductivity (25°C) | µS/cm | 1500 | Max 2500 | - |
| Iron | mg/l | 0.21 | Max 0.3 | Max 0.3 |
| Manganese | mg/l | 0.00 | Max 0.1 | Max 0.5 |
| Calcium | mg/l | 24.8 | Max 100 | Max 150 |
| Magnesium | mg/l | 25.8 | Max 100 | Max100 |
| Sodium | mg/l | 11 | Max 200 | Max 200 |
| Potassium | mg/l | 6.2 | Max 50 | - |
| Total Hardness | $mgCaCO_3/l$ | 168 | Max 500 | Max300 |
| Total Alkalinity | $mgCaCO_3/l$ | 218 | Max 500 | - |
| Chloride | mg/l | 238 | Max 250 | Max 250 |
| Fluoride | mg/l | 2.74 | Max 1.5 | Max 1.5 |
| Nitrate | mgN/l | 6 | Max 50 | Max50 |
| Nitrite | mgN/l | 1.01 | Max 0.1 | Max 0.003 |
| Sulphate | mg/l | 33.5 | Max 450 | Max 400 |
| Free Carbon Dioxide | mg/l | 38 | | - |
| Total Dissolved Solids | mg/l | 930 | Max 1500 | Max 1000 |
| Arsenic | µg/l | - | Max 10 | Max 10 |
| Others | | - | | |

**Borehole C 14910**

REPUBLIC OF KENYA

MINISTRY OF HEALTH

GOVERNMENT CHEMIST'S DEPARTMENT

Tel. +254-20-2725806/7
Fax: +254-20-2717567
P.O. Box 20753-00202
NAIROBI, KENYA

# REPORT ON CHEMICAL ANALYSIS OF WATER

Report Reference No.
Laboratory Sample No. W 19/06

Date
Date Received: 21/01/06
Date Sample Taken:

## RESULTS

### PHYSICAL TESTS

Colour: <5 (Hazen Units)
Deposit: NONE
Taste: -
pH: 10.0

Turbidity: CLEAR (J.T.U.'s)
Odour: NONE (T.O.N.)
Electrical Conductivity at 25°C (Micro mhos/cm) 185.5

### CHEMICAL TESTS

| | *Results mg/l(ppm)* | *Max. Guideline Value mg/l(ppm)* | *me/l* |
|---|---|---|---|
| Total Alkalinity as $CaCO_3$ | 80.0 | 500.0 | |
| Phenolphthalein $(CO_3)=$ | 52.0 | - | |
| Methyl Orange $(HCO_3)-$ | 28.0 | - | |
| Chloride (Cl)- | 20.0 | 250.0 | |
| Sulphate $(SO_4)=$ | 4.0 | 250.0 | |
| Nitrate $(NO_3)-$ | NOT DETECTED | 50.0 | |
| Nitrite $(NO_2)-$ | NOT DETECTED | 3.0 | |
| Fluoride (F)- | 2.2 | 1.5 | |
| Total Anions | | | |
| Sodium (Na)+ | 5.4 | 200.0 | |
| Potassium (K)+ | 0.1 | - | |
| Calcium (Ca)++ | NOT DETECTED | - | |
| Magnesium (Mg)++ | NOT DETECTED | - | |
| Iron (Total) (Fe)+++ | 0.1 | 0.3 | |
| Manganese (Mn)++ | 0.005 | 0.4 | |
| Ammonia—Free and Saline (N) | - | - | |
| Ammonia—Albuminoid (N) | - | - | |
| Total Cations | | | |

| | Results mg/l(ppm) | Max. guideline value mg/l (ppm) |
|---|---|---|
| Carbonate Hardness as ($CaCO_3$) | NOT DETECTED | |
| Non-Carbonate Hardness as ($CaCO_3$) | NIL | |
| Total Hardness as ($CaCO_3$) | NOT DETECTED | |
| Free Carbon Dioxide | NOT DETECTED | |
| Silica ($SiO_2$) | 20.0 | |
| Oxygen absorbed. 4 hr. at 27$^0$C (P.V.) | 0.2 | |
| Total Dissolved Solids, residue dried at 180$^0$C | 130.0 | |

**Optional Parameters (done on request)**

| | | |
|---|---|---|
| Lead ($Pb^{2+}$) | | |
| Copper ($Cu^{2+}$) | | |
| Zinc ($Zn^{2+}$) | | |
| Phosphate ($PO^{3-}_4$) | | |
| | | |
| | | |
| | | |

REMARKS: VERY SOFT AND HIGHLY ALKALINE WATER THAT IS FAIRLY WELL MINERALIZED. THE FLUORIDE LEVEL EXCEEDS THE WHO MAXIMUM GUIDELINE LIMIT OF 1.5PPM FOR DRINKING WATER. THE PH OF THE WATER IS OUT OF THE RECOMMENDED RANGE OF (6.5 - 8.5). TREATMENT TO LOWER THE FLUORIDE LEVEL FOLLOWED BY NEUTRALIZATION OF THE WATER IS RECOMMENDED.