# Assessment of Groundwater Quality in Nairobi County, Kenya

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**A thesis submitted in partial fulfillment for the degree of Master of Science in Environmental Legislation and Management in the Jomo Kenyatta University of Agriculture and Technology**

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# DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with our approval as University supervisors.

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# DEDICATION

This work is dedicated to my dear brother, Mr. David Ndirangu, and my loving family. Their love and support was my source of inspiration. To the almighty God, for giving me strength and endurance. To God be the glory, Amen.

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# ABREVIATIONS AND ACRONYMS

| | |
|---|---|
| **APHA** | American Public Health Association |
| **AWWA** | American Water Works Association |
| **CWTL** | Central Water Testing Laboratories |
| **DF** | Degree of Freedom |
| **EC** | European Commission |
| **EPA** | Environmental Protection Agency |
| **GoK** | Government of Kenya |
| **IARC** | International Agency for Research on Cancer |
| **JKUAT** | Jomo Kenyatta University of Agriculture and Technology |
| **KARI** | Kenya Agricultural Research Institute |
| **KEBS** | Kenya Bureau of Standards |
| **MCL** | Maximum Contaminant Level |
| **MWI** | Ministry of Water and Irrigation |
| **NEMA** | National Environmental Management Authority |
| **NTU** | Nephelometric Turbidity Units |
| **pH** | Potentialmetric Hydrogen |
| **TCU** | True Colour Units |
| **TDS** | Total Dissolved Solids |
| **UN** | United Nations |
| **UNEP** | United Nations Environment Programme |
| **UNESCO** | United Nations Education, Scientific and Cultural Organization |

| | |
|---|---|
| **USEPA** | United States Environmental Protection Agency |
| **WEF** | Water Environment Federation |
| **WHO** | World Health Organization |
| **WRMA** | Water Resources Management Authority |

# ABSTRACT

Nairobi is one of the regions where limited resources and services are facing relentless pressure due to rapid population growth and water as a resource is of no exception. Although Water Resources Management Authority (WRMA) carries out regular monitoring of water quality in Nairobi, only a few boreholes are monitored and only very few parameters are analyzed. The objective of the present study was to assess the quality of groundwater in Nairobi to ascertain its quality and compare with World Health Organization (WHO) (2008) and National Environment Management Authority drinking water standards. Water samples were obtained from thirty selected boreholes distributed in various divisions of Nairobi during the wet and dry seasons. The study area was divided into six administrative zones namely; Kasarani/Roysambu (Zone A), Dagoretti/Kawangware (Zone B), Embakasi (Zone C), Karen/Lang'ata (Zone D), City Centre (Zone E) and Industrial area (Zone F). Physical parameters: temperature, pH, total dissolved solids, turbidity and conductivity are some of the parameters that were determined on site. Concentrations of nutrients: $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, $NO_3^-$, $NO_2^+$, $Cl^-$, $SO_4^{2-}$and heavy metals; Zn, Cd, Hg, Cu, Ni, As, Cr and Pb were all analyzed using standard methods. The data was analyzed using Excel software. Physical parameters varied; total dissolved solids (207-688 mg/L), turbidity (1.7-19.7 NTU), conductivity (0.32-0.99 µS/cm), temperature (22.8-27.3$^{o}$C) and colour (<5-5 TCU). Chemical parameters also varied; free $CO_2$ (0.0-27.2 mg/L), dissolved $O_2$ (6.7-17.7 mg/L), pH (5.7-8.8), $Na^+$ (23-207 ppm), $K^+$ (1.9-5.7 ppm), $Ca^{2+}$ (3.8-16.3 ppm), $Mg^{2+}$ (0.0-4.8 ppm), $NO_3^-$ (0.5-2.8 mg/L), $NO_2^-$ (<0.01-0.09 mg/L), $Cl^-$ (7.6-120.8 mg/L), $SO_4^{2-}$ (1.1-

30.4 mg/L), total hardness (9.6-44.8 mg/L), Zn (0.01-0.38 ppm), Cd (0.00-0.03 ppm), Cu (0.0-2.6 ppm), Ni (0.024-0.38 ppm), Cr (0.0-0.49 ppm), Pb (0.11-0.30 ppm), As (0.00-0.013 ppm) and Hg (0.001-0.003 ppm). The parameters total dissolved solids, $NO_3^-$, $NO_2^-$ , $Cl^-$, $SO_4^{2-}$, $Ca^{2+}$, $Mg^{2+}$, total hardness, Zn and Hg were within the WHO (2008) consumers' acceptable limits. Only one borehole exceeded the consumers' acceptable colour limit of 15 TCU, all other boreholes were within the WHO (2008) drinking water standards. Highest pH mean value of 8.75 was recorded from zone D. For boreholes sampled, Cu was found to be below detection limit except for two boreholes in industrial area (A.C 29 and F.E.30) which were above WHO (2008) drinking water standards during the wet season. High levels of Cd and Cr were detected in boreholes in zones A, B and F during the dry season, with zone B recording the highest mean value of 0.03±0.01 ppm and 0.49±0.02 ppm of Cd and Cr respectively. Arsenic was within WHO (2008) drinking water standards for most sampled boreholes except for boreholes E.A.21 and M.W.25 in the city centre. All the sampled boreholes showed high concentrations of Ni and Pb which were above WHO (2008) drinking water standards during the dry season. The results suggest that groundwater from Nairobi boreholes need to be treated so that the water could meet WHO (2008) drinking water standards. Plain sedimentation or use of cloth/membrane filters may remove turbidity while nanofiltration could be used to remove heavy metals.

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.2 Background information

The Water Act, 2002 defines “pollution” in relation to a water resource as any direct or indirect alteration of the physical, thermal, chemical or biological properties of the water resource so as to make it less fit for any beneficial purpose for which it is or may reasonably be expected to be used; or make it harmful or potentially harmful to the welfare, health and safety of human beings, any aquatic or non-aquatic life or property or the environment.

There are several governing legislations in Kenya that undertake water quality surveillance by controlling, regulating or monitoring and/or evaluation, among them being the Environmental Management and Coordination Act (EMCA) 1999, the Water Act 2002, the Public Health Act Cap 242, and the Standards Act Cap 496 of the Laws of Kenya.

## 1.2 The study area

### 1.2.1 Position and size

Nairobi City, the capital of Kenya, is situated at an elevation of about 1661 m above sea level (a.s.l) in the highlands of the southern part of the country with a total area of 696 km$^2$ (268.7 sq mi). Nairobi is adjacent to Kajiado to the eastern edge of the Rift Valley and neighbours Kiambu county to the North and Machakos county to the Southeast. Nairobi is Kenya's principal economic, administrative, and cultural center and is one of the largest and fastest growing cities in Africa. Nairobi is divided into a series of parliamentary constituencies, namely Makadara, Kamukunji, Starehe, Langata, Dagoretti, Westlands, Kasarani and Embakasi. The main administrative divisions of Nairobi are Central, Dagoretti, Embakasi, Kasarani, Kibera, Makadara, Pumwani and Westlands (Wikimedia, 2013).

### 1.2.2 Population growth

The 2009 national population census established the Nairobi city population to be about 3.14 million up from 2.14 million in 1999, living within 696 km$^2$ (269 sq mi) (GoK, 2010). Nairobi is the most populous city in East Africa with a population density of 4,509 per square kilometer. It is estimated that Nairobi's population will reach 5 million in 2020 (Omwenga, (2011). Nairobi is currently the 12th largest city in Africa, based on population (Wikimedia, 2013).

The rapid population growth in Nairobi City has exerted relentless pressure on limited resources and services such as housing, water supply and sanitation, education and health facilities. The increased demand for housing has resulted in mushrooming of unplanned settlements and slums, with inadequate or lack of water supply and sanitation services. Surface water is still the main source of drinking water in Nairobi. Consequently, inhabitants have had to increasingly rely on groundwater to supplement their sources. Groundwater is has become the principal and sometimes the only source of drinking and industrial water in several parts of Nairobi. The number of boreholes and hand-dug wells keep on increasing annually. The increasing groundwater usage is based on the postulation that groundwater, being precluded from the atmosphere, is less susceptible to pollution.

### 1.2.3 Topography and climate

The topography of the study area drops from 2000 m a.s.l. in the west to 1600 m a.s.l. in the east showing a general eastwards declining trend. The Ngong hills, located to the west of the city, are the most prominent geographical features of the Nairobi Area. The Nairobi River and its tributaries traverse through the Nairobi County. Nairobi has an elevation of 1661 m (5450 ft) above the sea-level and hence enjoys a fairly moderate climate. The altitude makes for some chilly evenings, especially in the June/July season when the temperature can drop to 10 °C (50 °F). The long rainy season falls between April and June while the short rainy season is October to November. August to September and December to March comprises the sunny and warm times of the year when temperatures average the mid-twenties during the day. As Nairobi is situated close to the equator, the difference between the seasons is minimal and has a subtropical highland climate (Wikimedia, 2013).

### 1.2.4 Land use

The sequence of land use, soil and vegetation zones is closely related to altitude and rainfall. Above 2300 m, a dense indigenous forest still exists, replaced locally by commercial conifer plantations. Below this level the forest has largely been cleared and the land given over to mixed smallholder farming with perennial tea, pasture and a range of annual crops. Nairobi area has been categorized into five key land uses mainly plantation, forest, grassland, agriculture and town. Figure 1 shows the distribution of various land uses in Nairobi.

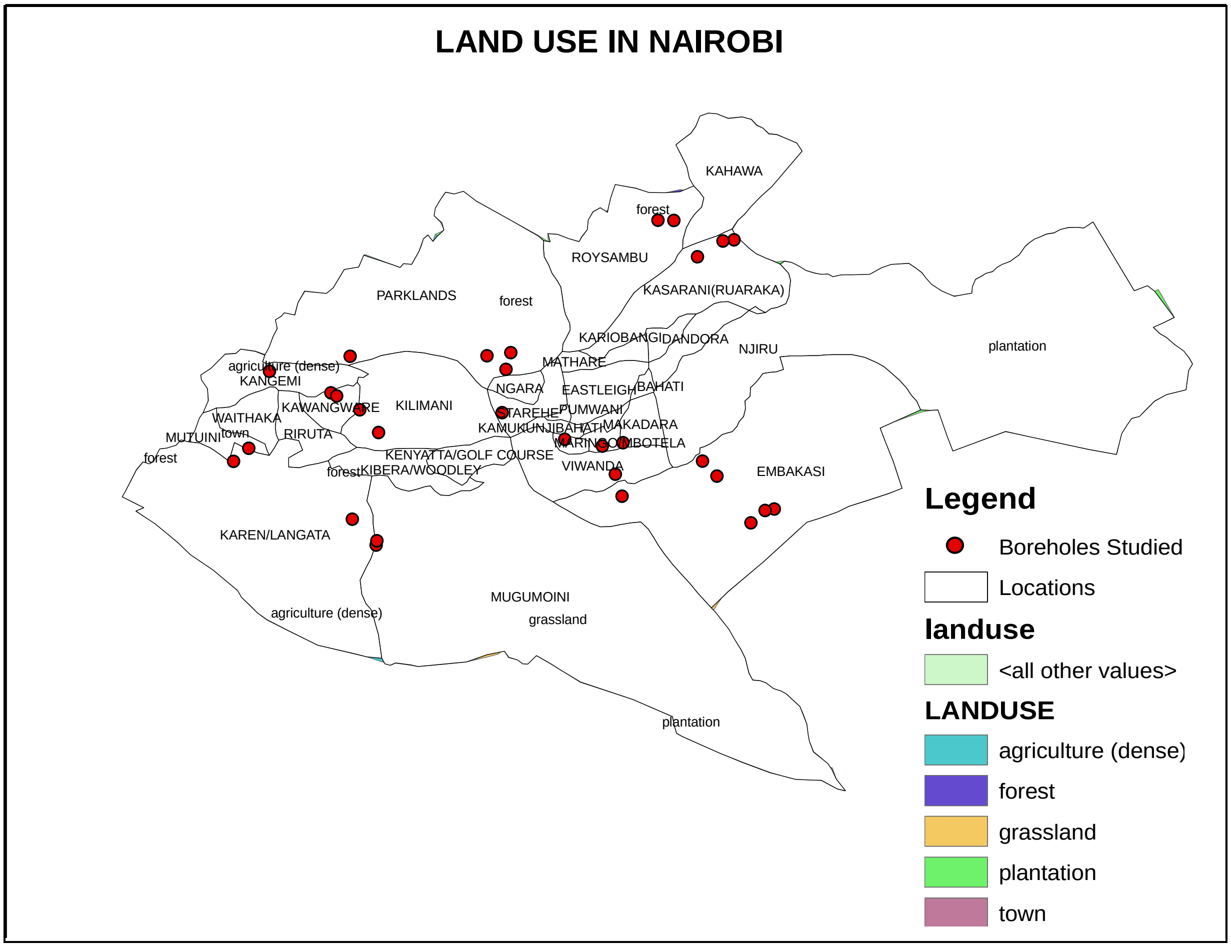


**Figure 1: Land use in Nairobi**
**Source: GoK (1983).**

### 1.2.5 Water supply and waste management practices

Water supply is managed by Nairobi Water and Sewerage Company which is contracted by the Water Services Boards which are under the Ministry of Water and Irrigation that oversees the overall management of water resources in the Kenya. Nairobi Water and Sewerage Company has treatment plants in various locations and sewage and surface water quality is monitored. Waste is managed by private companies that are licensed by NEMA. The management is not efficient as wastes take long to be collected. Oozing liquid also percolates into the soil. In many places, we have endangered the quality of groundwater by dumping poisonous waste materials where leachate from wastes could reach an aquifer (Michael, 1994).

Water supply and management in urban areas is complicated not only by increases in population, but also due to the nature of urbanization itself. The large number of multiple pollution sources such as sewers/latrines, cemeteries, domestic waste and landfills found in urban areas, complicate urban groundwater protection. These sources are compounded by variable dynamic distributions in hydraulic head due to complex abstraction patterns and often a multitude of abandoned boreholes in urban areas (Cronin *et al.*, 2003). In addition to these technical problems, there are socio-economic issues such as under-investment in the infrastructure needed for water provision (Sinclair, 2000). In formulating the Water Policy and Management Strategy, it was recognized that the major causes of morbidity are due to diseases or conditions arising from the low level of safe drinking water, lack of hygienic sanitation and poor environmental conditions (GoK, 2002b).

Groundwater may become contaminated due to improper disposal of liquid wastes, defective well construction and failure to seal abandoned wells. These provide openings for the downward movement of water into subsurface formations without the process of natural infiltration. Contamination may also take place through the movement of waste water through large openings such as animal burrows, fissures in rocks, coarse gravel formations or manmade excavations (Raghunath, 1987). A greater diversity of re-use management systems needs to be actively considered for developing country cities, especially in their peri-urban areas, as rapid urbanization, increasing volumes withdrawn from the underlying urban aquifers, and the high capital and maintenance costs associated with convectional piped systems mean that they are not viable options for the near future (Drangert and Cronin, 2004). Careful and informed choices are vital.

## 1.3 Problem statement

Urbanization has led to constraint of water resources while climate change has led to reduced amounts of surface water. Many parts in Nairobi have been experiencing water shortage of late with some areas lacking reliable water supply for several months. This has led to the population opting for borehole water as an alternate source. By 1964, the Nairobi area contained many more boreholes than any other comparable area of the country (Gevaerts, 1964). Available data from the Ministry of Water and Irrigation shows that there are over two thousands five hundred (2,500) boreholes in Nairobi (GoK, 2009).

Although Water Resources Management Authority is required to monitor water quality, it is limited to a few parameters and few boreholes due to high cost of analysis and lack of facilities.

## 1.4 Rationale and justification

Nairobi city has realized tremendous increase in human population, coupled with industrial expansion and other land uses thus overstretching water requirements in Nairobi. With increased drilling of boreholes and the pollution of surface water in Nairobi, there is a possibility of groundwater pollution through seepage. Inadequate liquid and solid waste management especially of industrial refuse may also contribute to groundwater contamination, as the pollutants infiltrate into the aquifer. If some ions/trace elements are above certain limits, they become hazardous to human health.

The Kenya national long term planning strategy referred to as ‘Kenya Vision 2030’, covering the period 2008 – 2030 aims to transform Kenya into a newly industrializing, “middle-income country, providing a high quality life to all its citizens by the year 2030”. It is therefore important to conduct a study on groundwater quality with emphasis to heavy metals to help in the planning and management of groundwater. Provision of safe water will be a contribution towards achievement of the 'Kenya Vision 2030'.

## 1.5 Hypothesis

### 1.5.1 Null hypothesis

(i) Groundwater in Nairobi is not contaminated with heavy metals

(ii) There is no polluted surface water seepage into underground aquifers

(iii) There is no inter-relationship between water quality and land use in the study area

### 1.5.2 Alternative hypothesis

(i) Groundwater in Nairobi is contaminated with heavy metals

(ii) There is polluted surface water seepage into underground aquifers

(iii) There is an inter-relationship between water quality and land use in the study area

## 1.6 Objectives

### 1.6.1 Main Objective

The main objective of the study was to determine the quality of groundwater in Nairobi and to ascertain if it was within WHO (2008), and NEMA/KEBS drinking water standards.

### 1.6.2 Specific objectives

(i) To determine physical properties of groundwater (turbidity, total dissolved solids (TDS), conductivity, colour and temperature)

(ii) To determine chemical properties of groundwater ($NO_3^-$, $NO_2^+$ ,$K^+$, $Na^+$, $Ca^{2+}$, $Mg^{2+}$, Cl, $SO_4^{2-}$, total hardness, pH, total alkalinity, dissolved oxygen (DO) and free $CO_2$)

(iii) To determine the concentration of selected heavy metals in groundwater (Zn, Cd, Hg, Cu, Ni, As, Pb, Cr)

(iv) To compare concentration of analytes/parameters with those of WHO (2008) so as to determine the water quality.

## 1.7 Significance of study

To ensure sustainable provision of good quality water to the population and achieve the ‘Kenya Vision 2030’, continuous monitoring and evaluation of trace metals is essential. The results of the study are expected to be useful to planners, scientists, researchers, policy makers and decision makers involved in the monitoring and regulation of water quality especially the Ministry of Water and Irrigation (MWI), Water Resources Management Authority (WRMA), National Environment Management Authority (NEMA) and Kenya Bureau of Standards (KEBS), whereby the quality status of underground water will be known with certainty and applicable recommendations given. Owners of the boreholes will be advised on whether the water will require further treatment before pumping for domestic consumption. This will have a direct health benefit to domestic water users.

## 1.8 Scope and limitations

The study area was divided into Kasarani/Roysambu area (Zone A), Dagoretti/Kawangware area (Zone B), Embakasi area (Zone C), Karen/Lang’ata area (Zone D), City Centre area (Zone E) and Industrial area (Zone F) according to their various land uses.

In regard to land use, Industrial area is dominated by light and heavy commercial industries while Dagoretti/Kawangware area is an agricultural zone near Ngong, which is one of the recharge zones for groundwater in Nairobi. Karen/Lang’ata area neighbours the national park, the City Centre area is an administrative and commercial zone while Embakasi area neighbours the lower part of industrial area. Kasarani area is on a lower elevation neighbouring plantations.

## 1.9 Definition of terms

### (a) Limit of Detection (LOD) or detection limit

This is the lowest concentration level that can be determined to be statistically different from a blank (99 percent confidence). The LOD is typically determined to be in the region where the signal to noise ratio is greater than 5. Limits of detection are matrix, method, and analyte specific.

### (b) Precision

Precision is a measure of the random error associated with a series of repeated measurements of the same parameter within a sample. Precision describes the closeness with which multiple analyses of a given sample agree with each other, and is sometimes referred to as reproducibility. Precision is determined by the absolute standard deviation, relative standard deviation, variance, coefficient of variation, relative percent difference, or the absolute range of a series of measurements.

**(c) Sensitivity** means the ability of a method or instrument to detect an analyte at a specified concentration.

### (d) Maximum Contaminant Level (MCL)

MCL is a numerical value expressing the maximum permissible level of a contaminant in water which is delivered to any user of a public water system.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Introduction

Ground water is the water under the earth’s surface that flows freely through tiny pores and cracks in rock and soil. Major cations, principally $Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$ are generally essential for human health and metabolism. Anions such as $Cl^-$, $NO_3^-$ , $NO_2^-$ and $SO_4^{2-}$ as well as traces of heavy metals such as Cd, Hg, Cu, Ni, As, Cr and Pb are toxic to human health. However, if some of these substances particularly the minor and trace elements occur in drinking water above certain limits, they become hazardous to health or affect aesthetic of water that makes it objectionable to the consumer.

### 2.1.1 Factors influencing water composition

A number of factors influence water chemistry. Gibbs (1970) proposed that rock weathering, atmospheric precipitation, evaporation and crystallization control the chemistry of surface water. The influence of geology on chemical water quality is widely recognized (Gibbs, 1970). The influence of soils on water quality is very complex and can be ascribed to the process controlling the exchange of chemicals between the soil and water (Hesterberg, 1998). Acid rain may encourage dissolution of elements such as Al, Mn, Be, and Fe from host rocks (Kortatsi, 2007). For instance, (William and Smith, 1994) reported acid waters draining from a gold mining area in Zimbabwe with arsenic concentration of up to 72 $mgL^{-1}$. (Smedley *et al.*, (1995) stated that many hard rock aquifers contain sulphide minerals particularly in their vein complexes that may include high concentrations of other toxic metals such as As, Sb, Pb, and Ba.

Report by (Raghunath, 1987) highlighted saltwater intrusion, organic, and inorganic and heat pollution by sewage and industrial wastes and pollution of good quality aquifers by bad quality aquifers because of faulty construction methods as the main factors affecting quality of groundwater. Contamination and disturbance of natural conditions caused by drilling operations bring new materials into the aquifer, comprising drilling fluids, gravel pack or casing materials. Boreholes which have been out of production for some time may yield a water chemistry which is different during production. Excessive pumping or over pumping may draw waters with different composition towards the screen and cause mixing of waters (Appelo and Postma, 1996). Vertical fluxes of pesticides can cause contamination of groundwater, particularly in areas with negligible slope, high rainfall and soils having high infiltration rates. *Haria et al.,* (2003) found contamination of shallow groundwater by pesticides due to high rates of both matrix and preferential flow, whilst where the groundwater was deeper, ‘intermediate’ storage sites remained empty and unsaturated water profiles showed that rainfall pulses were attenuated. The depth of the groundwater table is also very relevant (Johnson *et al.,* 2001). Vertical fluxes depend on rainfall/irrigation conditions (Schierholz *et al*., 2000), irrigation method (Blackwell, 2000) and tillage (Malone *et al.*, 2003).

Spatial variability plays a major role in vertical fluxes. Investigations by (Netto *et al.,* 1999) showed variability in the transport characteristic of pesticides, coming to the conclusion that this was affected by spatial variability in particular through preferential flow. Nitrate-N groundwater contamination, a global problem, arises mainly from diffuse agricultural sources. It is important to note that nitrate pollution is not only an environmental issue but also an economic and human health problem (DEFRA, 2002a; DEFRA, 2002b). A study conducted in southern Alberta, Canada, showed that high concentrations of sulfate in the vicinity of the excavation (above 1000 mg/L) were inferred to derive from the downward migration of recharge water with high sulfate concentrations from the weathered zone to the water table associated with excavation-focused infiltration and recharge (Stempvoort *et al.,* 2007). Groundwater is often less vulnerable to the immediate influence of contamination sources due to the barrier effects provided by the overlying soil and its unsaturated zone. Groundwater contamination is more frequent where these protective barriers are breached, allowing direct contamination. This may occur through contaminated or abandoned wells or underground pollution sources, such as latrines and sewer lines. However, a number of studies have demonstrated pathogens and indicator organisms in groundwater, even at depth in the absence of such hazardous circumstances, especially where surface contamination is intense, as with land application of manures or other faecal impacts from intensive animal husbandry such as feedlots (WHO, 2008).

Studies on vulnerability and pollution of groundwater in Kisauni, Kenya, by (Munga *et al.*, 2004) revealed that groundwater in Kisauni was experiencing a high degree of microbial contamination. (Kilonzo, 2005) carried out a hydrogeochemical study of Nairobi area. He analyzed the major and minor ions and key physical-chemical parameters. In his conclusion, he classified groundwater resources into two water types; CaCl (or NaCl), according to the Piper method water type which occurs in the Kikuyu area, and $NaHCO_3$ type for the Industrial area, City centre area and Karen/Langata area according to both the Stuyfzand classification system and Piper method (Stuyfzand, 1986). The $NaHCO_3$ water type is influenced by the dominance of sodium in the alkaline igneous rock while the bicarbonate water type is as a result of $CO_2$ dissolution and carbonation of silicate rock minerals. The NaCl sub type occurs under the conditions $(Na+K+NH_4)>0.5\sum k^*$; $(Na+K)>NH_4$; $Na>K$; $Cl>0.5\sum a^{**}$ while CaCl subtype occurs when $(Na+K+NH_4)\leq 0.5\sum k$; $(Ca+Mg)>Al+H+Fe+Mn)$; $Ca>Mg$; $Cl>0.5\sum a$ where $\sum k^*$ is the sum cations and $\sum a^{**}$ is the sum anions (Stuyfzand, 1986). Nairobi area was also identified to be characterized by high fluoride content.

Inadequate solid waste management especially industrial refuse, is also a source of groundwater contamination through infiltration. With Nairobi being a City, increasingly uncontrolled abstraction of groundwater may eventually reverse the natural hydraulic gradient. It is therefore important to carry out water quality assessment for sustainable management of water bodies. The Water Act, 2002, legalizes the abstraction of groundwater and every person abstracting groundwater by means of a well is required to prevent contamination or pollution of the water. This study will provide an indication of groundwater quality status in Nairobi City.

### 2.1.2 Driving forces of groundwater contamination

#### (i) Population growth

Population density affects the degree of pressure on the water resources among other resources. The natural balance of groundwater quality in Nairobi is countered by migration from other areas in search for settlement, land for public utilities such as schools, dispensaries and churches, or other commercial activities such as processing and manufacturing industries. In general, the population in Nairobi make most use of the resources and thus utilising the resources unsustainably including groundwater since they all compete for the same resources.

#### (ii) Industrialization

Nairobi has seen a growth in industries due to a ready market of their produce from the high population. Environmental friendly chemicals are used in processing and manufacturing, and heavy metals are used in industries; there is discharge of these chemicals and heavy metals into the sewers as well as into the soil. These pose a great risk to surface and groundwater resources.

### (iii) Black markets

Though the government has put strict measures for substandard products, substandard imported products as well as locally manufactured goods still get their way into the Kenyan market. A good example is Eastleigh and Kariobangi where imitated electronics products are dominant. There is a possibility that some products may contain levels of chemicals and/ heavy metals which have been prohibited or above permissible limits.

### (iv) Climate change

Climate change has resulted to imbalance of hydrological cycle. In 2009, Nairobi was faced by severe water shortage due to decreased river flows due to unreliable rainfall. This led to a massive demand of borehole water as the only reliable water for domestic and industrial water in some areas. Reduced surface water has led to reduced groundwater recharge; hence the natural dilution process of groundwater is expected to change. This can have an adverse effect on water quality.

### (v) Changes in land use

Natural land use is being turned into different use not limited to industrial, settlements and urbanization. Such conversions lead to change in landscape which can alter flows and infiltration characteristics of surface and groundwater. Building materials are imported from other areas which change natural characteristics of ground such as permeability. Some of these uses increase weathering of rock materials thus increasing infiltration. Digging of shallow wells which are not equipped can also pose a threat to groundwater contamination.

## 2.2 Sources, effects and acceptable limits of water quality parameters

### 2.2.1 Physical-chemical parameters

The term “colour” is used to mean true colour, that is, the colour of water from which turbidity has been removed. Colour in water result from the presence of minute quantities of metallic ions, peat and humus materials from decaying vegetation matter and industrial wastes (Khopkar, 2006). Drinking water should ideally have no colour. Levels of colour below 15 TCU (True Colour Units) are usually acceptable to consumers, but acceptability may vary. No health-based guideline value is proposed for colour in drinking-water. Coloured water may become objectionable to consumers. Taste and odour can originate from natural inorganic and organic chemical contaminants and biological sources or processes such as aquatic microorganisms, from contamination by synthetic chemicals, from corrosion, or as a result of water treatment, such as chlorination. Taste and odour may also develop during storage and distribution due to microbial activity. Taste and odour in drinking-water may be indicative of some form of pollution or of a malfunction during water treatment or distribution. It may therefore be an indication of the presence of potentially harmful substances (WHO, 2008).

The pH is defined as “intensity” factor of acidity. At a given temperature, the intensity of acidic or basic character of a solution is indicated by pH or hydrogen ion activity. WHO (2008) determined a range of 6.5 to 8.5 which would achieve the maximum environmental and aesthetic benefits. For effective disinfection with chlorine, the pH should preferably be less than 8; however, lower-pH water is likely to be corrosive. The alkalinity of water is its acid-neutralizing capacity. It is the sum of all the titratable bases. Slightly acidic ground water in Norway seemed to be more influenced by the leachate from the landfill increasing acidity and elevated levels of most metals and salts (Haarstad, 2008). Strongly alkaline waters have an objectionable "soda" taste. Highly mineralized alkaline waters also cause excessive drying of the skin due to the fact that they tend to remove normal skin oils. For some metals, alkalinity (carbonate and bicarbonate) and calcium (hardness) also affect corrosion rates. Without acid-neutralizing capacity, any acid added to a stream would cause an immediate change in the pH.

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather that transmitted with no change in direction or flux level through the sample. The appearance of water with a turbidity of less than 5 NTU is usually acceptable to consumers, although this may vary with local circumstances. Turbidity is caused by suspended and colloidal matter mainly from finely divided organic and inorganic contents (Khopkar, 2006).

Dissolved oxygen is one of the best indicators of the health of a water ecosystem and typically range from 0 to 18 parts per million (ppm), but most natural water systems require 5 to 6 ppm to support a diverse population. Natural stream purification processes require adequate oxygen levels in order to provide for aerobic life forms. As dissolved oxygen levels in water drop below 5.0 mg/l, aquatic life is put under stress. Decreases in the dissolved oxygen levels can cause changes in the types and numbers of aquatic macroinvertebrates which live in a water ecosystem. In addition, the amount of oxygen that can dissolve in water depends on temperature. Colder water can hold more oxygen in it than warmer water. The solubility of dissolved gasses is 14.6 mg/L at 0 °C and reduces to 7 mg/L at 35 °C at one atmospheric pressure (Khopkar, 2006).

Free carbon dioxide can cause death by suffocation if inhaled in large amounts. It is a fairly stable compound but decomposes at very high temperatures into carbon and oxygen. It is fairly soluble in water, one volume of it dissolving in an equal volume of water at room temperature and pressure; the resultant weakly acidic aqueous solution is called carbonic acid. The copper corrosion rate increase with the concentration of free carbon dioxide. The total dissolved solids concentration can be related to the conductivity of the water, but the relationship is not a constant.

The relationship between total dissolved solids and conductivity is a function of the type and nature of the dissolved cations and anions in the water and possibly the nature of any suspended materials. Total dissolved solids (TDS) is a measure of the total ions in solution while electrical conductivity (EC) is a measure of the ionic activity of a solution in term of its capacity to transmit current. The TDS comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) and small amounts of organic matter that are dissolved in water. The TDS in drinking-water originates from natural sources, sewage, urban runoff and industrial wastewater. Therefore, a TDS test provides a qualitative measure of the amount of dissolved ions, but does not tell us the nature or ion relationships (Oram, 2001). WHO (2008) has set TDS acceptable limits at 1200 mg/L.

Hardness is caused primarily by mineral compounds of calcium and magnesium, but is expressed as mg/L equivalent of calcium carbonate. Total hardness is commonly expressed in parts per million (ppm) of calcium carbonate ($CaCO_3$), degrees hardness (dH), grains per gallon (gpg) or, more properly, the molar concentration of $CaCO_{3.}$ However, in most waters, alkalinity and hardness have similar values because the carbonates and bicarbonates responsible for total alkalinity are usually brought into the water in the form of calcium carbonate or magnesium carbonate. The American Society of Engineers (ASE, 1996) classifies water hardness containing up to 60 ppm as soft water and more than 180 ppm as hard water.

The major concern with elevated levels of hardness would demonstrate the following signs: difficulty working up lather from a bar of soap, decreased washing ability of many soaps and detergents having dingy laundry in spite of one's efforts to get it clean, dry skin and dull, limp hair due to a film left by soap on one's body and hair when taking shower or bath; one has to battle soap scum on bathtubs, shower tiles and doors, basins, and fixtures. High levels of hardness also cause increased build-up of scale on cookware such as tea kettle, coffee maker, and pasta pot. Plumbing also contains scale, clogged pipes or appliances which reduce water flow hence increasing water heating costs. Build up of mineral deposits necessitates replacement of hot water heating elements more often. High hardness level can make water have an unpleasant taste.

Calcium is vital to the strength of our bones. Small concentrations of calcium carbonate combat corrosion of metal pipes by laying down a protective coating. Appreciable calcium salts on the other hand, precipitate on heating to form harmful scale in boilers, pipes and cooking utensils. Humans take in between 250 and 350 mg/day of magnesium and need at least 200 mg, but the body deals very effectively with this element, taking it from food when it can, and recycling what we already have when it cannot. There is no evidence that magnesium produces systemic poisoning although persistent over-indulgence in taking magnesium supplements and medicines can lead to muscular weakness, lethargy and confusion (Lenntech, 2009).

Nitrates and nitrites are naturally occurring inorganic ions that are part of the nitrogen cycle. Microbial action in soil or water decomposes wastes containing organic nitrogen into ammonia, which is then oxidized to nitrite and nitrate. Because nitrite is easily oxidized to nitrate, nitrate is the compound predominantly found in groundwater and surface waters. Many local sources of potential nitrate contamination of groundwater exist such as sites used for disposal of human and animal sewage; industrial wastes related to food processing, munitions, and some polyresin facilities and sites where handling and accidental spills of nitrogenous materials may accumulate (Hallberg and Keeney, 1993). Contamination also results from nitrogen containing fertilizers such as potassium nitrate and ammonium nitrate. Nitrate containing compounds in the soil are generally soluble and readily migrate with groundwater. Many areas of the United States and other countries have reported significant contamination of groundwater from septic tanks with groundwater contamination usually related to the density of septic systems (Hallberg and Keeney, 1993). In densely populated areas, septic systems can represent a major local source of nitrate to the groundwater. Nitrate does not appear to be acutely toxic to adult fish except at extremely high concentrations where mortality is due to salinity effects (USEPA, 1977). However, available research indicates that nitrate concentrations lower than the drinking water standard cause substantial egg and fry mortality in some salmonid fish species (Kincheloe *et al.,* 1979). High nitrate levels in drinking water cause infant methaemoglobinaemia and, at higher levels, livestock poisoning. The case is evident in Southern Africa (Super *et al.,* 1981, Hesseling *et al.*, 1991, Tredoux *et al.,* 2005).

As water moves through soil and rock formations that contain sulphate minerals, some of the sulfate dissolves into the groundwater. Sulphates occur naturally in numerous minerals, including sodium sulfate (Glauber's salt), barite ($BaSO_4$), epsomite ($MgSO_4{\cdot}7H_2O$) and gypsum ($CaSO_4{\cdot}2H_2O$) (Greenwood and Earnshaw, 1984). The origin of most sulfate compounds is the oxidation of sulphite ores, the presence of shales, or the industrial wastes. The main process that derives sulfate in Nairobi is weathering of silicate rocks. People not used to drinking water with high levels of sulfate can experience dehydration and diarrhea. Children are often more sensitive to sulfate than adults.

Chloride in drinking-water originates from natural sources (deep aquifers), sewage and industrial effluents, urban runoff containing de-icing salt and saline intrusion. Chloride is widely distributed in the environment, generally as sodium chloride (NaCl), potassium chloride (KCl) and calcium chloride ($CaCl_2$). The main source of human exposure to chloride is the addition of salt to food, and intake from this source is usually greatly in excess of that from drinking-water. Excessive chloride concentrations increase the rates of corrosion of metals in the distribution system, depending on the alkalinity of the water. This can lead to increased concentrations of metals in the supply. No health-based guideline value is proposed for chloride in drinking-water. However, chloride concentrations in excess of about 250 mg/L can give rise to detectable taste in water (WHO, 2008).

Potassium occurs in various minerals, from which it may be dissolved through weathering processes. Potassium plays a central role in plant growth, and it often limits it. Potassium from dead plant and animal material is often bound to clay minerals in soils, before it dissolves in water.  Potassium is a dietary requirement for humans who take up about 1 to 6 grams per day at a requirement of 2 to 3.5 grams per day. The total potassium amount in the human body lies somewhere between 110 and 140 g and mainly depends upon muscle mass. The muscles contain most potassium after red blood cells and brain tissue. Whereas its opponent sodium is present in intracellular fluids, potassium is mainly present within cells. It preserves osmotic pressure. The relation of potassium in cells to potassium in plasma is 27:1, and is regulated by means of sodium-potassium pumps. Vital functions of potassium include its role in nerve stimulus, muscle contractions, blood pressure regulation and protein dissolution. It protects the heart and arteries, and may even prevent cardiovascular disease. No adverse effects have been associated with potassium intake.

Sodium is often naturally found in groundwater because most rocks and soils contain sodium compounds from which sodium is easily dissolved. The most common sources of elevated sodium levels in groundwater are erosion of salt deposits and sodium bearing rock minerals, naturally occurring brackish water of some aquifers, irrigation and precipitation leaching through soils high in sodium, groundwater pollution by sewage effluent and infiltration of leachate from landfills or industrial sites. Sodium is a principal chemical in bodily fluids, and it is not considered harmful at normal levels of intake from combined food and drinking water sources. However, increased intake of sodium in drinking water may be problematic for people with hypertension, heart disease or kidney problems that require them to follow a low sodium diet. In water, sodium has no smell but it can be tasted by most people at concentrations of 200 mg/L or more.

### 2.2.2 Heavy metals

The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. Heavy metals are natural components of the Earth's crust. They cannot be degraded or destroyed. To a small extent they enter our bodies via food, drinking water and air. As trace elements, some heavy metals like copper and zinc are essential to maintain the metabolism of the human body. However, at higher concentrations they can lead to poisoning. Heavy metal poisoning could result, for instance, from drinking-water contamination from lead pipes, high ambient air concentrations near emission sources, or intake via the food chain.

Heavy metals are dangerous because they tend to bio-accumulate. Bioaccumulation means an increase in the concentration of a chemical in a biological organism over time, compared to the chemical's concentration in the environment. Compounds accumulate in living things any time they are taken up and stored faster than they are broken down (metabolized) or excreted. Heavy metals can enter a water supply by industrial and consumer waste, or even from acidic rain breaking down soils and releasing heavy metals into streams, lakes, rivers, and groundwater.

### (a) Zinc

Zinc is an essential trace mineral that we get through the foods. Next to iron, zinc is the most common trace mineral in the body and is found in every cell. Zinc is an essential food element needed by the body in small amounts. The daily requirement for adult men is 15 –20 mg/day (WHO, 2008). At least forty different enzyme systems in the body require the mineral zinc as a cofactor.  Zinc also prevents toxicity arising from the presence of cadmium in the body. This also depletes the level of zinc as cadmium also uses up zinc if present in the body in high amounts. Zinc requirements tend to increase if the diet is high in cadmium.

The effects of zinc deficiency may be severe, ranging from impaired neuropsychological functions, growth retardation and stunting, impaired reproduction, immune disorders, dermatitis, impaired wound healing, lethargy, loss of appetite and loss of hair (FAO, 1998). Zinc deficiency in agricultural soils is also a major worldwide problem, affecting both crop yield and quality. Severe soil zinc deficiency can cause complete crop failure whilst losses of up to 30 percent can occur in yield of cereal grains in crops such as wheat, rice and maize as a result of even mild deficiencies. Research has showed that marginal deficiencies of zinc seem to affect many more low income pregnant women and pregnant teenagers than it does other people and the outcome of a pregnancy in these groups of people can be improved by supplementing with 25 to 30 mg of zinc daily (Osendarp, 2001). Radionuclides can also be found in groundwater, the primary sources being erosion and decay of natural deposits containing radioactive minerals (Job, 2009).

### (b) Arsenic

Arsenic occurs in large quantities in the earth's crust and in trace quantities in rocks, soil, water and air. Industrial effluents also contribute arsenic to water in some areas. Arsenic is used commercially in alloying agents and wood preservatives. Inorganic arsenic can occur in the environment in several forms but in natural waters, and thus in drinking-water, it is mostly found as trivalent arsenite (As(III)) or pentavalent arsenate (As(V)). Organic arsenic species, abundant in seafood, are very much less harmful to health, and are readily eliminated by the body. Severe poisoning can arise from the ingestion of as little as 100 mg arsenic dioxide; chronic effects may result from the accumulation of arsenic compounds in the body at low intake levels. The serious arsenic contamination of groundwater in Bangladesh has come out recently as the biggest natural calamity in the world with 75 million people at risk and 24 million potentially exposed to arsenic contamination (Talukder *et al.*, 1998).

According to one estimate, at least 100,000 cases of skin lesions caused by arsenic have occurred and there may be many more (Smith *et al.*, 2000). Symptoms of exposure to high levels of arsenic may include stomach pain, vomiting, diarrhoea and impaired nerve function that may result in “pins and needles” sensation in hands and feet. Arsenic can also produce a pattern of changes in your skin which includes darkening of wart-like growths – most frequently found on the palms or soles. Long-term (years to decades) exposure to even relatively low concentrations of arsenic in drinking water can increase ones risk of developing certain cancers including skin, lung, and kidney and bladder cancer (Elkins and Pagnotto, 1980). Cases of skin lesions on palm and soles have been reported (Mandal *et al.*, 1998; Smith *et al.*, 2000). WHO (2008) has provided a standard of 0.01 ppm. Carcinogenic properties also have been imputed to arsenic compounds.

### (c) Mercury

Mercury is found in a variety of products, such as fluorescent and other lights, batteries, electrical switches and relays, barometers, and thermometers, much of which ends up in municipal landfills. Like all metals, mercury dissolves easily in the acidic leachate and slowly seeps out of the landfill into the soil and groundwater. Available data show that mercury in groundwater can exceed drinking water standards from older, unlined landfills, but is less likely to leach into groundwater from landfills that are lined and use leachate collection systems. However, even liners and leachate collection systems are not fool proof. Several researchers have documented that liners eventually leak (Line and Miklas, 1989; Bonaparte and Gross, 1990). Mercury is toxic by ingestion, inhalation and skin absorption with acute and chronic exposure effects including central nervous system and kidney damage. Acute exposure includes nausea, blurred vision, painful breathing, excessive salivation and pneumonitis, while chronic or longer- term exposure includes memory disturbance, hypertension, vision problems, hallucinations, tremors and personality changes. Because mercury can cross the blood-brain barrier, and because it can affect brain development, its effects are of special concern to pregnant or lactating women and young children. Many of these advisories are directed towards pregnant or lactating women and young children, or are stricter for these populations, due to concerns over developmental disabilities in infants from mercury exposure (LeBeau, 2008).

### (d) Nickel

Nickel is one of the most mobile of the heavy metals in the aquatic environment. Nickel combined with other elements occurs naturally in the earth's crust. It is found in all soil, and is also emitted from volcanoes. The most common harmful health effect of nickel in humans is an allergic reaction. While food has been mentioned as the major source of exposure to nickel, one may also be exposed to nickel by breathing air, drinking water, or smoking tobacco containing nickel or skin contact with substances containing nickel such as jewellery, stainless steel and coins contain nickel. More nickel is absorbed from the lungs into the body when the nickel particles can dissolve easily in water. The most serious harmful health effects uptake of too large quantities of nickel are chronic bronchitis, reduced lung function, and cancer of the lung and nasal sinus (Stephenson, 1998). The International Agency for Research on Cancer (IARC) has listed nickel compounds within group 1 as carcinogenic and nickel within group 2B (agents which are possibly carcinogenic to humans). The US Environment Protection Agency (USEPA, 1986) has determined that nickel sulphide is carcinogenic.

### (e) Lead

Lead is occurring naturally in the groundwater because of ancient geologic processes that occurred hundreds of millions of years ago. When copper pipes replaced lead pipes, lead solder and flux were often used to join the pipes which is a major cause of lead contamination in drinking water today. Due to its widespread use, lead is commonly found in the air, food, soil and water. The most common cause is corrosion, a reaction between the water and the lead pipes or solder. Dissolved oxygen, low pH (acidity) and low mineral content in water are common causes of corrosion. All kinds of water, however, may have high levels of lead. Short-term exposure to high levels of lead can cause vomiting, diarrhea, convulsions, coma or even death. Early symptoms of lead poisoning in adults are commonly nonspecific and include depression, loss of appetite, intermittent abdominal pain, nausea, diarrhoea, constipation, and muscle pain (Merrill *et al.,* 2007). Other early signs in adults include malaise, fatigue, decreased libido, and problems with sleep. Exposure to low levels of lead over an extended period of time can have severe effects. High concentration of lead can cause damage to human brain, kidneys, nervous system, and cause hemolysis. Lead poisoning can also cause anemia and hemoglobin in the urine (Canada, 2008). Even with short-term exposure, pregnant women and young children absorb lead more rapidly since they are growing. Lead is also known to be carcinogenic (Foster *et al.,* 2002).

### (f) Copper

Copper in our diet is necessary for good health. Human beings eat and drink about 1 mg/L of copper per day. Drinking water normally contributes approximately 150 micrograms per day. Copper is often found near mines, industrial settings, landfills and waste disposals. When copper ends up in soil it strongly attaches to organic matter and minerals and it hardly ever enters groundwater. Corrosion of household plumbing systems and erosion of natural deposits water from copper pipes, as well as from additives designed to control algal growth, are some of the sources of copper.

Immediate effects from drinking water which contains elevated levels of copper include: vomiting, diarrhoea, stomach cramps, nausea. The seriousness of these effects can be expected to increase with increased copper levels or length of exposure. Children under one year of age are more sensitive to copper than adults. Long-term exposure (more than 14 days) to copper in drinking water which is much higher than 1 mg/L has been found to cause kidney and liver damage in infants. Other persons who are highly susceptible to copper toxicity are people with liver damage or Wilson's disease (DNR, 2003). Early signs of elevated levels include a metallic taste in drinking water before copper levels are high enough to cause adverse health effects. One may also notice blue or blue-green stains around sinks and plumbing fixtures.

### (g) Cadmium

Cadmium is highly toxic and has been implicated in some cases of poisoning through food. Cadmium may enter water as a result of industrial discharges or the deterioration of galvanized pipes. Acute exposure to cadmium fumes may cause flu like symptoms including chills, fever, and muscle ache sometimes referred to as "the cadmium blues." Symptoms may resolve after a week if there is no respiratory damage. More severe exposures can cause tracheo-bronchitis, pneumonitis, and pulmonary edema. Ingestion of any significant amount of cadmium causes immediate poisoning and damage to the liver and the kidneys. Cadmium also causes anaemia and hepatic disorder (Elkins and Pagnotto, 1980).

### (h) Chromium

Chromium has been released to the environment via leakage, poor storage, or improper disposal practices (Palmer and Wittbrodt, 1991; Calder, 1988). Water also gets contaminated from tannery waste (Khopkar, 2006). Major sources of chromium-6 and chromium-0 in drinking water are discharges from steel and pulp mills, and erosion of natural deposits of chromium-3. Chromium compounds are very persistent in water as sediments. There is a high potential for accumulation of chromium in aquatic life. Some people who use water containing chromium (total) well in excess of the maximum contaminant level (MCL) over many years could experience allergic dermatitis. The greatest use of chromium is in metal alloys such as stainless steel; protective coatings on metal; magnetic tapes; and pigments for paints, cement, paper, rubber, composition floor covering and other materials. Its soluble forms are used in wood preservatives. EPA has found chromium to potentially cause the following health effects when people are exposed to it at levels above the MCL for relatively short periods of time: skin irritation or ulceration. Chromium has the potential to cause the following effects from a lifetime exposure at levels above the MCL: damage to liver, kidney circulatory and nerve tissues; skin irritation. Chromium is carcinogenic when in the hexavalent state (Khopkar, 2006).

## 2.3 Geology and hydrogeology

### 2.3.1 Geology

The Nairobi area covers part of the eastern flank of the Great Rift Valley and its geological history has been dominated by widespread volcanic activity of Caenozoic age. Lavas, welded tuffs and other pyroclastics cover nearly the entire area and overlie a foundation of poorly exposed, folded and metamorphosed Precambrian rocks of the Mozambique Belt. The characteristic magmatism changed from nephelinitic through phonolitic to trachytic and sometimes peralkaline salic, with basalt accompanying all stages but tending to change from alkali to transitional type (Clarke *et al.*, 1990). A period of erosion prior to the deposition of volcanic rocks on top of basement rocks manifests as layers of gneissic ruble, clays, sands and detritus as evidenced by exposures at Mbagathi River and boreholes at Nairobi station and near Athi River town (Saggerson, 1991).

#### 2.3.1.1 Structures

The structures in the Basement System rocks are fairly complicated while those in the volcanics are fairly simple. (Fairburn, 1963; Saggerson, 1991). Figure 2 shows cross section of the Nairobi area. In the eastern part of Nairobi, faulting is rare and only minor faults were observed in the northern part of this area (Fairburn, 1963). Two small faults throwing east were recorded in the volcanics, one in the Thika valley and the other in the Thiririka valley. The volcanic rocks in the eastern part are consistently horizontal or near horizontal over a wide area. There is a gentle dip to the east of about 3.7m per mile, with the volcanic beds rising towards the Rift Valley, however, east of the Athi River, the dip is to the west and this is probably due to piling up of the volcanics on a basement floor rising rapidly towards Ol Donyo Sabuk.

#### 2.3.1.2 Soils in Nairobi

The soils of the Nairobi area are products of weathering of mainly volcanic rocks under relatively high temperature and rainfall, good drainage prevailing in the Kikuyu Highlands in the west and poorer drainage conditions typifying the Athi Plains in the east (Saggerson, 1991). The principal soils overlying the trachytic rocks of the northwest part of the area include strong brown to yellow-red friable clays (ando-like soils) and dark red friable clays (latosolic soils) with a high humus layer overlying clay (rainfall 1000mm) – these give way south-eastwards to red friable clays (rainfall 762-1000mm) (Saggerson, 1991). Where drainage is impeded over the Athi Plains east of Nairobi, the soils are black to dark grey clays (grumosolic) comprising black cotton soils with calcareous and non-calcareous variants, and they mainly overlie the Nairobi and Kapiti phonolites (Saggerson, 1991). Reddish-brown sandy clay loams occur in pockets and bands in Athi River area as products of erosion of the Athi Series tuffs (Saggerson, 1991).

The soil drainage conditions are better in the west than in the east as outlined earlier, and in the eastern part, improve from south to north with improved drainage correlating with the dip in the surface of the Kapiti phonolite flow which also thins in the north direction. See the Nairobi geological map in Appendix XVI.

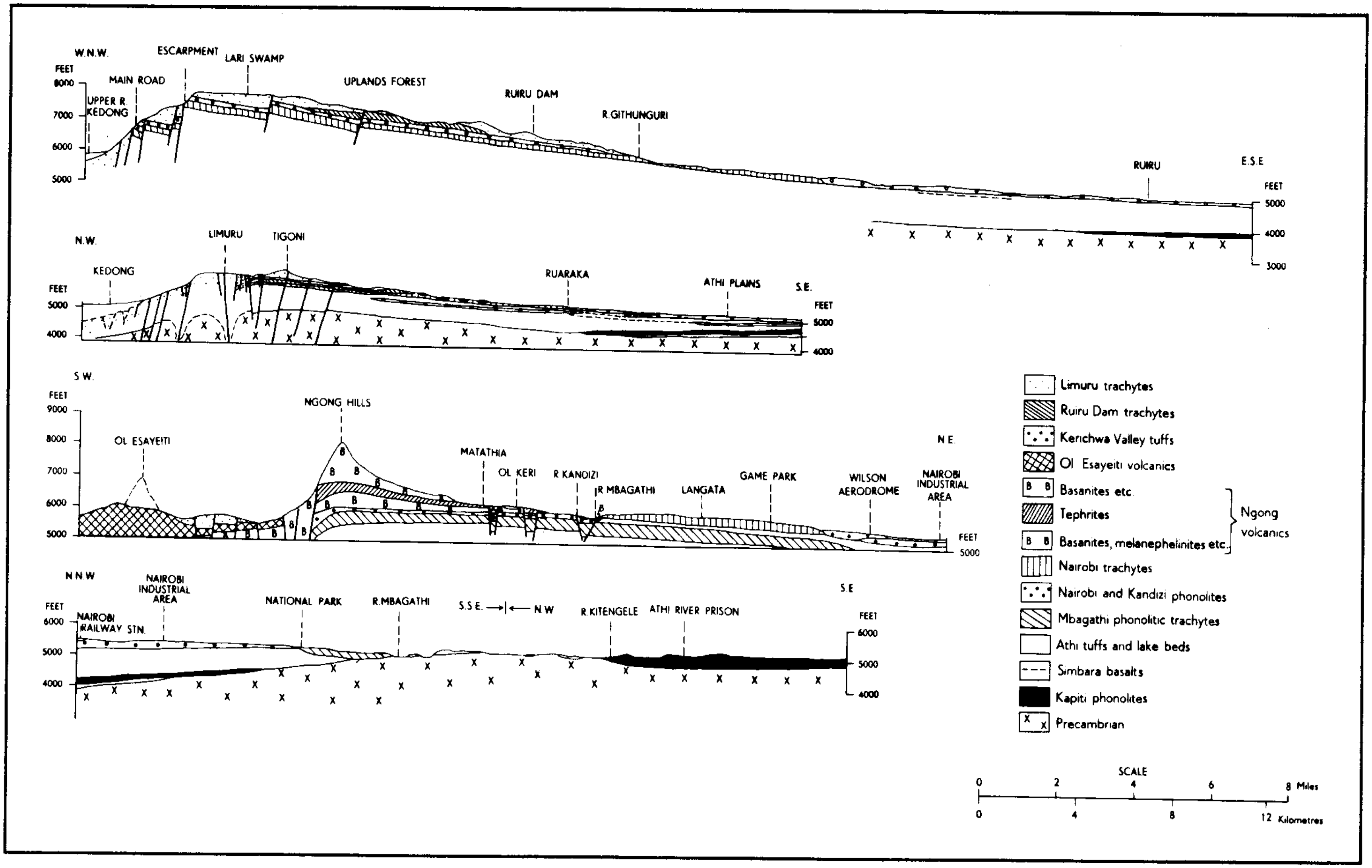


**Figure 2: Cross Section of the Nairobi area**
**Source: Saggerson (1991).**

### 2.3.2 Hydrogeology

#### 2.3.2.1 General hydrogeology

The Nairobi area contains many more boreholes than any other comparable area of the country (Gevaerts, 1964). The underlying geological layer along Ngong road and the Dagoretti forests is the Upper Athi Series, which is porous and permeable, allowing for percolation, making it favourable as a watershed for discharge into rivers and recharge of aquifers. The Upper Athi Series is the main aquifer in the region while the Lower Athi Series is more clayey and therefore forms an aquiclude. The Ngong river basin has clay soils making it swampy with good grass cover and light forests. In some place, it has deposits of shallow stony soils associated with rocky outcrops along its course.

During weathering, much of the lava and tuff change into a pale brown or reddish ferriginous soil and ferricrete (also referred to as murram). The material is frequently hard and of sufficient thickness to allow quarrying. The Motoine river soils are shallow, yellow-brown to yellow-red, friable clay overlying laterite horizon. They have low humus content and are overlying friable clays passing downwards into massive laterite (ferricrete) representing soils with slightly impeded drainage. At the Kibera/Nairobi dam area, the top geological formation over which the dam rests, comprises the Middle and upper Kerichwa Valley Tuffs while the immediately down the dam the rivers flows over alluvial clays and swamp soils.

Karen zone is characterized by an adequate shallow supply from Kerichwa Valley Series which directly underlies the ground surface. Confined water provides the main supply and the contribution of free groundwater is negligible. Thereafter, from Nairobi West area, and downstream through Industrial area and Embakasi the top formation is mainly Nairobi Phonolite, forming the basis for extensive quarrying activity. The Kerichwa Valley Tuffs are ashy to black in colour. The texture is soft, pumice rich and very permeable, thus allowing for water percolation. This formation buried a pre-existing landscape covered by Nairobi Trachyte and Nairobi Phonolite. The series also comprises welded tuffs (also referred to as Nairobi building stone), which are massive and generally impervious. Appendix XV summarizes the hydro-geology of Nairobi area.

Water draining eastwards accumulates on the low lying ground in Nairobi South, forming a perched water table above the Nairobi Phonolite (Kilonzo, 2005). The Kerichwa Valley Tuffs behave like a sponge (Saggerson, 1991) and form a perfect aquifer protected by the underlying impermeable Nairobi Phonolite. (see the geological map for Nairobi on Appendix XVI). Three general types of aquifer lithology are recognized as follows:

(i) Sands and sediment deposits intercalated in tuff, in which case, (Saggerson, 1991) and (Gevaerts, 1964) concur that most aquifers are either fluviatile or lacustrine deposits intercalated in most formations.

(ii) Rock formations with an appreciably good porosity and permeability. These types of aquifers occur in formations such as weathered basalt, trachytes and tuffs.

(iii) Contact between two rock formations such as basalt and tuffs or sands and sediments intercalated in weathered tuff. These contacts are the old land surfaces reported by (Saggerson, 1991) and (Gevaerts, 1964).

#### 2.3.2.2 Groundwater occurrence

The Nairobi groundwater basin extends from the zone of north-south rift faulting west of the city (with an elevation of about 2400 m asl) towards the Athi river floodplain (with an elevation of 1500 m asl) east of the city center. The Nairobi aquifers occur in the multi-layered volcanic rocks that show a wide range of porosity and permeability, mainly in the Kerichwa Valley Series and Upper Athi Series (transmissivity of 5-50 $m^2/d$ and low storability) whose extension is well known from the boreholes that have been drilled to depths of 60-350 m. The tuffs and lavas give no supply, being as a whole unfractured and impervious. The former may to an extent be porous, but they do not transmit water. The permeable lateritic materials underlying the surface of the ground and the reddish or brownish weathered materials on old land surfaces are often aquifers. In addition faults, fissures and cooling joints are potential aquifers. The latter are often well developed in the thin flow tuffs, in contrast to the lavas which, with the exception of the Kapiti Phonolite, show no appreciable jointing (Gevaerts, 1964).

#### 2.3.2.3 Groundwater flow

Groundwater moves from regions where it has high head to regions where it has lower head through gravity, suction or pressure forces otherwise known as hydraulic gradient. Head is the height to which the water can raise itself above a reference level (datum), and is measured in meters; it is a way of measuring how much energy the water possesses. Groundwater flow is principally directed east-south-east from the main recharge area towards the Athi floodplain, where most of the groundwater formerly discharged as springs or seepages into local streams and depressions. Today, the many water wells in Greater Nairobi intercept most of this groundwater flow.

Ground water moves so slowly that its energy due to movement is negligible. Ground water can also posses energy by virtue of its elevation and of its pressure. When groundwater moves, some energy is dissipated and therefore a “head loss” occurs. When a borehole is drilled into an aquifer, the level at which the water stands in the borehole (water rest level) is for most purposes the head of the water in the aquifer. Darcy’s law states that the flow rate (Q) will be directly proportional to the cross-sectional area (A) through which flow is occurring and directly proportional to the hydraulic gradient (I) The hydraulic gradient is the difference in head between two points on the flow path divided by the distance (measured along the flow direction) between them. Groundwater can move through aquifers with speeds ranging from many meters a day to less than a metre a year (Michael, 1994).

#### 2.3.2.4 Free groundwater

Free groundwater contributes substantially to the supply where the surface is underlain by a thick pervious formation and the rainfall is high. In a restricted area east of the Athi River, adequate supplies from free groundwater are obtained along dry sandy stream courses where shallow boreholes, not deeper than 30.48 metres (100 feet), tap the subsurface flow (Gevaerts, 1964).

#### 2.3.2.5 Aquifers

Groundwater can be defined as the subsurface water in a saturated zone. The amount of groundwater is dependent on the on porosity of the material within the saturated zone, on the ease of flow (permeability), and on the possibility of recharge. An aquifer is commonly thought of as a geological unit that contains water in sufficient quantities to allow economic development. A number of factors affect percolation and infiltration like surface conditions, topography, amount of rainfall and its distribution, vegetation cover, porosity or permeability of materials. Porosity is defined as the ratio of volume of interstices in a given sample of porous medium like sand to the gross volume of the medium. Points of equipotential form a piezometric surface or a groundwater table (Freeze and Cherry, 1979).

The distribution of aquifers in a geologic system is controlled by lithology, statigraphy and structural features. Lithology is the physical make of the aquifer material, while statigraphy describes the geometrical and age relations of the formations. Structural features include linearments, fractures, fault and folds. Lithology gives the various rock types mainly sedimentary, igneous and metamorphic. Sedimentary rocks are formed from generally weathering of existing rocks and hence in all cases form layers with the older below and the younger above (Freeze and Cherry, 1979).

#### 2.3.2.6 Aquifer behaviour

Gevaerts (1964) observed water levels in various boreholes drawing from Kerichwa Valley Series and Upper Athi Series aquifers in 1963 and noted the following:- confined aquifers suffered loss of storage in Kahawa, Ruaraka and Athi River station due to continuous large abstraction; rest levels for boreholes drawing from Kerichwa Valley Series aquifer rose after a very rainy season while majority of boreholes in the

Upper Athi Series showed a fall in rest levels, and, several boreholes with large abstractions that showed depressions in pressure surface had no recovery of water level after twelve hours of monitoring. He concluded that depressions were permanent and attributed the falls to depletion of storage and permanent compaction.

Before large-scale groundwater development took place in Nairobi, there used to be water flow within the aquifers from the west through the deep, confined aquifer section. The flow emerged in the east near Athi River and boreholes drilled to Kapiti Phonolite encountered artesian conditions at the contact with the Athi tuffs and sediments, for instance borehole number 252 and 498. Rapid population growth has had a disproportionate impact on the groundwater situation due to increased pumping in many areas and extensive pollution of both surface streams and the upper aquifers. There are consistent reports of groundwater level decline, and deeper aquifer units have been increasingly tapped by new boreholes.

Intensification of land use, with consequent increases in contamination potential, places the groundwater at serious risk. Aquifer-vulnerability assessment is the first step in protecting this vital resource. Characteristics of the aquifer medium affect vulnerability because the concentration of contaminants is controlled partly by the ability of the aquifer to dilute them. Higher hydraulic conductivity promotes greater dilution. This results in lower vulnerability to contamination.

### 2.3.2.7 Recharge of the aquifer

Groundwater recharge can be defined as the entry into the saturated zone of water made available at the water table surface. This is through infiltration and percolation from precipitation or seepage from rivers, lakes, irrigation or manmade structures (Freeze and Cherry, 1979; Larsson, 1984). The recharge points of Nairobi area are at Ngong, Kikuyu and Tigoni. The recharge of the free groundwater appears to be adequate but the confined aquifers have suffered loss of storage at localities of continuous large abstraction (Ruaraka, Kahawa, Athi River Station (Gevaerts, 1964). The two possible ways of replenishment of the confined aquifers is by direct replenishment at the surface and indirect replenishment by water stored in fractured zones.

Most natural groundwater recharge occurs on the slopes of the rift zone, west of the city, where the volcanic rocks are incised by numerous streams related to fault lines and weathered zones of the previous land surfaces. The upstream portions of these streams form an important source of aquifer recharge. The higher rainfall (1200 mm/a), dense vegetation, permeable soils and drainage pattern along the upper parts of these streams provide good recharge conditions – and although reliable recharge estimates do not exist, about 25 $Mm^3/a$ has been estimated to occur on average in this area. Recharge also takes place in Greater Nairobi through infiltration of wastewater, water mains leakage and excess rainfall. The total leakage from the water-distribution system is estimated to be 180 Ml/d, but it is difficult to say how much of this reaches groundwater. There is some evidence that part of the infiltration in Greater Nairobi (rainfall averaging 850 mm/a) is intercepted by localized perched aquifers and discharged locally to springs and streams (Gevaerts, 1964).

#### 2.3.2.8 Groundwater supplies in Nairobi

The drilling of boreholes started in the 1930s with the number of water wells in greater Nairobi increasing from less than 10 in 1940 to almost 2000 in 1997 and further increased to 2250 in 2001 as a result of the drought. As by today, the number of boreholes is over 2500. The amount of groundwater abstracted has steadily increased to an estimated 85 Ml/d (85,000 $m^3$/d) in 2002, which amounts to 25 percent of the overall water-supply of the population of Greater Nairobi. Drilling is either by rotating or percussions methods. Cuttings are produced in different sizes which are also dependent on type of drilling bit used and type of rock penetrated. They are collected at reasonable intervals and are called geological log samples. A good driller can give a reasonable interpretation of the sample. A site geologist gives a detailed geological log from drilling samples. Cuttings give valuable information on rocks penetrated but can also be used to interpret surface geology. Drilling of borehole enables acquisition of subsurface data and information which can be used for research and reports on aquifers. Among the data acquired are the water struck levels, water rest levels, parameters on water quality and geological information from logs (Larsson, 1984).

#### 2.3.2.9 Groundwater chemistry

Chemical and biochemical constituents in groundwater determine its usefulness for industry, agriculture, home and domestic purposes. Water is a solvent for many salts due to its high dielectric constant, and its molecules tend to combine with ions and form hydrated ions. Chemical and biochemical interactions between groundwater and geologic materials through which it flows results in it containing a wide variety of dissolved organic and inorganic constituents in various concentrations. Water can also be viewed as an electrolyte solution because all its major and minor dissolved constituents are in ionic form. A general indication of the total dissolved ionic constituents can be obtained by determining the capability of the water to conduct an applied electric current. This property is reported as electrical conductance and is expressed in terms of the conductance of a cube of water ($1cm^3$) on a side; which is the reciprocal of resistance. It is expressed in micro Siemens per centimetre (µS/cm) (Freeze and Cherry, 1979).

#### 2.3.2.10 Groundwater quality and variability

Research on the hydrogeology of the Nairobi area (Gevaerts, 1964; Saggerson, 1991) showed that pH, total dissolved solids, chlorides, sulphates, total hardness, excess alkalinity and free $CO_2$ were within drinking water standards except for the fluoride content which is in excess of the desirable limit of 1.5 ppm over a large part of the area. There is also high chloride and sulphate contents in water from sediments intercalated in the Kapiti Phonolites and are thought to be derived from lacustrine deposits rather than from the phonolite (Sagggerson, 1991).

Variations in recharge influence groundwater through leaching of soluble substances by infiltration or rising water tables, causing increases in chemical constituent levels;

dilution of groundwater by infiltration of water with lower constituent concentrations, and movement of groundwaters of different quality, occurs in response to changes in hydraulic head (Whittemore *et al.*, 1989). Some recharge variations which affect groundwater quality are natural (Hackbarth, 1981) while others are affected or caused by mans' activities (Close, 1987). Recharge often varies seasonally (Montgomery *et al.*, 1987) but there are longer term variations as well (Close, 1987; Whittemore *et al.*, 1989).

## 2.4 Analytical techniques

A designated analytical laboratory should follow protocols according to the "Standard Methods for the Examination of Water and Wastewater" (Clesceri *et al.*, 1995). Standard procedures should be used for the physical-chemical determinations using volumetric (titrimetric), colorimetric and instrument methods. Metal ions in water are measured by the use of Atomic Absorption Spectrophotometer (AAS). For this method, a solution of lanthanum chloride is added to the sample and the treated sample is sprayed into a frame using an atomizer. Each metallic element in the sample impacts a characteristics colour to the frame, whose intensity is then measured spectrophotometrically (Clesceri *et al.*, 1995; Jeffrey *et al.*, 1997).

# CHAPTER THREE

## 3.0 MATERIALS AND METHODS

### 3.1 Research design

Comparison of physical and chemical parameters of boreholes in Nairobi city during dry and wet seasons was done and formed the base of suspected seepage of polluted water. Available secondary data (physical and chemical) from the Ministry of Water and Irrigation of the sampled boreholes just after the drilling was compared with the primary data. Generally, the project involved the following three main steps:

(i) Sample collection
(ii) Sample treatment
(iii)Laboratory analysis

### 3.1.1 Sample collection

**Apparatus**: Clean glass bottles with a capacity of approximately 1 litre with close-fitting clean stoppers of glass were used.

**Volume and number of samples:** Each sample consisted of at least 250 ml and two samples that were taken from each borehole.

**Preparation of bottles:** A total of 60 bottles and their stoppers were washed with a nitric acid solution and then thoroughly rinsed out with water to remove the acid. Each bottle was half-filled with the water from which a sample was taken, shaken thoroughly and then emptied. This procedure was repeated three more times after which the sample was taken.

### 3.1.2 Sampling

The study area was divided into Kasarani/Roysambu area (Zone A), Dagoretti/Kawangware area (Zone B), Embakasi area (Zone C), Karen/Lang'ata area (Zone D), City Centre area (Zone E) and Industrial area (Zone F) according to land use. Figure 3 and Table 1 show the sampled zones and position of sampled boreholes respectively in the six zones of Nairobi area. Five boreholes were sampled per zone adding up to a total of thirty boreholes.

Water sampling dependent on seasons was conducted between 26th May and 30th June, 2009 for the wet season and between 19th and 26th August, 2009 for the dry season.

Samples were taken from a pump outlet pipe through which water was in continuous flow. Thereafter, the tap was turned on fully and water was allowed to flow for two minutes before taking the sample according to the standard sampling procedure (Clesceri et al., 1995). To prevent unnecessary aeration while the sample was being taken, the tap was turned partially open and the bottle was filled to within 15 mm of the top of the neck. The stopper was closed to make a tight seal and the bottle was properly labeled with the given code, the date and the time of sampling; acidified sample for metal analysis as labeled with a special identifying mark.

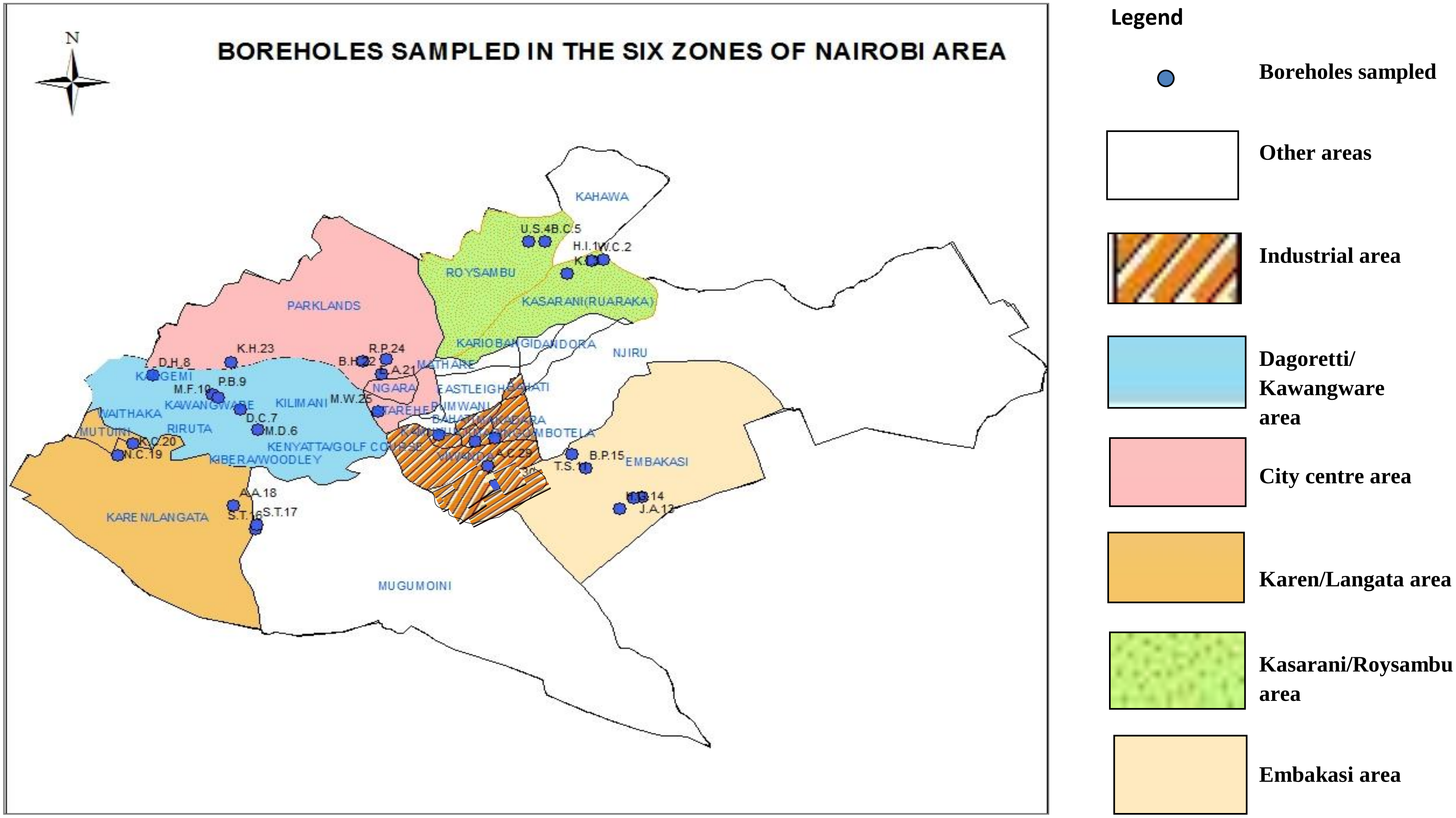


Figure 3: Boreholes sampled in Nairobi area

### Table 1: Position of boreholes sampled

| Zone | ORGANIZATION | CODE | LONGITUDE | LATTITUDE | HEIGHT (m.a.s.l) |
|---|---|---|---|---|---|
| **Kasarani/ Roysambu (Zone A)** | HACO INDUSTRIES | H.I.1 | 267472 | 9865318 | 1692 |
| | WARREN CONCTETE | W.C.2 | 266948 | 9865260 | 1600 |
| | K.I.S.E. | K.I.3 | 265737 | 9864534 | 1615 |
| | U.S.I.U. | U.S.4 | 263859 | 9866248 | 1621 |
| | BIBLE COLLEGE OF E.A. | B.C.5 | 264612 | 9866233 | 1632 |
| **Dagoretti/ Kawangware (Zone B)** | KENYA MET DEPT. | M.D.6 | 250612 | 9856264 | 1823 |
| | DELIVERANCE CHURCH | D.C.7 | 249721 | 9857334 | 1797 |
| | DAGORETTI HIGH SCHOOL | D.H.8 | 245426 | 9859139 | 1881 |
| | PRECIOUS BLOOD - RIRUTA | P.B.9 | 248333 | 9858123 | 1838 |
| | MARHIUM ENT | M.F.10 | 248617 | 9857983 | 1808 |
| **Embakasi (Zone C)** | TONONOKA STEEL INDUSTRIES | T.S.11 | 265986 | 9854938 | 1643 |
| | J.K.I.A. (STATE PAVILION) | J.A.12 | 269395 | 9852699 | 1626 |
| | J.K.I.A. (M1) | J.A.13 | 268962 | 9852616 | 1636 |
| | HOME GROWN | H.G.14 | 268286 | 9852050 | 1646 |
| | BASCO PRODUCTS | B.P.15 | 266670 | 9854232 | 1642 |
| **Karen/ Lang'ata (Zone D)** | ST. THOMAS AQUINAS SEMINARY | S.T.16 | 250494 | 9850986 | 1809 |
| | ST. THOMAS AQUINAS SEMINARY | S.T.17 | 250529 | 9851184 | 1812 |
| | AL. RASUL AL AKRUM ACADEMY | A.A.18 | 249371 | 9852192 | 1818 |
| | NYUMBANI CHILD. HOME | N.C.19 | 243733 | 9854908 | 1886 |
| | KAREN COUTRY LODGE | K.C.20 | 244447 | 9855517 | 1808 |
| **City Centre (Zone E)** | EAST AFRICA S. MOSQUE | E.A.21 | 256871 | 9860022 | 1687 |
| | BOVELAND HOTEL | B.H.22 | 256653 | 9859241 | 1770 |
| | KANGEMI HIGH SCHOOL | K.H.23 | 249249 | 9859851 | 1836 |
| | RIVERSIDE PARK | R.P.24 | 255749 | 9859882 | 1650 |
| | MINISTRY OF WATER AND IRRI. | M.W.25 | 256465 | 9857206 | 1718 |
| **Industrial Area (Zone F)** | K.C.B INDUSTRIAL AREA | K.C.26 | 259443 | 9855953 | 1650 |
| | CROWN BERGER (SALES OFFICE) | C.B.27 | 261225 | 9855645 | 1665 |
| | CROWN BERGER (FACTORY) | C.B.28 | 262206 | 9855798 | 1649 |
| | ALPINE COLLERS | A.C.29 | 261847 | 9854315 | 1695 |
| | FIRESTONE E.A LTD | F.E.30 | 262168 | 9853292 | 1649 |

### 3.1.3 Sample treatment

One sample for each collection site was acidified using 2 ml concentrated nitric acid to preserve for metal analysis. Samples for laboratory analysis were filtered using a 0.45µm pore diameter and stored in a cool box set at 4°C.

### 3.1.4 Analysis

Physical and chemical properties as well as traces of heavy metals from selected boreholes in Nairobi were determined either on the field or in laboratories. Each sample collected underwent analyses of all parameters mentioned below using standard methods for examination of water and wastewater (Clesceri *et al.*, 1995).

### 3.1.5 Materials and reagents

Reagents used in analysis were of anyl as grade. De-ionized water was used in preparation of solutions. The materials used in the study included a geological map of Nairobi (Scale 1: 125000), and its associated literature (Saggerson, 1991); hydrogeology literature and map (Gevaerts, 1964); a topographical map of Nairobi and its environs, borehole logs, GPS equipment and ArcGIS software.

#### 3.1.5.1 Physical and chemical parameters

#### (a) Colour test

Representative samples were collected in clean glassware and colour was determined by the visual comparison method. Colour test was conducted using Lovebond Nesserriser equipment at Central Water Testing Laboratories (CWTL) - Nairobi, Kenya. Comparison of water colour with that of glass disks held at the end of metallic tubes containing glass comparator tubes filled with sample and colourless distilled water was done. Sample colour was matched with the colour of the tube of clear water plus the calibrated coloured glass when viewing by looking towards a white surface. Each disk was calibrated to correspond with the colours on the platinum-cobalt scale.

**Procedure:**

A volume of 50 ml of the sample was put into 50 ml Nesserriser tubes placed into the machine and disc reading which corresponded to the physical colour of the sample was taken. Using an appropriate colour disc (either long range or short range), the colour of the sample which matched with the distilled water was noted. If the colour exceeded 70 units, the sample was diluted with distilled water in known proportions until the colour was within the range of the standards. The procedure above was then repeated to determine the colour.

**(b) Free $CO_2$**

Titrimetric method was used to determine the degree of free $CO_2$ in water at CWTL. Caution was taken not to shake the sample.

**Procedure:**

Phenolphthalein indicator 2-3 drops were added to 50 ml of the sample. If the sample changed to purple, it was an indication of no free $CO_2$ and the value was recorded. If there was no colour change, the solution was titrated drop wise against 0.0227N NaOH till the solution changed to purple colour and persisted for at least 5 seconds and the titrant used was recorded.

**Calculation**

$mg\ CO_2/L = (\text{Volume of titrant used} \times \text{concentration of the titrant} \times 44000)/\text{Volume of the sample}$

$mg\ CO_2/L = (\text{Volume of titrant} \times 0.0227 \times 44000)/50ml$

$= \text{Titre} \times 20$

### (c) pH

pH was determined by electrometric method using pH meter Model: HANNA pH 211 (Mauritius). The basic principle of electrometric pH measurement is determination of the activity of the hydrogen ions by potentionmetric measurement using a standard hydrogen electrode and a reference electrode.

**Procedure:**

The pH meter was calibrated before sample determination using pH 4 and pH 7 standard buffers. A magnetic stirrer was inserted inside the sample on a 50 ml beaker and the electrodes of the pH meter were submerged. Readings were recorded when the meter stabilized. pH was also determined on site using dissolved oxygen meter type: JENWAY 3405 (Manufacturer: Barloworld Scientific Ltd-England).

### (d) Total alkalinity

Titration method was used to determine total alkalinity. The principle behind this method being hydroxyl ions present in a sample as a result of dissociation or hydrolysis of solutes reacting with additions of standard acid.

**Procedure:**

The pH 4 and pH 7 standard buffers were used to calibrate the pH meter. A volume of 50 ml of the sample was titrated using 0.02 M $H_2SO_4$. The reading was noted when the meter read a pH of 4.5.

**Calculation**

$$\text{Total Alkalinity} = \text{Titre} \times 0.02N \times 50000/\text{Vol. of sample}$$

$$= \text{Titre} \times 20$$

### (e) Turbidity

Nephelometric method was used for turbidity determination. The principle of this method is based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions.

**Procedure:**

Turbid meter, type PAQUALAB (Manufacturer: ELE-England) was standardized to zero NTU using distilled water, then 80 NTU standard and lastly 40 NTU standard. The sample was shaken, poured into a cuvette and readings taken using turbid meter.

### (f) Temperature

Temperature was read on site using a dissolved oxygen meter JENWAY 3405 (Manufacturer: Barloworld Scientific Ltd-England) and the readings were noted.

### (g) Conductivity and total dissolved solids

A conductivity meter type JENWAY SENSODIRECT Con200 Lovibond (Indonesia) was used to determine water conductivity both on site and at Central Water Testing Laboratories (CWTL).

**Procedure:**

The sample was shaken and then about 40 ml of the sample measured into a 50 ml beaker. Conductivity meter electrode was rinsed with distilled water and then placed into the sample. The value was taken in µS/cm when the conductivity meter drew a graph on the screen. If the number given was in mS/cm, the figure was multiplied by a 1000, recorded and the temperature noted. This was done on site.

### (h) Dissolved oxygen ($DO_2$)

The value of $DO_2$ was read on site using dissolved oxygen meter JENWAY 3405 (Manufacturer: Barloworld Scientific Ltd-England).

### (i) Total hardness

**Procedure:**

Total hardness buffer ($NH_4Cl$-$NH_4OH$) 1 ml was added to 50 ml of the sample. A spatula of the total hardness indicator was added to the solution and titrated against 0.01N EDTA solution. The colour change from pink to blue was an indication of the end point. The titre was read, recorded and multiplied by 20 by dilution factor (D.F).

**Calculation**

Total Hardness = (Titre x 20 x D.F.)

### (j) Calcium and magnesium hardness

The concentration of calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_{3)}$ in the water was measured to get the $Ca^{2+}$ and $Mg^{2+}$ respectively. Total hardness was also determined.

**Procedure:**

For determination of magnesium hardness, 1.5 ml of $Mg^{2+}$ buffer was added to 50 ml of the sample in a beaker. A spatula of magnesium indicator was added and titrated against 0.01N EDTA until the colour turned purple. For determination of calcium hardness, 1.5 ml of $Ca^{2+}$ buffer was added to 50 ml of the sample in a beaker. A spatula of calcium indicator was added and titrated against 0.01N EDTA until the colour turned purple. Titration was carried out immediately after adding the indicator because it is unstable under alkaline media.

**Calculation**

$Ca^{2+}$ = (Titre x 8 x D.F.); $Mg^{2+}$ = (Titre x 0.67 x D.F.)

### (k) Nitrates

Concentration of nitrates ($NO_3^-$) was determined by the use of ultraviolet spetrophotometric screening method. Standard concentrations of 2 and 20 were transferred into separate beakers and nitrate buffer {$(NH_4)_2SO_4$} 1 ml was added into each. Absorbance of standards were read using JENWAY 3345 (Manufacturer: Barloworld Scientific Ltd-England) and recorded. A volume of 50 ml of sample was poured into a beaker and 1.0 ml of nitrate buffer added. Nitrate readings of the sample were read at $\lambda_{max}$ 550 nm and recorded (see Appendix II for the working standards and calibration curves).

**Calculation**

*A graph of readings (mV) against concentration (mg/L) was drawn using the standards' readings. Sample concentration was read from the graph in mg/L* $NO_3^-$.

**(l) Nitrites**

Colourimetric method was used for nitrites determination. Photometer type WTW - MPM 3000 (Germany) was used at CWTL.

**Procedure:**

Filtration of water was carried out using 0.45- µm-pore-diam membrane filter. Sulfanamide amide acid 1 ml was added to 50 ml of the sample and allowed to stand for about two minutes. N-(1-Naphthyl-ethylenediaminedihydrochloride (NED) 1 ml was added and the solution was left to stand for 10 minutes. A pink colour was developed and the absorbance was read at a $\lambda_{max}$ 543 nm using ultraviolet spectrophotometer (see Appendix I for the working standards and calibration curves).

**Calculation**

*A graph of absorbance readings against concentration (mg/l) was drawn using the standards' readings. Samples concentrations were read from the graph in mg/L* $NO_2^-$.

**(m) Chlorides**

**Procedure:**

The conductivity of the sample was checked. If it was greater than 1,000, it was diluted with distilled water in the ratio of one to five. If it was greater than 20,000, the sample was diluted to a ratio of about 1 to 10. Distilled water (blank) 50ml was measured into a beaker. The sample was shaken and 50 ml of the sample measured into a beaker. Potassium chromate ($K_2CrO_4$) indicator 1 ml was added and titrated against 0.0141N Silver Nitrate ($AgNO_3$) until the colour changed to pinkish yellow. The amount of the titrant used was recorded.

**Calculation**

*$Cl^-$ ppm (parts per million)= {(A-B) x N x 35450}/Vol. of sample (ml*

*Or $Cl^-$ ppm = (A-B) x 10 (standard formula when 50ml of sample is used.)*

*Where A - Volume of titre used*

*B- Volume of titre for blank*

*N- Normality of Silver nitrate*

**(n) Sulphates**

Sulphates readings were calculated from free turbidity measurements using nephelometric method. The turbidity meter was standardized as in free turbidity test. A volume of 50 ml of the sample was measured into a beaker and sulphate buffer (conditioning reagent) 2.5 ml was added. A spatula full (or 1 g) of barium chloride 2-hydrate ($BaCl_2 .2H_2O$) was added and stirred for one minute. The solution was put into a cuvette and turbidity measured. If on addition of BaCl2 the sample turned too milky, the original sample was diluted and dilution factor noted.

**Calculation**

*Turbidity due to $BaCl_2$ x D.F – free turbidity = Turbidity due to $BaSO_4$/Slope of graph (3.5)*

*Sulphates, $MgSO_4$/L = {(B x D.F) – A}/Slope of graph (3.5)*

*Where, A – free turbidity*

*B – Turbidity due to Barium chloride, $BaCl_2$*

*D.F – Dilution Factor*

### 3.1.5.2 Determination of metals

#### (a) Preparation of standard stock solutions (1000 ppm)

The weight of salts and metals used to prepare stock solutions were measured using Cole-Parmer Symmetry PA-Analytical Balance, England).

**As 1000 ppm:** $NaAsO_2$ weighing 9.7 g was transferred to a 1000 ml volumetric flask. Distilled de-ionized water was added to dissolve the salt. $HNO_3$ measuring 5 ml was added and diluted to the mark with distilled de-ionized water. The solution was stored in a polyethylene bottle.

**Cd 1000 ppm:** Cadmium metal weighing 1.0 g was transferred into a beaker and dissolved in 10 ml $HNO_3$. The solution was then be transferred to a 1000 ml volumetric flask and diluted to the mark with distilled de-ionized water. The solution was stored in a polyethylene bottle.

**Cu 1000 ppm:** $CuSO_4{}^{\cdot}5H_2O$ weighing 3.9 g was transferred to a 1000 ml volumetric flask and distilled de-ionized water was added to dissolve the salt. $HNO_3$ measuring 5 ml was added and diluted to the mark with distilled de-ionized water. The solution was stored in a polyethylene bottle.

**Ni 1000 ppm:** $NiSO_4{}^{\cdot}6H_2O$ weighing 4.5 g was transferred to a 1000 ml volumetric flask. Distilled de-ionized water was added to dissolve the salt. $HNO_3$ measuring 5 ml was added to the solution and diluted to the mark with distilled de-ionized water. The solution was stored in a polyethylene bottle.

**Pb 1000 ppm:** $Pb(NO_3)_2$ weighing 1.6 g was transferred to a 1000 ml volumetric flask. Distilled de-ionized water was added to dissolve the salt. $HNO_3$ measuring 5 ml was added to the solution and diluted to the mark with distilled de-ionized water. The solution was stored in a polyethylene bottle.

**Hg 1000 ppm:** HgCl weighing 1.4 g was transferred into a 1000 ml volumetric flask. Distilled de-ionized water was added to dissolve the salt. $HNO_3$ measuring 10 ml was added to the solution and diluted to the mark using distilled de-ionized water. The solution was stored in a polyethylene bottle.

**Cr 1000 ppm:** Cr metal weighing 1.0 g was transferred into a 1000 ml volumetric flask. Distilled de-ionized water was added to dissolve the salt. HCL acid measuring 5 ml was added to the solution with gentle heating. The solution was cooled and diluted to the mark with distilled de-ionized water. The solution was stored in a polyethylene bottle.

**Zn 1000 ppm:** Zn metal weighing 1.0 g was transferred into a 1000 ml volumetric flask. Distilled de-ionized water was added to dissolve the salt. HCL acid measuring 40 ml was added to the solution and diluted to the mark with distilled de-ionized water. The solution was stored in a polyethylene bottle.

**K 1000 ppm:** KCl weighing 0.5 g was dissolved in a litre of de-ionized water. The stock solution contained 250 mg of potassium per 1000 ml. Required standards (see Appendix III) were made by diluting the stock solution to generate the calibration curve of standards. Lanthanum measuring 1 ml was added to each standard and sample to eliminate the interference of phosphates.

**Na 1000 ppm:** Dried NaCl weighing 2.5 g was transferred into a 1000 ml volumetric flask. Distilled de-ionized water was added to dissolve the salt and diluted to the mark with distilled de-ionized water. The solution was stored in a polyethylene bottle.

Working standards for calibrating Atomic Absorption Spectrophotometer (AAS) equipment (Model: SPETRA AA10) and Flame Photometer (Model: Gallenkamp) were prepared serially by diluting the stock solutions using the formula $C_1V_1=C_2V_2$, where $C_1$ was the concentration of the stock solution, $C_2$ was the required concentration of the standard, $V_1$ was the volume of the stock solution taken for dilution and $V_2$ was the volume of the standard prepared from the stock solution.

### (b) Determination of Zn, Pb, Cu, Ni, Cd and Cr

Samples of Zn, Pb, Cu, Ni, Cd and Cr were digested using concentrated $HNO_3$ (anyl grade). For each metal determination, the standards prepared were introduced to the flame and the absorbance values obtained were used to plot the calibration graph of absorbance versus concentration of the standards. The samples were then introduced into the flame and their absorbance values were used to deduce the concentration by interpolating (see Appendix V to Appendix X for the working standards and calibration curves).

### (c) Determination of arsenic and mercury

For each, working standard was introduced to AAS by first generating the $AsH_3$ using $NaBH_4$ in acid or $SnCl_2$. The hydride was swept into the flame placed in the hollow cathode lamp beam using an inert gas like argon or nitrogen. The absorbance of each standard was plotted against the concentration to obtain a calibration curve. The sample was then introduced and its adsorption value was used to determine the concentration of arsenic in the water sample. (See Appendix XI and XII for the working standards and calibration curves for mercury and arsenic respectively).

### (d) Determination of potassium and sodium

Potassium and sodium ions were determined by flame photometric method. Trace amounts were determined in a direct reading of a frame spectrophotometer at $\lambda_{max}$ 766.5 nm for potassium and $\lambda_{max}$ 589 nm for sodium ions (Clesceri et al., 1995). In case the sample was highly concentrated, which was indicated by high conductivity, it was diluted to a factor. The equipment was standardized and 1 ml of sample analyzed.

Table 2 shows maximum absorbance for As, Cd, Hg, Ni, Pb, Cu, Cr, Zn, K and Na at $\lambda_{max.}$

**Table 2: Maximum absorbance for metals**

| **Metal** | **Maximum absorbance at $\lambda_{max}$ (nm)** | **Metal** | **Maximum absorbance at $\lambda_{max}$ (nm)** |
|---|---|---|---|
| Arsenic | 193.7 | Copper | 324.7 |
| Cadmium | 228.8 | Chromium | 357.9 |
| Mercury | 253.7 | Zinc | 213.9 |
| Nickel | 232.0 | K | 766.5 |
| Lead | 217.0 | Na | 589.6 |

## 3.2 Mapping of boreholes

Physical locations of the boreholes were read by the use of a GPS machine and mapping was done by the help of ArcGIS software.

## 3.3 Data analysis

Microsoft excel statistical software was used to analyze the data focusing on determining analysis of variance by ANOVA, Chi square, regression and correlation analysis.

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

### 4.1 Introduction

This study was carried out in Nairobi, Kenya. The geographical location of sampled boreholes is described in Table 1 while the sampled zones are described in Figure 3. Samples were collected in both wet and dry seasons. Physical properties, nutrients and heavy metals were analyzed. Standardization curves for some of the analytes are shown in Appendix I to Appendix XII. A test on normality indicated that the data fell within the normal distribution curve.

The concentration for each analyte was compared with WHO (2008) and NEMA/KEBS drinking water standards so as to determine the quality of the sampled water. Analytes showing concentrations higher than WHO (2008) and NEMA/KEBS drinking water standards were shown in red colour in each of the tables. Only in cases where pH was lower than WHO (2008) standards was shown in blue colour. Analytes whose concentrations were below the detection limit are shown by the use of BDL.

The symbol ± shown on the results in tables indicates standard deviation. Chi-Square, regression and correlation tests were conducted.

### 4.2 Validation

Using data type checks, all numerical data input was checked. In an input box accepting numeric data, if the letter 'O' was typed instead of the number zero, an error message would appeared and was corrected. In addition, control checks ensued that all parameters added to a total of 26 parameters and all boreholes adding to a total of 30.

### 4.3 Physical parameters

Values of physical properties of groundwater during the wet and dry season are shown in Table 3 and Table 4 respectively. Regression, correlation and Chi-Square test statistics for the physical parameters were also conducted.

**Table 3: Mean values of physical parameters in groundwater during the wet season (n=30)**

| Zone: | Borehole Code | Free Turbidity (NTU) | TDS (mg/L) | Conductivity (µS/cm) | Colour (TCU) | Temperature ($^{o}$C) |
|---|---|---|---|---|---|---|
| **Kasarani/ Roysambu** | H.I.1 | 0.19±0.04 | 123.30±2.52 | 0.81±0.10 | <5 | 26.37±0.06 |
| | W.C.2 | 3.78±0.11 | 314.67±6.11 | 0.70±0.02 | <5 | 28.67±0.12 |
| | K.I.3 | 1.18±0.44 | 382.67±4.16 | 0.58±0.00 | <5 | 24.1±0.66 |
| | U.S.4 | 24.44±4.18 | 617.00±10.82 | 0.93±0.02 | <5 | 28.43±0.49 |
| | B.C.5 | 20.97±4.79 | 318.67±256.64 | 0.49±0.37 | <5 | 28.67±0.12 |
| **Dagoretti/ Kawangware** | M.D.6 | 1.61±0.42 | 216.67±0.58 | 0.34±0.03 | <5 | 31.17±1.04 |
| | D.C.7 | 0.68±0.14 | 179.33±0.58 | 0.27±0.01 | <5 | 28.17±0.25 |
| | D.H.8 | 0.79±0.77 | 306.33±1.15 | 0.46±0.01 | <5 | 22.53±0.15 |
| | P.B.9 | 2.08±0.87 | 161.33±3.79 | 0.24±0.02 | <5 | 22.97±0.06 |
| | M.F.10 | 3.23±0.26 | 176.33±2.52 | 0.28±0.02 | <5 | 27.43±0.31 |
| **Embakasi** | T.S.11 | 16.18±4.56 | 473.33±8.50 | 0.73±0.04 | <5 | 24.17±2.57 |
| | J.A.12 | 20.32±2.85 | 994.33±19.30 | 1.49±0.02 | <5 | 27.57±0.23 |
| | J.A.13 | 16.73±1.53 | 527.33±18.45 | 0.79±0.02 | <5 | 27.53±0.12 |
| | H.G.14 | 15.30±1.80 | 761.67±148.80 | 0.88±0.03 | 5.0 | 23.83±0.65 |
| | B.P.15 | 25.17±3.75 | 681.67±40.81 | 1.08±0.04 | <5 | 28.27±0.50 |
| **Langata/ Karen** | S.T.16 | 18.61±5.20 | 217.67±1.53 | 0.35±0.02 | <5 | 25.03±0.32 |
| | S.T.17 | 19.00±3.77 | 211.67±2.08 | 0.33±0.03 | <5 | 25.4±0.20 |
| | A.A.18 | 29.83±1.18 | 200.33±3.51 | 0.30±0.02 | <5 | 28.1±0.10 |
| | N.C.19 | 15.70±0.78 | 203.67±3.51 | 0.32±0.00 | <5 | 26.17±0.06 |
| | K.C.20 | 15.56±2.27 | 298.67±9.45 | 0.46.023 | <5 | 20.8±0.17 |
| **City Centre** | E.A.21 | 21.53±0.31 | 201.00±2.44 | 1.21±1.55 | <5 | 27.1±0.00 |
| | B.H.22 | 13.43±0.47 | 215.33±5.69 | 0.33±0.03 | 10.0 | 27.97±0.67 |
| | K.H.23 | 16.23±0.06 | 210.67±6.66 | 0.32±0.02 | 5.0 | 21.87±2.06 |
| | R.P.24 | 18.00±0.17 | 198.67±1.53 | 0.33±0.05 | <5 | 27.2±0.00 |
| | M.W.25 | 19.40±0.20 | 235.33±6.43 | 0.36±0.02 | <5 | 20.33±1.20 |
| **Industrial Area** | K.C.26 | 7.15±0.15 | 293.00±6.56 | 0.45±0.02 | <5 | 24.5±1.41 |
| | C.B.27 | 7.00±0.02 | 335.67±3.06 | 0.52±0.01 | 5.0 | 20.67±0.32 |
| | C.B.28 | 10.10±0.13 | 337.67±16.74 | 0.51±0.02 | <5 | 26.20±0.17 |
| | A.C.29 | 0.16±0.02 | 569.67±2.52 | 0.92±0.02 | <5 | 26.77±0.32 |
| | F.E.30 | 2.07±0.21 | 360.33±0.58 | 0.58±0.01 | <5 | 25.3±0.36 |
| **WHO Guideline Value** | | **5.00** | **1200.00** | **0.5-5** | **15.00** | **Cool** |
| **NEMA Standard** | | **-** | **1200.00** | **-** | **-** | **-** |
| **KEBS Limit** | | **5.00** | **1500.00** | **-** | **15.00** | **-** |

**Table 4: Mean values of physical parameters in groundwater during the dry season (n=30)**

| Zone: | Borehole Code | Free Turbidity (NTU) | TDS (mg/L) | Conductivity (µS/cm) | Colour (TCU) | Temperature ($^{o}$C) |
|---|---|---|---|---|---|---|
| **Kasarani/ Roysambu** | H.I.1 | 0.83±0.06 | 440.00±8.89 | 0.67±0.02 | <5 | 26.5±0.35 |
| | W.C.2 | 0.89±0.08 | 597.30±10.79 | 0.91±0.02 | <5 | 26.5±0.00 |
| | K.I.3 | 2.87±0.30 | 396.33±4.73 | 0.60±0.02 | <5 | 26.3±0.06 |
| | U.S.4 | 4.97±0.74 | 591.67±2.52 | 0.89±0.02 | <5 | 26.7±0.00 |
| | B.C.5 | 7.70±0.36 | 155.30±13.28 | 0.55±0.48 | <5 | 22.4±2.45 |
| **Dagoretti/ Kawangware** | M.D.6 | 4.90.95 | 219.33+2.31 | 0.33±0.02 | <5 | 27.2±1.02 |
| | D.C.7 | 4.10±0.00 | 176.33±3.51 | 0.28±0.03 | <5 | 27.5±0.23 |
| | D.H.8 | 3.13±0.06 | 318.3±7.37 | 0.49±0.03 | <5 | 21.8±0.46 |
| | P.B.9 | 3.10±0.1 | 170.30±2.31 | 0.28±0.03 | <5 | 24.6±0.23 |
| | M.F.10 | 2.87±0.58 | 175.60±1.53 | 0.25±0.01 | <5 | 25.2±0.00 |
| **Embakasi** | T.S.11 | 4.40.20 | 446.67±3.06 | 0.63±0.02 | <5 | 26.8±0.06 |
| | J.A.12 | 21.47±0.55 | 877.67±8.62 | 1.32±0.01 | <5 | 24.5±0.00 |
| | J.A.13 | 20.23±1.21 | 532.33±11.85 | 0.80±0.01 | <5 | 24.1±0.06 |
| | H.G.14 | 6.27±0.12 | 581.33±16.07 | 0.97±0.17 | 10.00 | 23.5±0.75 |
| | B.P.15 | 18.43±0.29 | 653.00±21.79 | 1.02±0.04 | <5 | 25.1±1.33 |
| **Langata/ Karen** | S.T.16 | 13.53±0.40 | 209.33±6.11 | 0.39±0.08 | <5 | 21.4±0.20 |
| | S.T.17 | 14.27±2.14 | 206.33±7.51 | 0.36±0.05 | <5 | 22.9±0.23 |
| | A.A.18 | 5.40±0.10 | 206.00±2.65 | 0.31±0.01 | <5 | 25.7±0.00 |
| | N.C.19 | 7.27±0.21 | 198.33±1.15 | 0.30±0.20 | <5 | 19.3±0.20 |
| | K.C.20 | 5.54±0.12 | 256.67±2.52 | 0.39±0.02 | <5 | 24.6±0.35 |
| **City Centre** | E.A.21 | 11.55±0.33 | 201.00±1.53 | 0.30±0.01 | <5 | 25.5±0.12 |
| | B.H.22 | 9.83±0.25 | 225.00±4.36 | 0.35±0.03 | 50.00 | 25.8±0.21 |
| | K.H.23 | 11.03±0.97 | 193.67±5.13 | 0.33±0.03 | 5.00 | 20.8±0.58 |
| | R.P.24 | 9.70±0.46 | 189.67±4.93 | 0.29±0.01 | <5 | 27.1±0.31 |
| | M.W.25 | 21.67±1.03 | 228.00±10.82 | 0.44±0.05 | <5 | 21.5±0.00 |
| **Industrial Area** | K.C.26 | 11.93±1.50 | 274.00±19.70 | 0.46±0.03 | <5 | 25.1±0.12 |
| | C.B.27 | 5.67±0.50 | 296.67±11.06 | 0.44±0.02 | 5.00 | 24.8±0.17 |
| | C.B.28 | 5.94±0.75 | 338.67±1.15 | 0.55±0.05 | <5 | 29.1±0.06 |
| | A.C.29 | 10.59±1.49 | 577.67±4.04 | 0.87±0.01 | <5 | 27.5±0.12 |
| | F.E.30 | 11.73±0.81 | 423.67±7.09 | 0.66±0.04 | <5 | 26.9±0.00 |
| **WHO Guideline Value** | | **5.00** | **1200.00** | **0.5-5** | **15.00** | **Cool** |
| **NEMA Standard** | | **-** | **1200.00** | **-** | **-** | **-** |
| **KEBS Limit** | | **5.00** | **1500.00** | **-** | **15.00** | **-** |

Values of colour shown on Table 3 and Table 4 were comparative. Colour for most samples showed values less than 15 TCU for both wet and dry seasons. The colour standard value for WHO (2008) and KEBS is 15 TCU. The only borehole which showed significantly higher value than the required standard was B.H.22 located at the city centre which gave 50 TCU during the dry season. This could be an indication of pollution arising from metallic ions or humus materials from decaying vegetation matter through seepage (Khopkar, 2006). Water from this borehole may become objectionable to consumers due to poor aesthetic. The fact that most boreholes were within WHO (2008) TCU guideline showed that the soil media is good enough to sieve most of the natural materials originating from humus, peat materials and other wastes.

Most sampled boreholes recorded high turbidity values above the WHO (2008) guidelines. Turbidity ranged between 0.16±0.02 NTU and 29.83±1.18 NTU in the wet season and between 0.83±0.06 NTU to 21.47±0.55 NTU in the dry season as shown in tables 3 and 4 respectively. Borehole A.A.18 in Karen/Lang'ata area recorded the highest turbidity values. Turbidity levels were higher during the wet season compared to the dry season due to transport of suspended particles into the aquifer after the rainy season. For most of the organizations where sampling was done, borehole water was used for processing, manufacturing, drinking or bottling purposes. High turbidity adds extra cost during treatment since it can quickly block filters and stop them from working effectively. Where chlorination of water is practiced, even quite low turbidity will prevent chlorine from killing the microbes in the water efficiently. High turbidity values could be attributed to particles originating from organic matter into the ground water though a porous soil media.

The temperature of water for sampled boreholes ranged between 20.33±1.20 $^{o}$C and 31.17±1.04 $^{o}$C in the wet season and between 19.3±0.20 $^{o}$C and 29.1±0.06 $^{o}$C in the dry season. For nearly all sampled boreholes, the measured TDS and conductivity for both seasons were all observed to meet WHO (2008), NEMA and KEBS drinking water standards. The correlation coefficient between conductivity and TDS was 0.864 and -0.013 between colour and free turbidity. This shows a strong positive correlation between conductivity and TDS and weak positive correlation between colour and free turbidity. Chi-Square test statistics for the physical parameters are shown in Table 5 while Table 6 Shows regression test of conductivity (dependent variable) with TDS and free turbidity as independent variables) with r=0.86.

**Table 5: Chi-Square test statistics for the physical parameters**

| **Test Statistics** | | | | | |
|---|---|---|---|---|---|
| | **TDS** | **Temp.** | **Free Turbidity** | **Colour** | **Conductivity** |
| **Chi-Square** | 1.867a | 4.800b | .000c | 102.700d | 6.000e |
| **df** | 57 | 53 | 59 | 2 | 54 |
| **Asymp. Sig.** | 1 | 1 | 1 | 0 | 1 |

**Table 6: Regression of conductivity (dependent variable) with TDS and free turbidity as independent variables).**

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.865504 |
| R Square | 0.749098 |
| Adjusted R Square | 0.740294 |
| Standard Error | 0.149146 |
| Observations | 60 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2 | 3.785566 | 1.892783 | 85.09004 | 7.69E-18 |
| Residual | 57 | 1.267935 | 0.022244 | | |
| Total | 59 | 5.0535 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 0.101134 | 0.043576 | 2.320891 | 0.023893 | 0.013876 | 0.188393 | 0.013876 | 0.188393 |
| X Variable 1 | 0.001288 | 0.000103 | 12.46001 | 6.52E-18 | 0.001081 | 0.001495 | 0.001081 | 0.001495 |
| X Variable 2 | 0.001709 | 0.002594 | 0.65892 | 0.5126 | -0.00349 | 0.006905 | -0.00349 | 0.006905 |

### 4.4 Chemical parameters

Values of free carbon dioxide, sulphates, nitrates, nitrites, chlorides, potassium and sodium for wet and dry season are shown in Table 7 and Table 8 respectively.

**Table 7: Levels of chemical parameters in groundwater during the wet season (n=30)**

| Zone: | Borehole Code | Free $CO_2$ (mg/L) | Sulphates (mg/L) | Nitrates (mg/L) | Nitrites (mg/L) | Chlorides (mg/L) | $K^+$ (ppm) | $Na^+$ (ppm) |
|---|---|---|---|---|---|---|---|---|
| **Kasarani/ Roysambu** | H.I.1 | 32.00 | 1.43 | 1.30 | <0.01 | 12.00 | 3.50 | 103.00 |
| | W.C.2 | 22.00 | 1.14 | 0.90 | <0.01 | 6.00 | 3.40 | 257.00 |
| | K.I.3 | 12.00 | 2.86 | 0.93 | <0.01 | 18.00 | 2.60 | 92.00 |
| | U.S.4 | 24.00 | 1.14 | 0.94 | 0.03 | 6.00 | 5.40 | 155.00 |
| | B.C.5 | 46.00 | 0.29 | 0.52 | <0.01 | 2.00 | 2.00 | 26.00 |
| **Dagoretti/ Kawangware** | M.D.6 | 0.00 | 1.14 | 0.53 | <0.01 | 8.00 | 1.90 | 41.00 |
| | D.C.7 | 30.00 | 1.14 | 0.50 | <0.01 | 9.00 | 1.80 | 33.00 |
| | D.H.8 | 6.00 | 3.71 | 10.30 | 0.41 | 63.00 | 2.10 | 25.50 |
| | P.B.9 | 14.00 | 1.71 | 1.10 | <0.01 | 7.00 | 1.70 | 26.00 |
| | M.F.10 | 0.00 | 1.43 | 1.30 | <0.01 | 14.00 | 2.00 | 26.00 |
| **Embakasi** | T.S.11 | 0.00 | 14.86 | 1.30 | <0.01 | 52.00 | 2.10 | 272.50 |
| | J.A.12 | 0.00 | 65.71 | 3.40 | <0.01 | 264.00 | 3.80 | 282.00 |
| | J.A.13 | 0.00 | 20.86 | 1.30 | <0.01 | 67.00 | 1.70 | 127.50 |
| | H.G.14 | 0.00 | 27.14 | 2.00 | 0.08 | 111.00 | 2.60 | 200.00 |
| | B.P.15 | 6.00 | 23.43 | 2.50 | <0.01 | 110.00 | 3.60 | 153.50 |
| **Langata/ Karen** | S.T.16 | 28.00 | 0.57 | 0.76 | <0.01 | 11.00 | 2.20 | 41.50 |
| | S.T.17 | 26.00 | 1.14 | 0.84 | <0.01 | 11.00 | 2.40 | 1.00 |
| | A.A.18 | 12.00 | 1.14 | 0.84 | <0.01 | 12.00 | 2.00 | 25.50 |
| | N.C.19 | 10.00 | 0.57 | 0.26 | <0.01 | 7.00 | 1.30 | 37.50 |
| | K.C.20 | 12.00 | 4.29 | 4.00 | <0.01 | 61.00 | 2.80 | 10.00 |
| **City Centre** | E.A.21 | 14.00 | 1.43 | 0.92 | <0.01 | 11.00 | 2.20 | 32.50 |
| | B.H.22 | 42.00 | 0.86 | 0.74 | <0.01 | 4.00 | 1.20 | 32.50 |
| | K.H.23 | 0.00 | 0.29 | 0.61 | <0.01 | 9.00 | 2.00 | 27.00 |
| | R.P.24 | 0.00 | 0.86 | 0.51 | <0.01 | 5.00 | 1.70 | 23.00 |
| | M.W.25 | 0.00 | 2.29 | 0.56 | <0.01 | 9.00 | 2.20 | 26.00 |
| **Industrial Area** | K.C.26 | 0.00 | 3.14 | 0.48 | <0.01 | 12.00 | 2.00 | 40.00 |
| | C.B.27 | 0.00 | 3.43 | 0.46 | <0.01 | 12.00 | 2.00 | 65.50 |
| | C.B.28 | 0.00 | 4.00 | 0.38 | <0.01 | 16.00 | 2.00 | 67.50 |
| | A.C.29 | 0.00 | 46.57 | 1.50 | <0.01 | 124.00 | 4.60 | 35.50 |
| | F.E.30 | 0.00 | 23.71 | 3.20 | <0.01 | 90.00 | 3.00 | 44.50 |
| **WHO Guideline Value** | | **-** | **250** | **50.00** | **0.2** | **250** | **200** | **200** |
| **NEMA Standard** | | **-** | **-** | **10** | **3** | **-** | **-** | **-** |
| **KEBS Limit** | | **-** | **400** | **10** | **-** | **250** | **-** | **200** |
| **Limit of Detection** | | **-** | **-** | **0.1** | **0.01** | **-** | **0.00** | **0.00** |

**Table 8: Levels of chemical parameters in groundwater during the dry season (n=30)**

| Zone: | Borehole Code | Free $CO_2$ (mg/L) | Sulphates (mg/L) | Nitrates (mg/L) | Nitrites (mg/L) | Chlorides (mg/L) | $K^+$ (ppm) | $Na^+$ (ppm) |
|---|---|---|---|---|---|---|---|---|
| **Kasarani/ Roysambu** | H.I.1 | 10.00 | 3.43 | 1.40 | 0.02 | 12.00 | 5.40 | 135.25 |
| | W.C.2 | 14.00 | 2.29 | 2.40 | <0.01 | 7.00 | 7.80 | 193.33 |
| | K.I.3 | 2.00 | 3.43 | 0.74 | <0.01 | 17.00 | 3.80 | 128.17 |
| | U.S.4 | 36.00 | 2.00 | 0.43 | 0.02 | 8.00 | 7.80 | 184.83 |
| | B.C.5 | 26.00 | 2.57 | 0.14 | 0.08 | 2.00 | 3.80 | 47.50 |
| **Dagoretti/ Kawangware** | M.D.6 | 0.00 | 7.43 | 0.70 | <0.01 | 7.00 | 2.00 | 61.00 |
| | D.C.7 | 0.00 | 2.57 | 0.12 | <0.01 | 9.00 | 2.00 | 53.83 |
| | D.H.8 | 54.00 | 6.00 | 0.70 | 0.32 | 73.00 | 2.40 | 58.58 |
| | P.B.9 | 4.00 | 2.29 | 10.40 | 0.02 | 11.00 | 3.20 | 54.50 |
| | M.F.10 | 2.00 | 0.57 | 1.20 | 0.02 | 12.00 | 2.60 | 49.08 |
| **Embakasi** | T.S.11 | 0.00 | 18.57 | 0.80 | 0.02 | 48.00 | 3.80 | 153.50 |
| | J.A.12 | 0.00 | 40.86 | 2.16 | 0.02 | 35.00 | 5.40 | 272.58 |
| | J.A.13 | 0.00 | 22.57 | 1.10 | <0.01 | 64.00 | 1.80 | 183.08 |
| | H.G.14 | 2.00 | 34.57 | 3.20 | 0.02 | 29.00 | 3.80 | 220.08 |
| | B.P.15 | 0.00 | 20.00 | 2.10 | 0.02 | 124.00 | 6.80 | 199.50 |
| **Langata/ Karen** | S.T.16 | 10.00 | 25.14 | 0.90 | <0.01 | 13.00 | 2.40 | 53.42 |
| | S.T.17 | 4.00 | 3.43 | 1.80 | <0.01 | 10.00 | 3.60 | 48.92 |
| | A.A.18 | 8.00 | 0.57 | 1.50 | <0.01 | 8.00 | 2.80 | 59.17 |
| | N.C.19 | 2.00 | 10.00 | 0.90 | <0.01 | 9.00 | 1.40 | 57.08 |
| | K.C.20 | 8.00 | 1.14 | 5.60 | <0.01 | 44.00 | 2.80 | 57.50 |
| **City Centre** | E.A.21 | 4.00 | 3.71 | 0.58 | 0.02 | 6.00 | 2.80 | 58.92 |
| | B.H.22 | 6.00 | 1.43 | 0.72 | 0.02 | 10.00 | 2.40 | 81.83 |
| | K.H.23 | 26.00 | 1.14 | 0.64 | <0.01 | 9.00 | 3.00 | 62.58 |
| | R.P.24 | 0.00 | 12.00 | 0.25 | <0.01 | 5.00 | 1.60 | 63.17 |
| | M.W.25 | 0.00 | 2.57 | 0.15 | <0.01 | 12.00 | 2.00 | 70.58 |
| **Industrial Area** | K.C.26 | 0.00 | 2.00 | 0.19 | 0.02 | 12.00 | 1.80 | 96.33 |
| | C.B.27 | 0.00 | 2.00 | 0.25 | 0.02 | 14.00 | 1.80 | 111.75 |
| | C.B.28 | 0.00 | 2.29 | 0.35 | 0.02 | 17.00 | 1.80 | 106.75 |
| | A.C.29 | 0.00 | 29.71 | 6.40 | <0.01 | 123.00 | 4.00 | 180.00 |
| | F.E.30 | 0.00 | 16.00 | 1.10 | 0.02 | 51.00 | 3.20 | 148.42 |
| **WHO Guideline Value** | | - | **250** | **50** | **0.2** | **250** | **200** | **200** |
| **NEMA Standard** | | - | - | **10** | **3** | - | - | - |
| **KEBS Limit** | | - | **400** | **10** | - | **250** | - | **200** |
| **Limit of Detection** | | - | - | **0.10** | **0.01** | - | **0.00** | **0.00** |

During the wet and dry seasons, concentrations of $SO_4^{2-}$, $NO^{3-}$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, dissolved oxygen and total hardness were all below the required standards for drinking water. For each analyte analyzed, concentrations in mg/L ranged; $SO_4^{2-}$ (0.29-65.7), $NO_3^-$ (0.12-10.4), $NO_2^+$ (0.01-0.4), $Cl^-$ (2-264), $K^+$ (1.2-7.8), $Ca^{2+}$ (1.6-21.6), $Mg^{2+}$ (0.001-11.2), dissolved oxygen (6.1-21.2) and total hardness (4-100). In both seasons, borehole D.H.8 showed $NO_2^+$ concentration higher than 0.2 mg/L which is the WHO (2008) requirement. Increased loading of dissolved agricultural pollutants (Olago, 2008) especially fertilizers may have resulted to input of nitrites considering that Dagoretti area is an agricultural zone. The fact that nitrates and nitrites are generally soluble implies that they might have easily seeped into the groundwater.

Borehole J.A.12 in Embakasi showed the highest $Cl^-$ concentration of 264 mg/L during the wet season which was far much higher than the WHO (2008) standard. Correlation between chlorides and sulphates showed a strong positive correlation of 0.82. Such water with high $Cl^-$ concentration may have a bad taste (WHO, 2008). High levels of chloride in human blood may cause hyperchloremia (NLM, 2011). Excessive chloride concentrations increase the rates of corrosion of metals in the distribution system, depending on the alkalinity of the water. The high chloride level noted in J.A.12 may have attributed to high TDS level recorded.

Results for sodium are shown in Tables 7 and 8. The study showed that boreholes W.C.2, T.S.11 and J.A.12 gave sodium concentration higher than the WHO (2008) standard during the wet season. Borehole J.A.12 and H.G.14 showed sodium levels above WHO (2008) standard during the dry season. It was interesting that borehole J.A.12 gave higher concentrations than WHO (2008) standards for $Cl^-$ ions in the wet season. Correlation between sodium and TDS showed a strong positive correlation of 0.81. Increased intake of such high levels of sodium may be problematic to people with hypertension, heart disease or kidney problems that require them to follow a low sodium diet. Reports from literature (Gevaerts, 1964) states that Embakasi area has a confined aquifer and therefore the sodium detected cannot be as a result of seepage but possibly from direct recharge.

No free carbon dioxide was detected for nearly half of the sampled boreholes. Free carbon dioxide ranged between zero and 54 mg/L. Absence of carbon dioxide in groundwater indicate absence of microorganisms in the soil media. Figure 4 indicate comparative levels of sodium during the wet and dry season while Chi-Square test statistics for the chemical parameters are shown in Table 9.

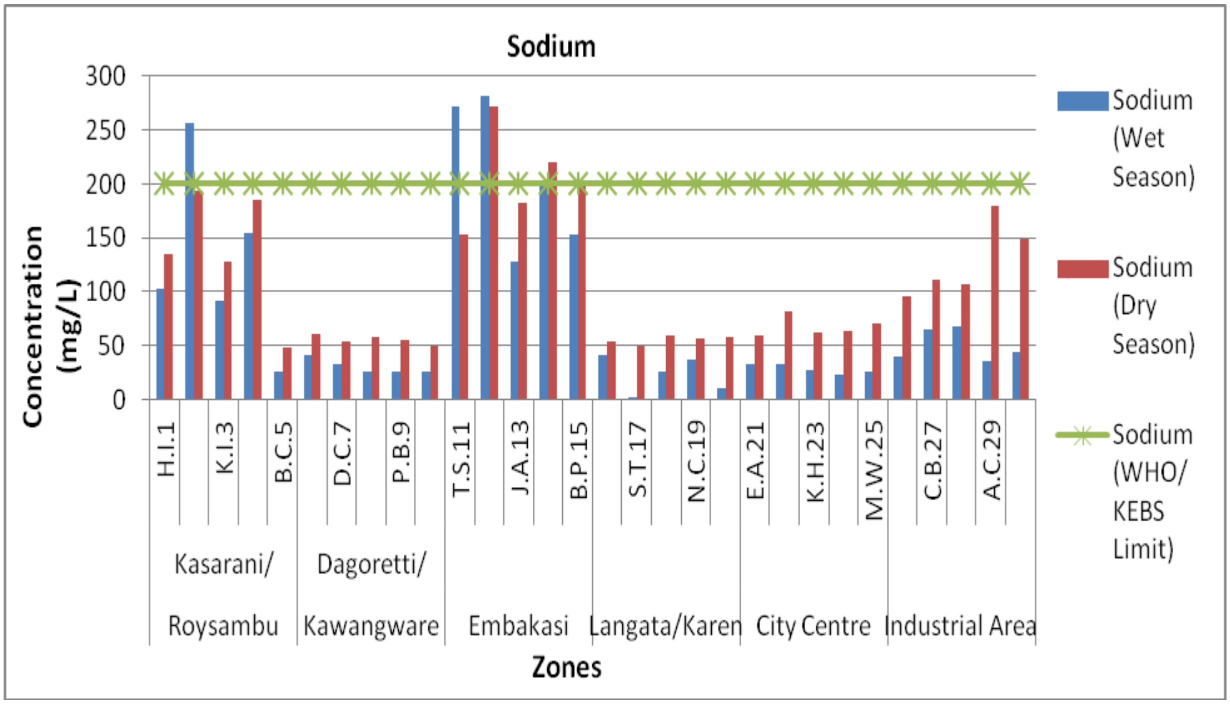


**Figure 4: Comparative levels of Na during the wet and dry seasons with WHO/KEBS Standards**

**Table 9: Chi-Square test statistics for the chemical parameters**

| Test Statistics | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Free $CO_2$** | **Sulphates** | **Nitrates** | **Nitrites** | **Chlorides** | **$K^+$** | **$Na^+$** |
| **Chi-Square** | 183.600b | 26.667c | 15.200d | 313.100a | 43.467e | 39.200k | 10.200l |
| **df** | 17 | 39 | 46 | 12 | 31 | 23 | 53 |
| **Asymp. Sig.** | 0 | 0.933 | 1 | 0 | 0.068 | 0.019 | 1 |

Values of total hardness, calcium, magnesium, total alkalinity, pH and dissolved oxygen are shown in Table 10 and Table 11 for the wet and dry season respectively.

**Table 10: Levels of chemical parameters in groundwater during the wet season (n=30)**

| Zone: | Borehole Code | Total Hardness (mg/L) | Calcium ($Ca^{2+}$) (mg/L) | Magnesium ($Mg^{2+}$) (mg/L) | Total Alkalinity (mg/L) | pH (pH Scale) | Dissolved Oxygen (mg/L) |
|---|---|---|---|---|---|---|---|
| **Kasarani/ Roysambu** | H.I.1 | 36.00 | 16.80 | 1.45 | 378.00 | 7.18±0.02 | 8.67±0.32 |
| | W.C.2 | 34.00 | 17.60 | 2.42 | 348.00 | 8.30±0.10 | 11.23±1.50 |
| | K.I.3 | 14.00 | 8.80 | 1.94 | 296.00 | 7.93±0.35 | 8.97±0.40 |
| | U.S.4 | 50.00 | 2.40 | 10.69 | 530.00 | 6.53±0.25 | 10.73±0.75 |
| | B.C.5 | 18.00 | 5.60 | 0.98 | 124.00 | 7.57±0.35 | 11.23±1.50 |
| **Dagoretti/ Kawangware** | M.D.6 | 6.00 | 3.20 | 0.49 | 162.00 | 8.17±0.15 | 8.00±0.95 |
| | D.C.7 | 8.00 | 4.00 | 0.48 | 108.00 | 7.15±0.21 | 8.1±0.20 |
| | D.H.8 | 98.00 | 20.80 | 11.20 | 86.00 | 4.88±1.01 | 9.5±0.56 |
| | P.B.9 | 8.00 | 1.60 | 0.97 | 108.00 | 5.64±1.12 | 10.1±1.48 |
| | M.F.10 | 12.00 | 4.80 | 0.00 | 108.00 | 6.87±0.32 | 8.13±0.35 |
| **Embakasi** | T.S.11 | 8.00 | 2.40 | 0.49 | 256.00 | 5.48±0.23 | 11.93±4.23 |
| | J.A.12 | 30.00 | 4.00 | 4.86 | 312.00 | 9.11±0.46 | 8.4±0.70 |
| | J.A.13 | 10.00 | 2.40 | 0.97 | 266.00 | 8.50±1.27 | 9.71±1.38 |
| | H.G.14 | 28.00 | 8.00 | 1.95 | 242.00 | 7.66±1.02 | 8.73±0.21 |
| | B.P.15 | 58.00 | 15.20 | 4.87 | 284.00 | 8.43±1.63 | 8.6±0.35 |
| **Langata/ Karen** | S.T.16 | 42.00 | 10.40 | 3.89 | 150.00 | 7.67±0.39 | 11.83±1.52 |
| | S.T.17 | 48.00 | 9.60 | 5.84 | 148.00 | 6.68±0.34 | 16.03±2.61 |
| | A.A.18 | 20.00 | 8.00 | 0.00 | 144.00 | 6.60±0.26 | 8.97±0.76 |
| | N.C.19 | 14.00 | 3.20 | 1.46 | 146.00 | 8.27±0.06 | 10.9±0.26 |
| | K.C.20 | 100.00 | 21.60 | 11.19 | 122.00 | 6.73±0.12 | 9.07±0.12 |
| **City Centre** | E.A.21 | 12.00 | 4.80 | 0.00 | 156.00 | 9.33±0.12 | 18.4±0.20 |
| | B.H.22 | 14.00 | 3.20 | 1.46 | 146.00 | 8.14±0.05 | 9.07±0.12 |
| | K.H.23 | 12.00 | 4.80 | 0.00 | 170.00 | 7.70±0.00 | 9.93±0.15 |
| | R.P.24 | 6.00 | 2.40 | 0.00 | 140.00 | 8.50±0.40 | 9.2±0.89 |
| | M.W.25 | 4.00 | 4.00 | 1.46 | 134.00 | 8.80±0.61 | 9.53±0.35 |
| **Industrial Area** | K.C.26 | 6.00 | 2.40 | 0.00 | 174.00 | 6.93±0.49 | 7.47±0.15 |
| | C.B.27 | 4.00 | 3.20 | 0.97 | 194.00 | 10.27±0.21 | 21.2±1.40 |
| | C.B.28 | 6.00 | 3.20 | 0.49 | 206.00 | 9.50±0.17 | 9.9±0.17 |
| | A.C.29 | 44.00 | 11.20 | 3.89 | 238.00 | 8.13±0.06 | 9.43±0.15 |
| | F.E.30 | 12.00 | 3.20 | 0.97 | 216.00 | 8.37±0.25 | 8.93±0.25 |
| **WHO Guideline Value** | | **200** | **100-300** | **-** | **-** | **6.5–9.5** | ***5** |
| **NEMA Standard** | | **-** | **-** | **-** | **-** | **6.5-8.5** | **-** |
| **KEBS Limit** | | **500** | **250** | **100** | **-** | **6.5-8.5** | **-** |

* Indicates that the guideline value was derived from European Union drinking water standards.

**Table 11: Levels of chemical parameters in groundwater during the dry season (n=30)**

| Zone: | Borehole Code | Total Hardness (mg/L) | Calcium ($Ca^{2+}$) (mg/L) | Magnesium ($Mg^{2+}$) (mg/L) | Total Alkalinity (mg/L) | pH (pH Scale) | Dissolved Oxygen (mg/L) |
|---|---|---|---|---|---|---|---|
| **Kasarani/ Roysambu** | H.I.1 | 50.00 | 17.60 | 1.47 | 384.00 | 4.52±0.93 | 7.73±0.06 |
| | W.C.2 | 48.00 | 18.40 | 0.50 | 348.00 | 4.94±0.24 | 8.87±0.35 |
| | K.I.3 | 40.00 | 15.20 | 0.50 | 320.00 | 5.88±1.41 | 8.3±0.20 |
| | U.S.4 | 42.00 | 14.40 | 1.47 | 556.00 | 5.63±0.25 | 9.03±1.01 |
| | B.C.5 | 40.00 | 16.00 | 0.01 | 140.00 | 7.64±1.63 | 9.2±1.48 |
| **Dagoretti/ Kawangware** | M.D.6 | 10.00 | 4.00 | 0.00 | 148.00 | 9.92±0.73 | 6.1±0.20 |
| | D.C.7 | 10.00 | 4.00 | 0.00 | 132.00 | 6.25±0.53 | 6.9±0.26 |
| | D.H.8 | 16.00 | 6.40 | 0.00 | 80.00 | 8.37±0.31 | 6.9±0.17 |
| | P.B.9 | 12.00 | 4.80 | 0.00 | 120.00 | 5.64±0.13 | 7.03±0.58 |
| | M.F.10 | 20.00 | 8.00 | 0.00 | 118.00 | 8.33±1.40 | 6.53±0.38 |
| **Embakasi** | T.S.11 | 14.00 | 4.80 | 0.49 | 280.00 | 7.73±0.12 | 17.27±0.23 |
| | J.A.12 | 30.00 | 4.00 | 4.86 | 344.00 | 6.8±0.00 | 14.7±1.80 |
| | J.A.13 | 18.00 | 3.20 | 2.43 | 278.00 | 5.47±o.12 | 18.63±1.27 |
| | H.G.14 | 30.00 | 8.00 | 2.43 | 304.00 | 6.6±0.35 | 17.87±1.39 |
| | B.P.15 | 36.00 | 5.60 | 5.35 | 332.00 | 5.4±0.20 | 16.83±1.15 |
| **Langata/ Karen** | S.T.16 | 44.00 | 14.40 | 1.95 | 162.00 | 7.83±0.25 | 9.13±0.50 |
| | S.T.17 | 50.00 | 16.00 | 2.44 | 170.00 | 6.9±0.1 | 18.37±0.46 |
| | A.A.18 | 36.00 | 10.40 | 2.44 | 150.00 | 10.43±0.41 | 6.37±0.21 |
| | N.C.19 | 30.00 | 8.80 | 1.95 | 158.00 | 9.58±0.44 | 7.47±0.06 |
| | K.C.20 | 54.00 | 14.40 | 4.38 | 120.00 | 8.98±0.32 | 7.8±0.00 |
| **City Centre** | E.A.21 | 14.00 | 4.80 | 0.49 | 160.00 | 7.7±0.26 | 18.37±1.37 |
| | B.H.22 | 16.00 | 4.00 | 1.46 | 158.00 | 9.37±0.15 | 7.13±0.46 |
| | K.H.23 | 14.00 | 5.60 | 0.00 | 162.00 | 9.13±0.32 | 7.8±0.20 |
| | R.P.24 | 18.00 | 3.20 | 2.43 | 130.00 | 9.57±1.42 | 6.53±0.23 |
| | M.W.25 | 12.00 | 4.80 | 0.00 | 134.00 | 8.37±0.25 | 18.03±6.19 |
| **Industrial Area** | K.C.26 | 10.00 | 4.00 | 0.00 | 184.00 | 7.47±0.31 | 15.07±6.21 |
| | C.B.27 | 14.00 | 4.80 | 0.49 | 202.00 | 7.6±0.35 | 16.2±5.20 |
| | C.B.28 | 12.00 | 4.80 | 0.00 | 218.00 | 9.33±0.42 | 15.7±0.10 |
| | A.C.29 | 18.00 | 3.20 | 2.43 | 240.00 | 9.53±0.31 | 20.13±0.15 |
| | F.E.30 | 14.00 | 4.80 | 0.49 | 250.00 | 9.37±0.38 | 21.13±0.90 |
| **WHO Guideline Value** | | **200** | **100-300** | **-** | **-** | **6.5-8.5** | ***5** |
| **NEMA Standard** | | **-** | **-** | **-** | **-** | **6.5-8.5** | **-** |
| **KEBS Limit** | | **500** | **250** | **100** | **-** | **6.5–9.5** | **-** |

For total hardness, $Ca^{2+}$ and $Mg^{2+}$, the sampled boreholes showed concentrations lower than WHO (2008) drinking water standards for both wet and dry seasons. Further, all sampled boreholes met dissolved oxygen concentrations not less than the WHO (2008) drinking water standard of 5 mg/L for both wet and dry seasons, as shown in Tables 10 and 11. Correlation between calcium and total hardness showed a strong positive correlation of 0.84 while correlation between magnesium and total hardness showed a strong positive correlation value of 0.8. Regression of total hardness (dependent variable) with magnesium and calcium as dependent variables gave r=0.98 as shown in Table 12. Dissolved oxygen ranged from 6.1 to 21.2 mg/L indicating that all boreholes sampled had adequate diffusion of dissolved oxygen that meet the minimum level of 5-6ppm to support diverse population of microorganisms.

Investigations on pH showed that a few boreholes did not meet the WHO (2008) and KEBS drinking water standard of 6.5-8.5 in the wet season, whereas more than a half of the sampled boreholes water did not meet the WHO (2008) drinking water standards in the dry season. In the wet season, the pH values of borehole water ranged between 4.88±1.01 and 10.27±0.21. The boreholes; D.H.8 and P.B.9 both of Dagoretti/ Kawangware and T.S.11 of Embakasi had acidic water while boreholes J.A.12 of Embakasi, E.A.21 and M.W.25 of City Centre, C.B.27 and C.B.28 of Industrial area showed alkaline water. In the dry season, the pH values of borehole water ranged between 4.52±0.93 and 10.43±0.41. Most of the samples of water that did not meet the WHO (2008) drinking water standards were alkaline apart from the boreholes from Roysambu/ Kasarani which had acidic water during this season. Water with low pH (<6.5) is acidic, corrosive and could contain dissolved metal ions in elevated levels. Chi-Square test statistics for the chemical parameters are shown in Table 13.

**Table 12: Regression test of total hardness (dependent variable) with calcium (X Variable 1) and magnesium (X Variable 2) as dependent variables.**

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.981513 |
| R Square | 0.963367 |
| Adjusted R Square | 0.962082 |
| Standard Error | 3.988501 |
| Observations | 60 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2 | 23845.97 | 11922.98 | 749.4895 | 1.18E-41 |
| Residual | 57 | 906.7641 | 15.90814 | | |
| Total | 59 | 24752.73 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -0.5421 | 0.894767 | -0.60585 | 0.547016 | -2.33384 | 1.249641 | -2.33384 | 1.249641 |
| X Variable 1 | 2.344826 | 0.10422 | 22.49872 | 4.93E-30 | 2.136128 | 2.553524 | 2.136128 | 2.553524 |
| X Variable 2 | 4.307914 | 0.216816 | 19.86897 | 2.68E-27 | 3.873747 | 4.742081 | 3.873747 | 4.742081 |

**Table 13: Chi-Square test statistics for the chemical parameters**

| **Test Statistics** | | | | | | |
|---|---|---|---|---|---|---|
| | **Total Hardness** | **$Ca^{2+}$** | **$Mg^{2+}$** | **Total Alkalinity** | **pH** | **Dissolved Oxygen** |
| **Chi-Square** | 27.267f | 50.667g | 32.467h | 10.500d | 7.133j | 6.300i |
| **Df** | 21 | 19 | 37 | 46 | 52 | 50 |
| **Asymp. Sig.** | 0.162 | 0 | 0.681 | 1 | 1 | 1 |

### 4.5 Heavy metals

All the sampled boreholes were analyzed for the heavy metals Zn, Cd, Cu, Ni, Cr, Pb, Hg and As. Samples were collected in both wet and dry seasons. Tabulation of the results is shown in tables 14 and 15.

**Table 14: Mean levels of heavy metals in groundwater during the wet season (n=30).**

| | Borehole Code | Zn | Cd | Cu | Ni | Cr | Pb | Hg | As |
|---|---|---|---|---|---|---|---|---|---|
| **Zone: Kasarani/ Roysambu** | H.I.1 | 0.01±0.01 | BDL | BDL | 0.03±0.00 | BDL | 0.13±0.01 | 0.0016±0.00 | 0.010 |
| | W.C.2 | 0.03±0.00 | BDL | BDL | 0.03±0.00 | BDL | 0.13±0.00 | 0.0015±0.00 | 0.004 |
| | K.I.3 | BDL | BDL | BDL | 0.04±0.01 | BDL | 0.20±0.00 | 0.0021±0.00 | BDL |
| | U.S.4 | BDL | BDL | BDL | 0.05±0.00 | BDL | 0.16±0.00 | 0.0016±0.00 | 0.006 |
| | B.C.5 | 1.09±0.01 | BDL | BDL | 0.05±0.00 | BDL | 0.21±0.00 | 0.0017±0.00 | 0.005 |
| **Dagoretti/ Kawangware** | M.D.6 | BDL | BDL | BDL | 0.05±0.00 | BDL | 0.10±0.00 | 0.0014±0.00 | BDL |
| | D.C.7 | BDL | BDL | BDL | 0.04±0.00 | BDL | 0.15±0.01 | 0.0014±0.00 | BDL |
| | D.H.8 | BDL | BDL | BDL | 0.06±0.00 | BDL | 0.18±0.00 | 0.0017±0.00 | BDL |
| | P.B.9 | BDL | BDL | BDL | 0.03±0.00 | BDL | 0.23±0.00 | 0.0016±0.00 | BDL |
| | M.F.10 | 0.39±0.00 | BDL | BDL | 0.04±0.00 | BDL | 0.30±0.00 | 0.0027±0.00 | BDL |
| **Embakasi** | T.S.11 | 0.08±0.00 | BDL | BDL | 0.04±0.00 | BDL | 0.19±0.00 | 0.0019±0.00 | BDL |
| | J.A.12 | BDL | BDL | BDL | 0.03±0.00 | BDL | 0.24±0.00 | 0.0019±0.00 | 0.008 |
| | J.A.13 | 0.62±0.01 | BDL | BDL | 0.03±0.00 | BDL | 0.20±0.00 | 0.0016±0.00 | 0.017 |
| | H.G.14 | 0.07±0.00 | BDL | BDL | 0.03±0.01 | BDL | 0.16±0.00 | 0.0018±0.00 | BDL |
| | B.P.15 | BDL | BDL | BDL | 0.03±0.00 | BDL | 0.25±0.00 | 0.0017±0.00 | BDL |
| **Langata/ Karen** | S.T.16 | 0.28±0.00 | BDL | BDL | 0.02±0.00 | BDL | 0.21±0.00 | 0.0017±0.00 | BDL |
| | S.T.17 | BDL | BDL | BDL | 0.03±0.00 | BDL | 0.25±0.00 | 0.0016±0.00 | BDL |
| | A.A.18 | 0.04±0.00 | BDL | BDL | 0.03±0.00 | BDL | 0.27±0.00 | 0.0018±0.00 | 0.007 |
| | N.C.19 | 0.02±0.01 | BDL | BDL | 0.02±0.00 | BDL | 0.26±0.00 | 0.0019±0.00 | BDL |
| | K.C.20 | BDL | BDL | BDL | 0.02±0.00 | BDL | 0.29±0.00 | 0.0017±0.00 | BDL |
| **City Centre** | E.A.21 | 0.03±0.00 | BDL | BDL | 0.04±0.00 | BDL | 0.25±0.00 | 0.0018±0.00 | 0.029 |
| | B.H.22 | BDL | BDL | BDL | 0.03±0.00 | BDL | 0.28±0.00 | 0.0016±0.00 | 0.005 |
| | K.H.23 | 0.18±0.01 | BDL | BDL | 0.03±0.00 | BDL | 0.29±0.00 | 0.0010±0.00 | BDL |
| | R.P.24 | BDL | BDL | BDL | 0.03±0.00 | BDL | 0.29±0.00 | 0.0006±0.00 | 0.013 |
| | M.W.25 | BDL | BDL | BDL | 0.04±0.00 | BDL | 0.29±0.00 | 0.0006±0.00 | 0.019 |
| **Industrial Area** | K.C.26 | BDL | BDL | BDL | 0.04±0.00 | BDL | 0.31±0.00 | 0.0005±0.00 | 0.012 |
| | C.B.27 | BDL | BDL | BDL | 0.05±0.00 | BDL | 0.33±0.00 | 0.0019±0.00 | BDL |
| | C.B.28 | BDL | BDL | BDL | 0.04±0.00 | BDL | 0.33±0.01 | 0.0021±0.00 | 0.008 |
| | A.C.29 | 0.05±0.01 | BDL | 8.18 | 0.05±0.00 | BDL | 0.22±0.00 | 0.0036±0.00 | BDL |
| | F.E.30 | 0.03±0.00 | BDL | 4.80 | 0.03±0.01 | BDL | 0.19±0.00 | 0.0034±0.00 | BDL |
| **WHO Guideline Value** | | **3.00** | **0.003** | **2.00** | **0.07** | **0.05** | **0.01** | **0.006** | **0.01** |
| **NEMA Standard** | | **1.50** | **0.01** | **0.05** | **-** | **-** | **0.05** | **-** | **0.01** |
| **KEBS Limit** | | **5.00** | **0.005** | **0.10** | **-** | **0.05** | **0.05** | **0.001** | **0.05** |
| **Limit of detection** | | **0.01** | **0.001** | **0.02** | **0.007** | **0.005** | **0.001** | **0.0001** | **0.002** |

**Table 15: Mean levels of heavy metals in groundwater during the dry season (n=30).**

| | **Borehole Code** | **Zn** | **Cd** | **Cu** | **Ni** | **Cr** | **Pb** | **Hg** | **As** |
|---|---|---|---|---|---|---|---|---|---|
| **Zone: Kasarani/ Roysambu** | H.I.1 | 0.22±0.00 | 0.02±0.00 | BDL | 0.12±0.02 | 0.37±0.01 | 0.06±0.01 | 0.0018±0.00 | BDL |
| | W.C.2 | 0.05±0.00 | 0.02±0.01 | BDL | 0.35±0.06 | 0.36±0.01 | 0.10±0.01 | 0.0020±0.00 | 0.005 |
| | K.I.3 | 0.42±0.00 | 0.02±0.00 | BDL | 0.41±0.04 | 0.37±0.02 | 0.19±0.01 | 0.0021±0.00 | 0.004 |
| | U.S.4 | BDL | 0.03±0.01 | BDL | 0.51±0.03 | 0.44±0.00 | 0.10±0.02 | 0.0017±0.00 | 0.003 |
| | B.C.5 | 0.12±0.00 | 0.03±0.01 | BDL | 0.50±0.03 | 0.44±0.00 | 0.10±0.01 | 0.0021±0.00 | BDL |
| **Dagoretti/ Kawangware** | M.D.6 | BDL | 0.03±0.00 | BDL | 0.43±0.04 | 0.46±0.01 | 0.12±0.02 | 0.0019±0.00 | 0.005 |
| | D.C.7 | BDL | 0.03±0.00 | BDL | 0.20±0.00 | 0.49±0.01 | 0.12±0.01 | 0.0013±0.00 | 0.005 |
| | D.H.8 | 0.04±0.00 | 0.03±0.00 | BDL | 0.23±0.02 | 0.50±0.01 | 0.15±0.01 | 0.0024±0.00 | BDL |
| | P.B.9 | BDL | 0.04±0.01 | BDL | 0.23±0.01 | 0.51±0.01 | 0.11±0.01 | 0.0018±0.00 | 0.005 |
| | M.F.10 | BDL | BDL | BDL | 0.21±0.02 | 0.51±0.01 | 0.15±0.02 | 0.0031±0.00 | BDL |
| **Embakasi** | T.S.11 | 0.06±0.00 | BDL | BDL | 0.23±0.01 | 0.52±0.01 | 0.17±0.01 | 0.0019±0.00 | BDL |
| | J.A.12 | BDL | BDL | BDL | 0.21±0.01 | BDL | 0.17±0.01 | 0.0018±0.00 | 0.010 |
| | J.A.13 | 0.58±0.00 | BDL | BDL | 0.18±0.01 | BDL | 0.32±0.32 | 0.0016±0.00 | 0.015 |
| | H.G.14 | 0.4±0.00 | BDL | BDL | 0.19±0.01 | BDL | 0.23±0.01 | 0.0018±0.00 | BDL |
| | B.P.15 | 0.14±0.00 | BDL | BDL | 0.20±0.01 | BDL | 0.21±0.01 | 0.0019±0.00 | BDL |
| **Langata/ Karen** | S.T.16 | 0.16±0.00 | BDL | BDL | 0.24±0.02 | BDL | 0.22±0.01 | 0.0017±0.00 | 0.013 |
| | S.T.17 | 0.73±0.00 | BDL | BDL | 0.22±0.01 | BDL | 0.33±0.01 | 0.0017±0.00 | 0.006 |
| | A.A.18 | 0.19±0.00 | BDL | BDL | 0.23±0.02 | BDL | 0.22±0.01 | 0.0020±0.00 | 0.008 |
| | N.C.19 | 0.32±0.00 | BDL | BDL | 0.24±0.01 | BDL | 0.30±0.04 | 0.0018±0.00 | 0.008 |
| | K.C.20 | 0.51±0.02 | BDL | BDL | 0.22±0.01 | BDL | 0.42±0.01 | 0.0019±0.00 | BDL |
| **City Centre** | E.A.21 | 0.21±0.00 | BDL | BDL | 0.24±0.01 | BDL | 0.24±0.02 | 0.0017±0.00 | BDL |
| | B.H.22 | 0.11±0.00 | BDL | BDL | 0.23±0.02 | BDL | 0.22±0.01 | 0.0016±0.00 | 0.007 |
| | K.H.23 | 0.68±0.00 | BDL | BDL | 0.25±0.01 | BDL | 0.27±0.02 | 0.0013±0.00 | BDL |
| | R.P.24 | 0.14±0.00 | BDL | BDL | 0.26±0.01 | BDL | 0.24±0.02 | 0.0010±0.00 | 0.014 |
| | M.W.25 | 0.12±0.00 | BDL | BDL | 0.30±0.03 | BDL | 0.25±0.01 | 0.0007±0.00 | 0.019 |
| **Industrial Area** | K.C.26 | 0.25±0.00 | BDL | BDL | 0.33±0.02 | 0.01±0.01 | 0.26±0.00 | 0.0010±0.00 | 0.003 |
| | C.B.27 | 0.33±0.00 | 0.01±0.00 | BDL | 0.22±0.01 | BDL | 0.33±0.03 | 0.0019±0.00 | 0.013 |
| | C.B.28 | 0.13±0.00 | 0.01±0.00 | BDL | 0.26±0.02 | 0.01±0.01 | 0.26±0.03 | 0.0024±0.00 | 0.007 |
| | A.C.29 | 0.08±0.00 | 0.01±0.00 | BDL | 0.21±0.01 | 0.10±0.01 | 0.28±0.02 | 0.0034±0.00 | 0.004 |
| | F.E.30 | 0.19±0.00 | 0.01±0.00 | BDL | 0.22±0.02 | 0.11±0.02 | 0.31±0.01 | 0.0037±0.00 | 0.009 |
| **WHO Guideline Value** | | **3.00** | **0.003** | **2.00** | **0.07** | **0.05** | **0.01** | **0.006** | **0.01** |
| **NEMA Standard** | | **1.50** | **0.01** | **0.05** | **-** | **-** | **0.05** | **-** | **0.01** |
| **KEBS Limit** | | **5.00** | **0.01** | **0.10** | **-** | **0.05** | **0.05** | **0.001** | **0.05** |
| **Limit of detection** | | **0.01** | **0.001** | **0.02** | **0.007** | **0.005** | **0.001** | **0.0001** | **0.002** |

The study revealed that zinc was within the WHO (2008), NEMA and KEBS drinking water standards with the dry season recording higher concentrations of zinc compared to the wet season. Mercury also showed concentrations that were lower than WHO (2008) requirements for both wet and dry seasons. However, concentrations of mercury were above KEBS requirement. Traces of mercury may not have their origin in Nairobi area but the source may be traced back from recharge areas where common wastes such as batteries and fluorescent tubes are carelessly disposed. This relates to concentrations of mercury greater than 0.001 ppm in Ngong rivers reported by Kithia (1992). Though levels detected were low, mercury is known to bi-accumulate and may have a negative long term effects when ingested. Mercury exposure is known to affect brain development in infants (LeBeau, 2008).

During the wet season, cadmium showed concentrations below the WHO (2008), NEMA and KEBS requirements for drinking water. However, cadmium was detected in all boreholes sampled in Kasarani/Roysambu area, Dagoretti/Kawangware area and Industrial area, except borehole M.F.10 and K.C.26 during the dry season. Figure 5 shows comparative levels of cadmium during the wet and dry season. Concentrations of cadmium analyte ranged from 0.01 to 0.04 ppm which was far above WHO (2008) drinking water standard of 0.003 ppm. Borehole P.B.9 in Dagoretti/Kawangware area recorded the highest concentration of 0.04 ppm. Presence of cadmium in groundwater in Nairobi may be explained by geological factors rather than anthropogenic pollutants input (Olago and Akech, 2001). Ingestion of any significant amount of cadmium causes immediate poisoning and damage to the liver and the kidneys. Cadmium also causes anaemia and hepatic disorder (Elkins and Pagnotto, 1980).

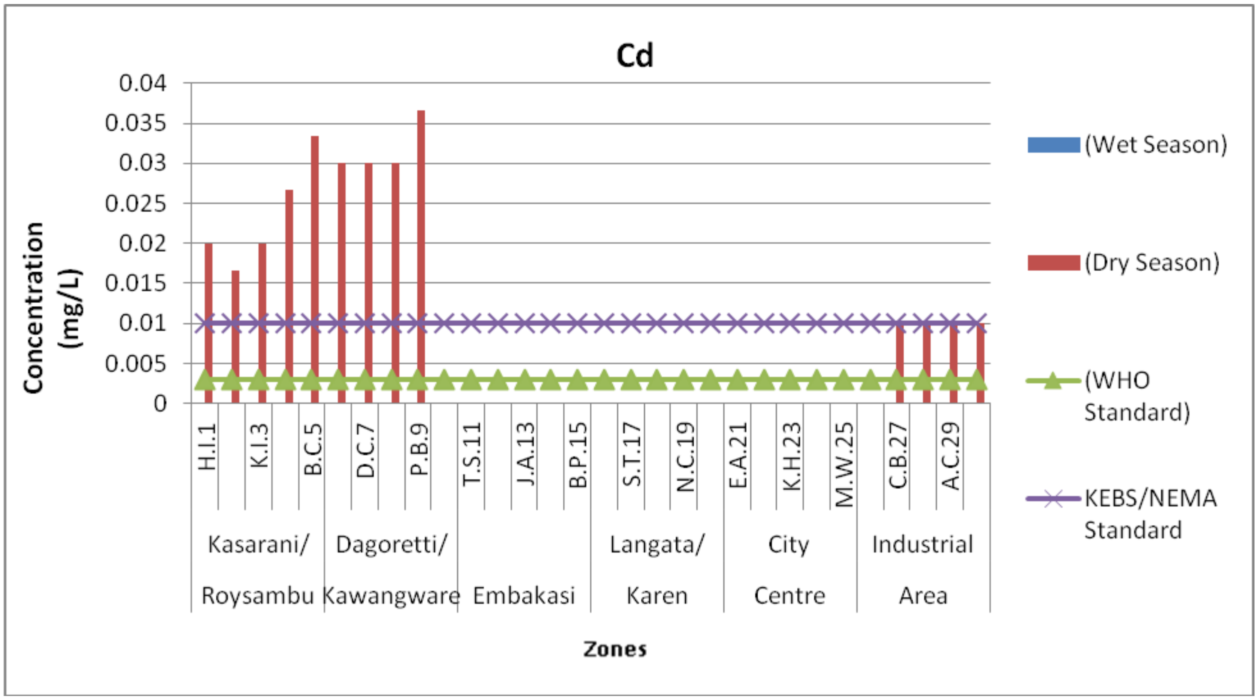


**Figure 5: Comparative levels of Cd during the wet and dry seasons with WHO/NEMA/KEBS Standards**

Analysis of presence of copper in groundwater from Nairobi boreholes for the two seasons showed concentrations that were below the WHO (2008), NEMA and KEBS standards for drinking water for most boreholes. However, two boreholes A.C.29 and F.E.30 located in Industrial area showed high concentrations of 8.18 ppm and 4.8 ppm respectively during the wet season. A plausible explanation of this high concentration could be anthropogenic activities around the industrial area or contamination from corrosion of copper containing plumbing fixtures. Effects of high copper concentrations are more sensitive to children under one year of age than adults. Long-term exposure exceeding 14 days to copper in drinking water above acceptable limit has been found to cause kidney and liver damage in infants. Other persons who are highly susceptible to copper toxicity are people with liver damage or Wilson's disease (DNR, 2003).

Figure 6 depicts comparative concentration of nickel during the wet and dry seasons. Nickel in sampled boreholes was below WHO (2008) requirement during the wet season. All boreholes showed high concentrations of nickel ranging between 0.12±0.02 ppm and 0.51±0.03 ppm during the dry season which was far higher above the recommended WHO (2008) guideline value of 0.07 ppm. Kasarani/Roysambu area showed the highest recording of 0.51±0.03 ppm. Correlation between nickel and cadmium showed a medium positive correlation value of 0.61 while correlation between nickel and chromium showed a medium positive value of 0.58. A plausible explanation would be geological factors (Olago and Akech, 2001) or direct recharge of nickel from the surface through anthropogenic activities into the aquifers and spread to groundwater. Uptake of too large quantities of nickel is known to cause chronic bronchitis, reduced lung function, and cancer of the lung and nasal sinus (Stephenson, 1998).

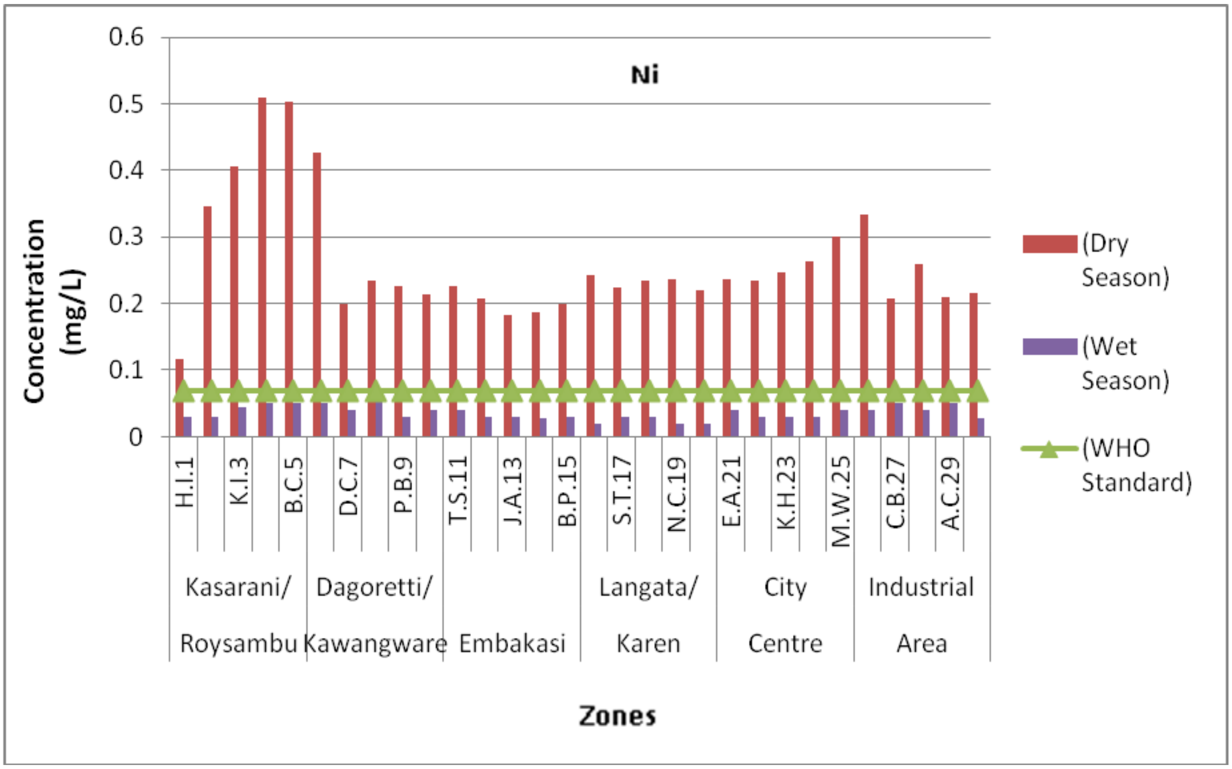


**Figure 6: Comparative levels of Ni during the wet and dry seasons with WHO standards**

Chromium levels were below the detection limit during the wet season for all boreholes sampled. However, all sampled boreholes in Kasarani/Roysambu and Dagoretti zones and one borehole in Embakasi zone (T.S.11) showed high levels of chromium during the dry season that exceeded permissible WHO (2008) guideline. Recorded levels of chromium ranged between 0.01±0.01 ppm and 0.52±0.01 ppm. Borehole T.S.11 showed the highest concentrations of 0.52±0.01 ppm. Correlation between chromium and cadmium showed a strong positive value of 0.82. A possible source of chromium could be high geological background levels since the area has a confined aquifer rather than input from anthropogenic pollutants (Olago and Akech, 2001). High levels of chromium detected in Dagoretti could have resulted from land based activities thus leaking into the aquifer through recharge (Palmer and Wittbrodt, 1991). Relatively short term exposure to chromium above maximum contamination level (MCL) of 0.1 mg/L can cause skin irritation or ulceration while long term exposure at levels above the MCL may cause damage to liver, kidney circulatory and nerve tissues. Chromium is carcinogenic in the hexavalent state (Khopkar, 2006).

The study area revealed high concentrations of lead above the WHO (2008) requirement of 0.01 ppm in both seasons. Recorded levels ranged between 0.10 and 0.33±0.01 ppm during the wet season and between 0.06±0.01 and 0.42±0.01 ppm during the dry season. The highest concentration (0.42±0.01 ppm) was detected in Karen, borehole K.C.20. Other areas which recorded high levels were the City centre and Industrial area. Correlation between lead and chromium was 0.58 and 0.51 between lead and cadmium. This showed a medium positive correlation. In Industrial area, widespread use of leaded products is expected in ceramic industries, glass industries, manufacture of Polyvinyl Chloride (PVC) plastics and most common use in lead acid batteries. Improper disposal of used lead products could easily have contaminated the soil hence finding its way into the groundwater. In addition, spills of leaded fuel into the soil and traces of lead from vehicles' exhaust could have been washed away by surface runoff finding its way into the ground through rock fractures. Short term exposure to high levels of lead can cause vomiting, diarrhea, convulsions, coma or even death. Long term exposure can damage human brain, kidneys, nervous system, and cause hemolysis. Acute poisoning can cause anemia and hemoglobin in the urine (Canada, 2008). Figure 7 shows comparative levels of lead analyte during the wet and the dry season.

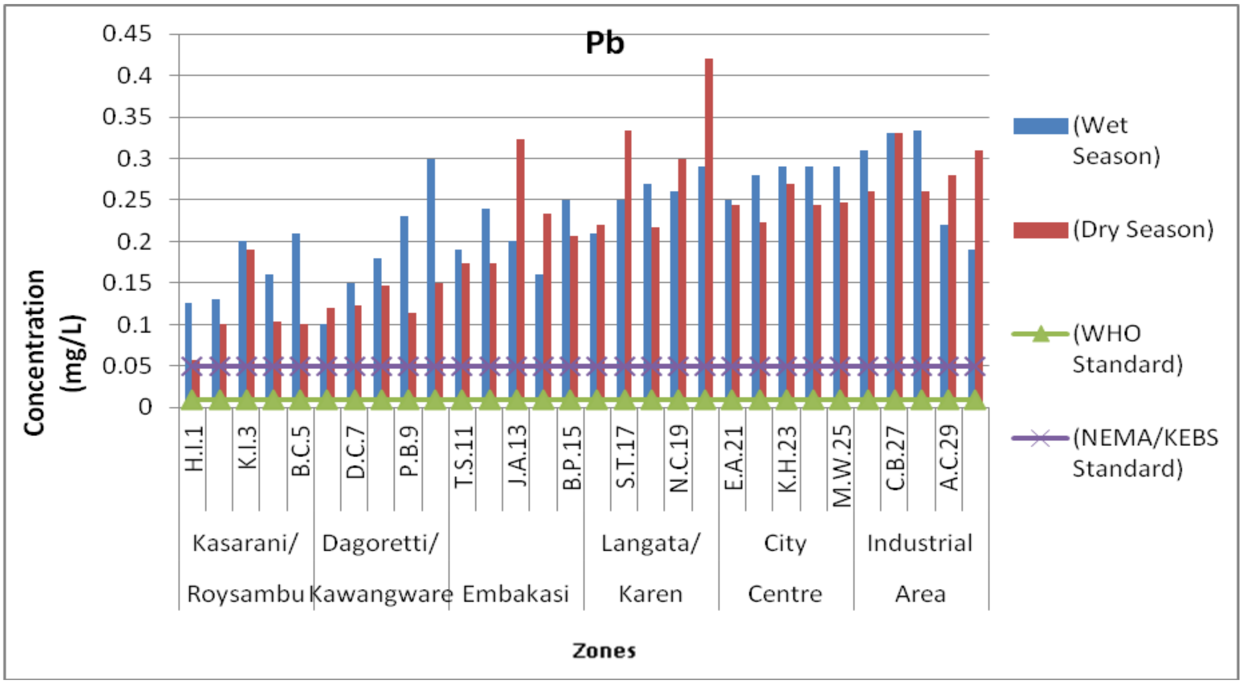


**Figure 7: Comparative levels of Pb during the wet and dry season with WHO/NEMA/KEBS Standards**

Most boreholes showed arsenic level below detection limit in both seasons except boreholes J.A.13, E.A.21, M.W.25 which showed concentrations of 0.017 ppm, 0.029 ppm and 0.019 ppm respectively during the wet season and borehole J.A.13 and M.W.25 which recorded 0.015 and 0.019 ppm during the dry season. Long-term exposure to even relatively low concentrations of arsenic in drinking water can increase risk of developing skin, lung, kidney and bladder cancer (Elkins and Pagnotto, 1980). The traces detected can be concluded to have originated from recharge and not necessarily natural background from rocks.

Regression test of TDS (dependent variable) with Zn, Cd, Cu, Ni, Cr, Pb, Hg and As (in the order given) showed low regression value of r=0.3 as shown in Table 16.

**Table 16: Regression test of TDS (dependent variable) with heavy metals**

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.336519 |
| R Square | 0.113245 |
| Adjusted R Square | -0.02585 |
| Standard Error | 196.3676 |
| Observations | 60 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 8 | 251145.3 | 31393.16 | 0.814133 | 0.593528 |
| Residual | 51 | 1966572 | 38560.24 | | |
| Total | 59 | 2217718 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 344.9676 | 128.8202 | 2.677899 | 0.009943 | 86.35018 | 603.585 | 86.35018 | 603.585 |
| X Variable 1 | -28.5956 | 124.7222 | -0.22927 | 0.819573 | -278.986 | 221.7946 | -278.986 | 221.7946 |
| X Variable 2 | -2279.57 | 4712.903 | -0.48369 | 0.630678 | -11741.1 | 7181.974 | -11741.1 | 7181.974 |
| X Variable 3 | -5.11112 | 25.16363 | -0.20312 | 0.839853 | -55.6292 | 45.40698 | -55.6292 | 45.40698 |
| X Variable 4 | 114.5752 | 268.57 | 0.426612 | 0.671457 | -424.602 | 653.7519 | -424.602 | 653.7519 |
| X Variable 5 | -224.038 | 289.0552 | -0.77507 | 0.441876 | -804.341 | 356.2641 | -804.341 | 356.2641 |
| X Variable 6 | -702.002 | 449.589 | -1.56143 | 0.124607 | -1604.59 | 200.586 | -1604.59 | 200.586 |
| X Variable 7 | 92448.05 | 50065.85 | 1.846529 | 0.070622 | -8063.33 | 192959.4 | -8063.33 | 192959.4 |
| X Variable 8 | 1362.263 | 4474.075 | 0.304479 | 0.762002 | -7619.82 | 10344.34 | -7619.82 | 10344.34 |

## 4.6 Groundwater quality variability with time

To check if the quality of groundwater had changed since the boreholes were drilled, the current water quality for nine boreholes was compared to the water quality when the boreholes were drilled. Secondary data was season specific with the wet season comprising boreholes drilled between 1st April and 30th July and between 1st October and 30th November. Secondary data for the dry season was for the boreholes drilled between 1st August and 30th September and between 1st December and 30th March.

The data show that there has not been a major shift in levels of colour, TDS, pH, conductivity, and total alkalinity in groundwater resources in the study area. However, a few boreholes indicated a significant change, for instance, borehole T.S.11 gave an indication that its yield has reduced over time. Chlorides levels for most boreholes have decreased with time with borehole K.1.3 having the highest decrease. The decline in chloride level could be as a result of high abstraction from the aquifer. Levels of turbidity and sodium have increased with time while total hardness, potassium, calcium, magnesium, sulphates, nitrates and nitrites have decreased.

Water table in Embakasi was high as indicated by the first struck level of a depth of 70 m, with the main aquifer being at a depth of 110m. Currently, boreholes are drilled at a depth of over 200 m to avoid straining one aquifer.

Appendix XIII shows the comparison of current water quality and the water quality when the boreholes were drilled while Appendix XIV shows specific information of the boreholes studied in Appendix XIII.

# CHAPTER FIVE

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Introduction

The purpose of this project was to determine the quality of groundwater in Nairobi and to ascertain if its within WHO (2008), and NEMA/KEBS drinking water standards. Research findings do concur with the hypothesis set for this study that majority of boreholes in Nairobi are contaminated with traces of heavy metals.

### 5.2 Conclusion

Groundwater in Nairobi met WHO (2008) requirements for TDS, conductivity, sulphates, nitrates, potassium, total hardness, calcium, magnesium, dissolved oxygen, zinc and mercury for the wet and dry season. In the case where NEMA/KEBS drinking water standards were available, TDS, sulphates, nitrates, total hardness, calcium, magnesium, zinc and mercury met the drinking water standards. Over 80 percent of the sampled boreholes met the WHO (2008) and NEMA/KEBS drinking water standards for colour, nitrites, sodium and arsenic. For most parameters analysed, the dry season showed higher concentrations than the wet season. A plausible explanation of low concentrations in the wet season compared to dry season is the rapid movement of water into the ground hence low concentration in the wet season caused by dilution and higher flow rates within aquifer. During the dry season, it is the reverse of the wet season. Recharge during the wet season also conveys pollutants into the aquifers which then concentrate in the dry season hence higher levels. Generally, the results showed that the groundwater in Nairobi is highly turbid with turbidity levels increasing during the wet season.

Boreholes in Kasarani/Roysambu showed higher average concentrations of Ca, Na, K, Cd, Cr and Ni compared with other areas.

The variations of the physical and chemical parameters observed in Nairobi groundwater may be affected by some controlling factors such as hydrological regime of groundwater at different times of the year which cause changes in water rest levels as a result of recharging groundwater while bedrock chemistry influences inputs of dissolved ions into the aquifers. Anthropogenic sources like poor waste management practices contribute negatively by adding pollutants which find their way to the groundwater through recharge zones and seepage.

Parameters that exceeded the WHO (2008) drinking water standards may expose the large population in Nairobi to health hazards due to long-term and cumulative effects of those ions.

The results suggest that groundwater from Nairobi boreholes need to be treated so that the water could meet WHO (2008), NEMA and KEBS drinking water standards.

## 5.3 Recommendations

Following the findings of this research, the following recommendations are suggested in order to curb the deterioration of groundwater in Nairobi:

### 5.3.1 Recommendations from this study

(a) Plain sedimentation or use of cloth/membrane filters may be used remove turbidity while reverse osmosis could be used where heavy metals are present. Lead could be removed by chelation therapy. Nano-filtration would be the applied to remove heavy metals as well as turbidity.

(b) Establish an efficient periodic monitoring system to evaluate levels of heavy metals in groundwater and maintain efficient filling system.

(c) Undertake inventories of all boreholes in Nairobi, revisit all sites and ensure compliance as per the laid down regulations and recommend on appropriate action if any for instance, replacement of the casing material with an environmentally friendly material for boreholes that might have been cased using lead.

(d) The government should give clear guidelines on the parameters to be analysed after drilling a borehole. EMCA, 1999 part 10 section 120 (1) provides that a laboratory designated as an analytical or analysis and reference laboratory under subsection 119 shall issue a certificate of analysis of any substance submitted to it under this Act. After drilling, contractors analyse the chemical parameters which are low-cost and leave out crucial parameters such as heavy metals.

(e) To conserve and protect the environment, the government should take an aggressive initiative to educate people on efficient waste water management practises such as separation, reuse and recycle techniques. This will contribute towards minimising pollution and groundwater abstraction and curbing further groundwater degradation.

(f) The department of water under the Ministry of Environment, Water and Natural Resources should take full charge in developing all drinking water standards.

### 5.3.2 Recommendations for further study

(a) It is highly desirable to form a research group with geologists, hydrologists, geo-chemists, water supply and environmental engineers, and public health experts to conduct in-depth investigation on the sources of heavy metals especially Hg, As, Pb and Cd in Nairobi through a comprehensive research plan. This should also come up with heavy metal risk reduction strategy and aquifer protection measures.

(b) Micro-organisms status of groundwater such as levels of *Escherichia coli (E.coli)* and organic micro-pollutants particularly aromatic hydrocarbons and chlorinated solvents should be monitored.

The above recommendation would guard groundwater in Nairobi against pollution and other degrading activities in order to contribute to better sustainability of the environment and the future of mankind.

# REFERENCES

**Appelo, C.A.J. and Postma, D. (1996).** Geochemistry, groundwater and pollution. 3rd Edition, pp. 11 – 12.

**Blackwell, P.S. (2000).** Management of water repellency in Australia, and risks associated with preferential flow, pesticide concentration and leaching. *Journal of Hydrology,* **8**, 231-395.

**Bonaparte, R. and Gross, B.A. (1990).** Field Behavior of Double-Liner Systems in Waste Containment Systems: Construction, Regulation, and Performance: ASCE Geotechnical Special Publication, **26**: 52-83.

**Calder, L.M. (1988).** "Chromium Contamination of Groundwater" In: *Chromium in the Natural and Human Environments*. John Wiley & Sons, New York, **20**: 215-230.

**Canada, H. (2008).** Effects of Lead on Human Health. [online] [accessed 1 July 2010]. <http://www.hc-sc.gc.ca/hl-vs/alt_formats/pacrb-dgapcr/pdf/iyh-vsv/environ/lead-plomb-eng.pdf>.

**Clarke, M., Woodhall, D., Allen, D. and Darling, G. (1990).** Geological, volcanological and hydrological controls of the occurrence of geothermal activity in the surrounding Lake Naivasha. Technical report, Government of Kenya, Ministry of Energy/British Geological Survey.

**Clesceri, L.S., Greenberg, A.E. and Eaton, A.D. (1995).** Standard Methods for the Examination of Water and Wastewater. 19th Edition. Washington D.C.: American Public Health Association.

**Close, M.E. 1987.** Effects of irrigation on water quality of a shallow unconfined aquifer. *Water Resources Bulletin,* **23(5):** 793-802.

**Cronin, A.A., Taylor, R.G., Powell K.L., Barrett, M.H., Trowsdale, S.A. and Lerner, D.N. (2003).** Temporal trends in the hydrochemistry and sewage-related microbiology of an urban sandstone aquifer – Nottingham. United Kingdom. *Hydrogeology Journal*, **11(2)**: 205-216.

**Department for Environment, Food and Rural Affairs (DEFRA), (2002a).** Climate Change Impact and Adaptation research Programme. Project Summaries Report, London. pp. 1987-2002.

**Department for Environment, Food and Rural Affairs (DEFRA), (2002b).** Knowledge transfer initiative on impacts and adaptation to climate change in agriculture. Project code: CC0365, London.

**Department of Natural Resources (DNR), (2003).** Copper and your health, Madison, Wisconsin State. [online] [accessed 10 May 2010]. <http://www.dnr.state.wi.us/org/water/dwg/copper.htm#health>.

**Drangert, J.O. and Cronin, A.A. (2004).** Use and abuse of the Urban Water Resource – Some policy implications, *Hydrogeology Journal*, **12(3)** :354-363.

**Elkins, H.B. and Pagnotto, L.D. (1980).** *Industrial Health Hazards* in Treatise of Analytical Chemistry. Wiley-Interscience, **4**: pp. 10-11.

**Foster, S., Hirata, R., Gomes, D., D'Elia, M. and Paris, M. (2002).** Groundwater quality protection: a guide for Water Utilities, Municipal Authorities and Environmental Agencies. World Bank publication, Washington D.C., USA.

**Fairburn, W.A. (1963).** Geology of the North Machakos-Thika Area. Report No. 59, Survey of Kenya.

**Freeze, R. A. and Cherry, J.A. (1979).** Groundwater. Prentice Hall Inc., New Jersey.

**Gevaerts, E.A.L. (1964).** Hydrogeology of the Nairobi Area. Technical report No. 1, Ministry of Natural Resources and Wild Life, Water Development Dept., **1:** 13 – 34.

**Gibbs, R. J. (1970).** Mechanisms controlling world water chemistry. Science, **170:** 1088 – 1090.

**Government of Kenya (GoK), (1983).** Land Use Map of Kenya. Kenya Rangeland Ecological Monitoring Unit, Ministry of Environment and Natural Resources.

**Government of Kenya (GoK), (2002a).** Water Act. Ministry of Water and Irrigation.

**Government of Kenya (GoK), (2002b).** Country strategy on the integrated water resources management. Ministry of environment and natural resources, Department of Water Development.

**Government of Kenya (GoK), (2009).** Drought Programme: Nairobi Groundwater Investigations Summaries Report, Ministry of Water and Irrigation.

**Government of Kenya (GoK), (2010).** Population and Housing Census. Central Bureau of Statistics.

**Greenwood, N. N. and Earnshaw, A. (1984).** Chemistry of the elements. Pergamon Press Oxford, **7:** 1542.

**Haarstad, K. (2008).** Long-Term Leakage of DDT and Other Pesticides from a Tree Nursery Landfill. *Journal of Ground Water Monitoring & Remediation,* **28(4):** 107–111.

**Hackbarth, D.A. (1981).** Natural temporal variations in the chemistry of shallow groundwater. Athabasca Oil Sands area, Alberta. *Canadian Journal of Earth of Earth Sciences,* **18:** 1599-1608.

**Hallberg, G.R. and Keeney, D.R. (1993).** Nitrate, Alley, William A., *Regional Groundwater Quality,* Van Nostrand Reinhold, New York. pp. 297-322.

**Haria, A.H., Hodnett, M.G. and Johnson, A.C. (2003).** Mechanisms of groundwater recharge and pesticides penetration to a chalk aquifer in southern England. *Journal of Hydrology,* **275(1-2):** 122-137.

**Hesseling, P.B., Toens, P.D. and Visser, H. (1991).** An epideomological survey to assess the quality of well-water nitrates on infant health at Rietfontein in the northern Cape Province, South Africa. *Journal of Science,* **87:** 300-304.

**Hesterberg, D. (1998).** Biogeochemical cycles and processes leading to changes in mobility of chemicals in soils. Agriculture. Ecosystem and Environment, **67:** 121–133.

**Jeffrey, J.J., Weiner, R.F. and Vesilind P.A. (1997).** Environmental pollution and control. British Library, USA, **4:** 73.

**Job, C. (2009).** Radionuclides Responsible for the Third Highest Water Quality Violations in Ground Water Supply Systems. *Journal of Ground Water Monitoring & Remediation,* **29(1):** 42–43.

**Johnson, A.C., Besien, T.J., Dixon, A., Gooddy, D.C., Haria, A.H. and White, C. (2001).** Penetration of herbicides to groundwater in an unconfined chalk aquifer following normal soils application. *Journal of contaminant Hydrology,* **53(1-2):** 101-117.

**Khopkar, S.M. (2006).** *Environmental Pollution, Monitoring and Control,* New Age International Publishers (P) Ltd., New Delhi.

**Kilonzo, F.N. (2005).** Hydrogeochemical study of the Nairobi area, Kenya. M.Sc. Thesis, Universiteit Gent.

**Kincheloe, J.W., Wedemeyer, G.A. and Koch, D.L. (1979).** *Tolerance of Developing Salmonid Eggs and Fry to Nitrate Exposure*, Bulletin of Environmental Contamination and Toxicology, **3:** 575-578.

**Kithia, S.M. (1992).** Effects of Industries and other Land Use Systems on the Water Quality Within the Nairobi Rivers Sub-catchments, Kenya. M.Sc. Thesis, University of Nairobi.

**Kortatsi, B.K. (2007).** *Hydrochemical framework of groundwater in the Ankobra Basin, Ghana, Aquatic Geochemistry,* **13:** 41–74.

**Larsson, I. (1984).** Groundwater in Hard Rocks: A contribution to the International Hydrological Programme. Studies and Reports in Hydrology No. 33. UNESCO. Paris, France.

**LeBeau, C. (2008).** Self-help for treating the common cold and seasonal flu. [online] [accessed 30 June 2010]. <http://www.keephopealive.org/j2008v6n3.html>.

**Lenntech, B.V. (2009).** Water treatment and purification. [online] [accessed 3 March 2010]. <http://www.lenntech.com/periodic-chart-elements/mg-en.htm>.

**Line, D.L., and Miklas, M.P. (1989).** Detection and Location of Leaks in Geomembrane Liners Using an Electrical Method: Case Histories, 10th National Superfund Conference, Washington D.C.

**Malone, R.W., Logsdon, S., Shipitalo, M.J., Weatherington-Rice, J., Ahuja, L., Ma, L. (2003).** Tillage effect on macroporosity and herbicide transport in percolate. Geoderma, **116 (1–2):** 191–215.

**Mandal, B.K., Chowdhury, T.R., Samanta, G., Mukherjee, D.P., Chanda, C.R., Saha, K.C. and Chakraborti, D. (1998).** Impact of Safe Water for Drinking and Cooking on Five Arsenic-Affected Families for 2 Years in West Bengal, India. *The Science of Total Environment*, **218:** 185-201.

**Merrill, J.C., Morton, J.J.P., Soileau, S.D. (2007).** "Metals". in Hayes, A.W. *Principles and Methods of Toxicology, 5th edition*. pp. 860, CRC Press.

**Michael, P. (1994).** Introducing groundwater. $4^{th}$ Edition, pp. 37-184.

**Montgomery, R.H., Loftis, J.C. and Harris, J. (1987).** Statistical characteristics of groundwater quality variables. *Ground Water* **25(2):** 176-184.

**Munga, D., Mwangi, S., Ong'anda, H., Kitheka, J.U., Mwaguni, S.M., Mdoe, F., Barongo, J., Massa, H.S. and Opello, G. (2004).** Vulnerability and pollution of groundwater in Kisauni, Mombasa, Kenya, **213:** 215-231.

**Netto, A.M., Pieritz, R.A. and Gaudet, J.P. (1999).** Field study on the local variability of soil water content and solute concentration. *Journal of Hydrology,* **215(1-4):** 23-37.

**National Library of Medicine (NLM), (2011).** Chloride Test - Blood. [online] [accessed 11 September 2013]. <http://www.nlm.nih.gov/medlineplus/ency/article/003485.htm>.

**Olago, D.O. (2008).** Interactions between Urban Agriculture and Fluvial Systems in Basin of Nairobi Rivers. pp. 71-72.

**Olago, D.O. and Akech, N.O. (2001).** Pollution Assessment in Nairobi River Basin. In P.F. Okoth and P. Otieno (eds). Pollution Assessment Report of the Nairobi River Basin Project. UNEP/Africa Water Network.

**Omwenga, M. (2011).** Integrated Transport System for Liveable City Environment: A Case Study of Nairobi Kenya, 47th ISOCARP Congress.

**Oram, B. (2001).** Total Dissolved Solids [online] [accessed 6 August 2007]. <*http://www.water-research.net/totaldissolvedsolids.htm*>.

**Osendarp, S.J.M. (2001).** Zinc supplementation in Bangladeshi women and infants: effects on pregnancy outcome, infant growth, morbidity and immune response, Wageningen. PhD thesis, Wageningen University. pp. 158.

**Palmer, C.D. and Wittbrodt, P.R. (1991).** "Processes Affecting the Remediation of Chromium-Contaminated sites." *Environmental Health Perspectives*. **92:** 25-40.

**Raghunath, H.M. (1987).** Groundwater. 2nd Edition, Wiley Eastern Ltd., New York. pp. 457–459.

**Saggerson E. P. (1967).** Geology of the Nairobi Area, Degree Sheet No. 51, Survey of Kenya.

**Saggerson, E.P. (1991).** Geology of Nairobi Area. Report No. 98. Mines and Geological Department, Nairobi.

**Schierholz, I., Schafer, D. and Kolle, O. (2000).** The Weiherbach data set: An experimental data set for pesticide model testing on the field scale. Agricultural Water Management, **44: (1-3):** 43-61.

**Sinclair, I.C. (2000).** 'Better Laws = Better Environment: The Role of the Environmental Lawyer in the Reconstruction and Modernization of the Water Sector in the Private Sector Participation', *Water, Air and Soil Pollution,* **123:** 353-360.

**Smedley, P.L., Edmunds, W.M., West, J.M., Gardaer, S.J. and Pelig, B.A.K. (1995).** Vulnerability of shallow groundwater quality due to Natural Geochemical Environment. *Health problems related to groundwater in the Obuassi and Bolgalanga areas, Ghana*. Report prepared for ODA under the ODA/BGS TECHNOLOGY Development and Research Programme. Project 92/5.

**Smith, A.H., Lingas, E.O., and Rahman, M. (2000).** Contamination of Drinking-Water by Arsenic in Bangladesh: a Public Health Emergency. *Bulletin of World Health Organization,* **78(8):** 1093-1103.

**Stempvoort, D.R., Armstrong, J. and Mayer, B. (2007).** Seasonal Recharge and Replenishment of Sulfate Associated with Biodegradation of a Hydrocarbon Plume.

*Journal of Ground Water Monitoring & Remediation*, **27:(4):** 110–121.

**Super, M., Heese, H e V MacKenzie, D., Dempster, W.S., Du Plessis, J. and Ferreira, J.J. (1981).** An epidemiological study of well water nitrates in a group of Namibian infants. *Water Resources*, **15:** 1265-1270.

**Stephenson, A. (1998).** Identification of Heavy Metals found in samples collected from the IDM Solvent Recovery and Hazardous Waste incinerator, San Lorenzo, Santa Fe Province, Argentina. [online] [accessed 10 May 2010]. <http://www.greenpeace.to/publications/GRL-TN-18-98.pdf>.

**Stuyfzand, P.J. (1986).** A new hydrochemical classification of water types; Principles and application to the coastal dunes aquifer system of the Netherlands – 9th saltwater intrusion meeting, Delft, proceedings, pp. 611-655.

**Talukder, S.A., Chatterjee, A., Zheng, J. and Kosmus, W. (1998).** Studies of Drinking Water Quality and Arsenic Calamity in Groundwater of Bangladesh. *Proceedings of the International Conference on Arsenic Pollution of Groundwater in Bangladesh: Causes, Effects and Remedies,* Dhaka, Bangladesh.

**Tredoux, G., Engelbrecht, J.F.P. and Talma, A.S. (2005).** Groundwater nitrate in arid and semi-arid parts of southern Africa. In: Vogel, H. and Chilume, C. (Eds), Environmental Geology in Semi-arid Environments, DGS, Lobatse, Botswana, pp. 121-133.

**USEPA, (1977).** *Quality Criteria for Water*, US Government Printing Office, Washington DC, 20402, Stock No. 05 5 -001-01049-4.

**USEPA, (1986).** Health Assessment Document for Nickel and Nickel Compounds. EPA/600/8-83/012FF. Washington, DC, pp. 466.

**Whittemore, D.O., McGregor, K.M. and Marotz, G.A. (1989).** Effects of variations in recharge on groundwater quality. *Journal of Hydrology*, **106:** 131-145.

**WHO (2008).** World Health Organization. *Guidelines for drinking-water quality*. Geneva, **1(3):** 306-492.

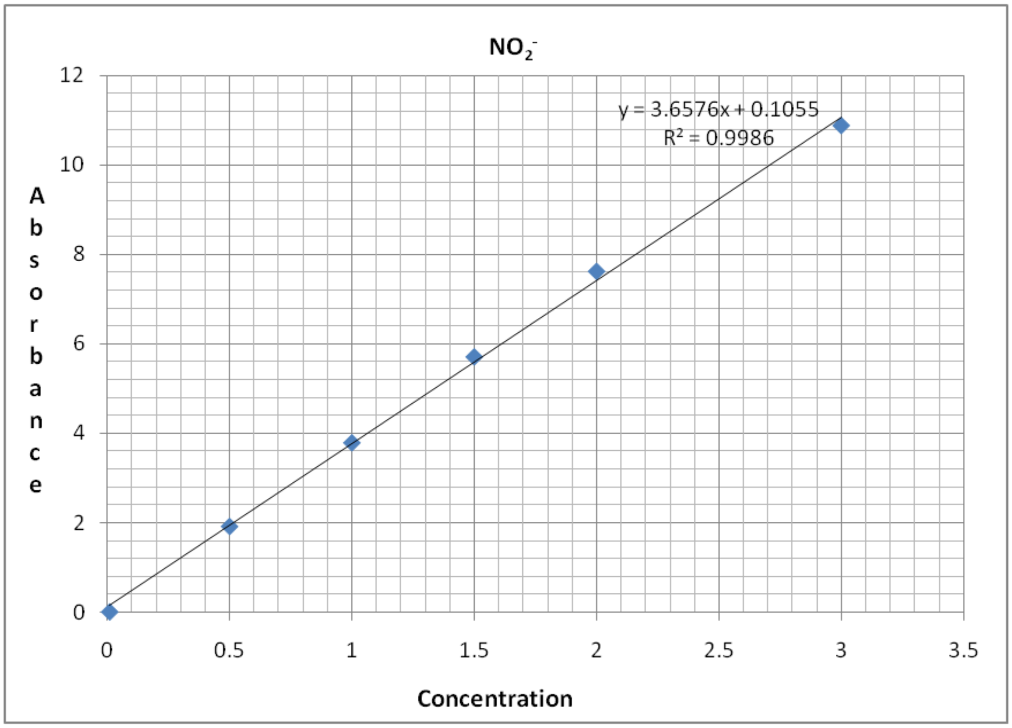
**Wikipedia, F. (2013).** [online] [accessed 13 September 2013] <http://en.wikipedia.org/wiki/Nairobi>.

**William, M.W. and Smith, B. (1994).** Empirical and modelled hydrochemistry of acid mine drainage, Iron Duke mine, Mazowe Zimbabwe. British Geological Survey Technical Report WC/94/78/R.

# APPENDICES

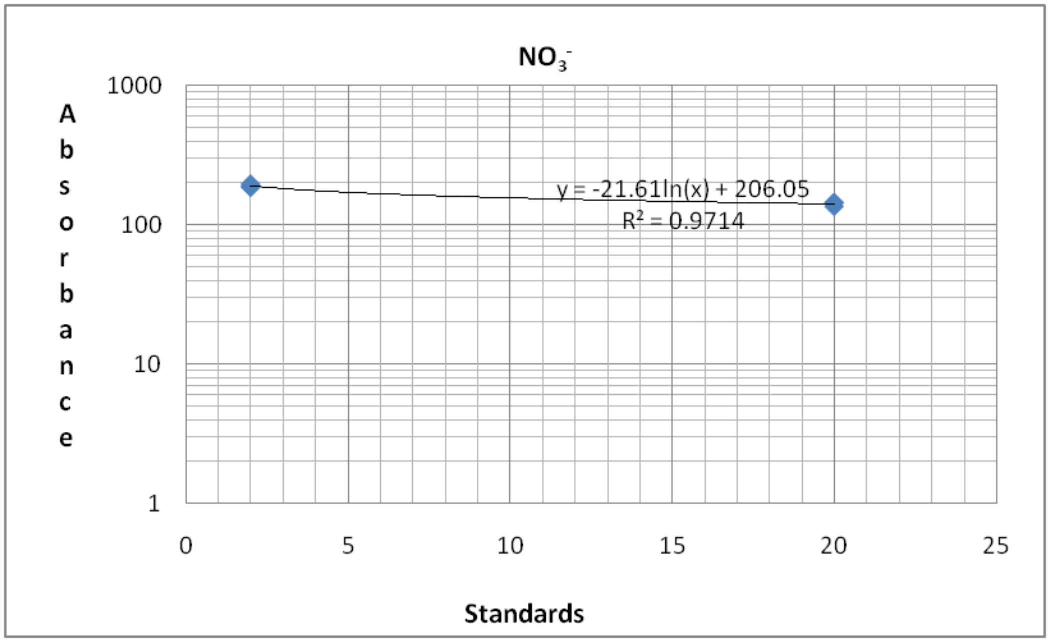
## Appendix I: Analytical calibration curves of Nitrites

| Concentration (mg/L) | Absorbance |
|---|---|
| 0.01 | 0.01 |
| 0.5 | 1.92 |
| 1 | 3.79 |
| 1.5 | 5.71 |
| 2 | 7.62 |
| 3 | 10.88 |



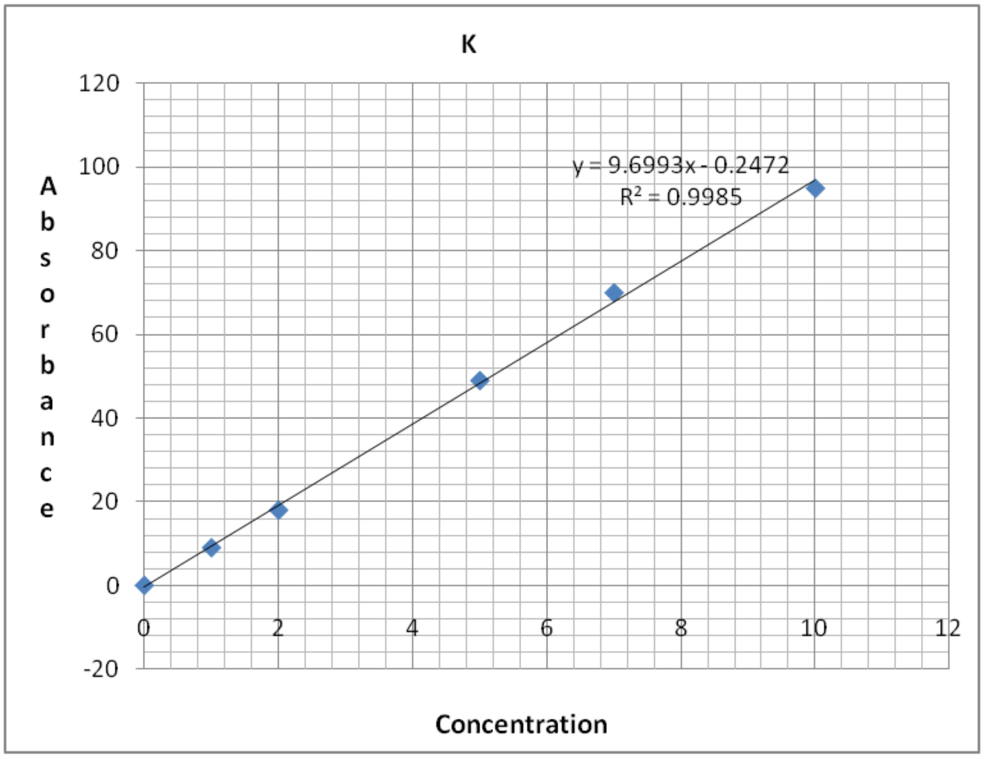
## Appendix II: Analytical calibration curves of Nitrates *(Logarithmic scale)*

| Concentration (mg/L) | Absorbance |
|---|---|
| 0 | 0 |
| 2 | 191.2 |
| 20 | 143.6 |



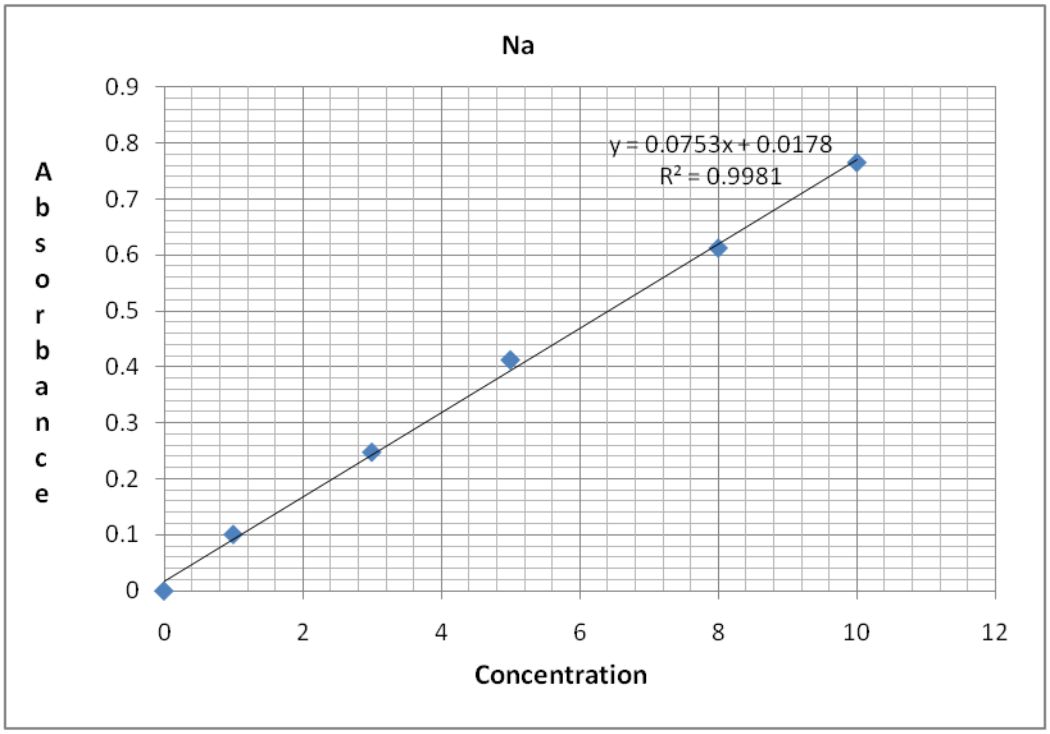
## Appendix III: Analytical calibration curves of Potassium

| **Concentration (ppm)** | **Absorbance** |
|---|---|
| 0 | 0 |
| 1 | 9 |
| 2 | 18 |
| 5 | 49 |
| 7 | 70 |
| 10 | 95 |



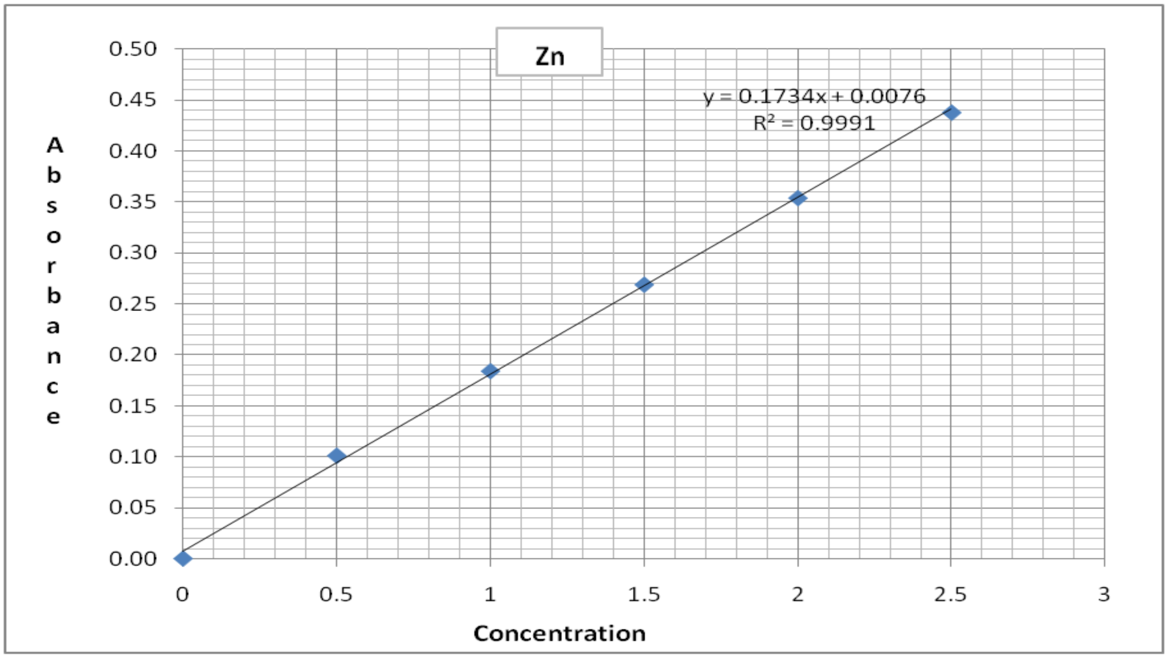
## Appendix IV: Analytical calibration curves of Sodium

| Concentration (ppm) | Absorbance |
|---|---|
| 0 | 0 |
| 1 | 0.101 |
| 3 | 0.248 |
| 5 | 0.413 |
| 8 | 0.613 |
| 10 | 0.766 |



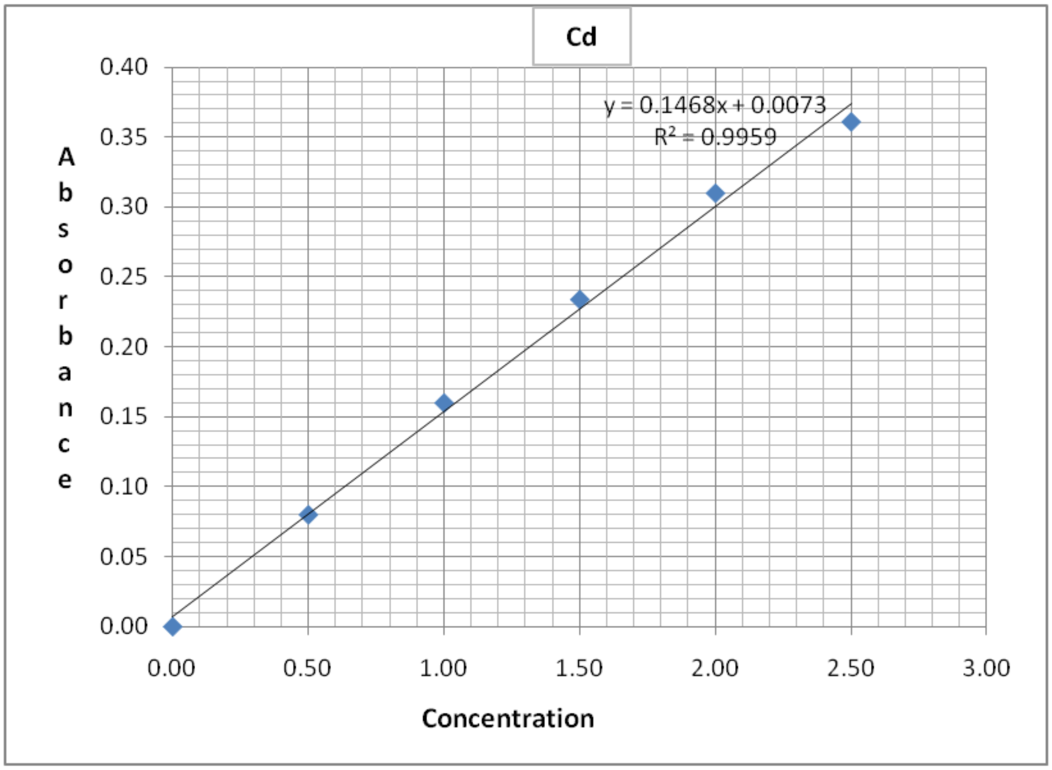
## Appendix V: Analytical calibration curves of Zinc

| Concentration (ppm) | Absorbance |
|---|---|
| 0 | 0.00 |
| 0.50 | 0.101 |
| 1.00 | 0.184 |
| 1.5 | 0.269 |
| 2.00 | 0.354 |
| 2.50 | 0.438 |



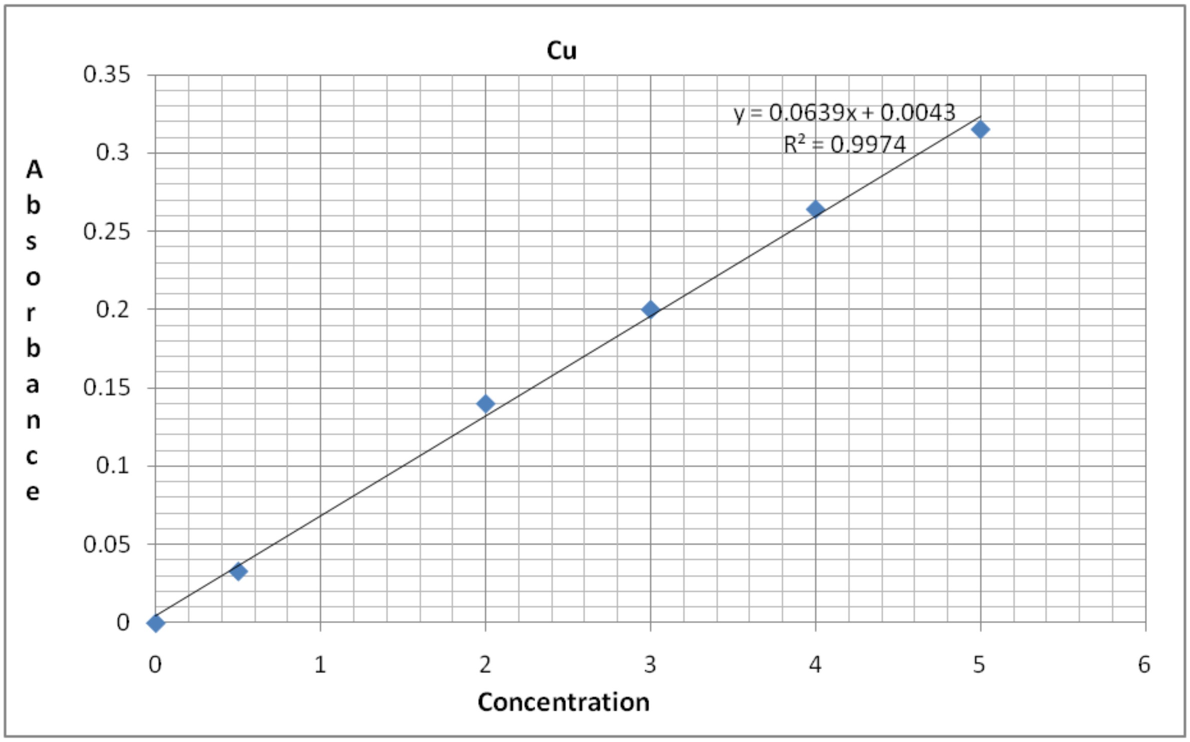
## Appendix VI: Analytical calibration curves of Cadmium

| Concentration (ppm) | Absorbance |
|---|---|
| 0.00 | 0.00 |
| 0.50 | 0.08 |
| 1.00 | 0.16 |
| 1.50 | 0.234 |
| 2.00 | 0.31 |
| 2.5 | 0.361 |



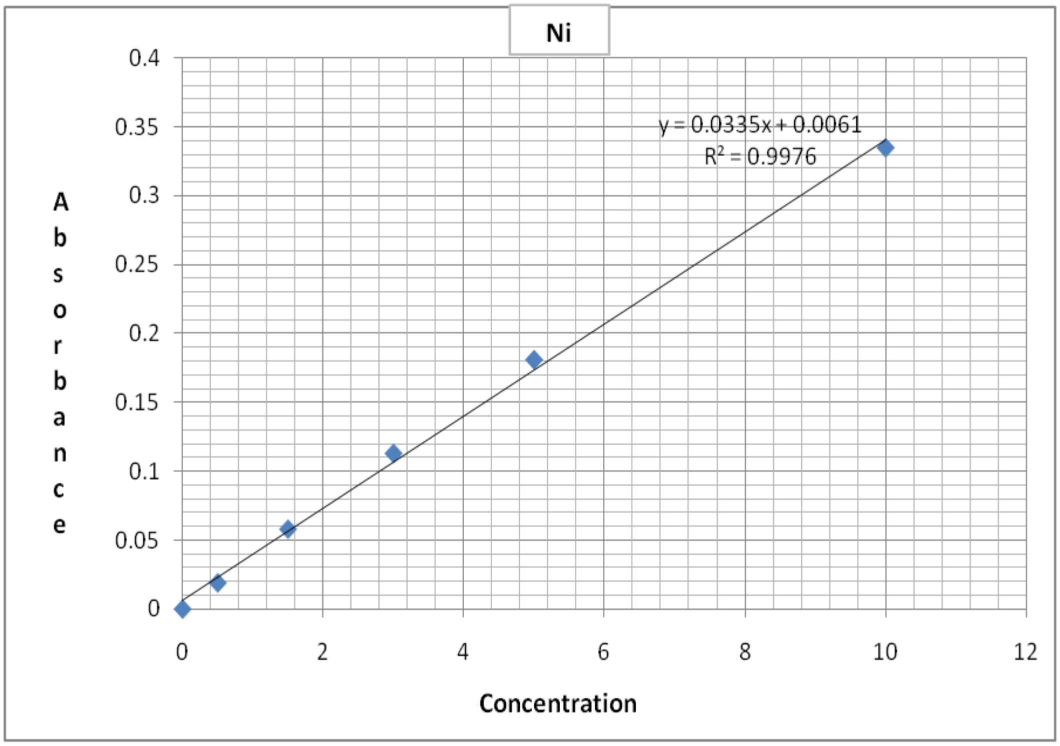
## Appendix VII: Analytical calibration curves of Copper

| Concentration (ppm) | Absorbance |
|---|---|
| 0 | 0 |
| 0.50 | 0.033 |
| 2.00 | 0.14 |
| 3.00 | 0.2 |
| 4.00 | 0.264 |
| 5.00 | 0.315 |



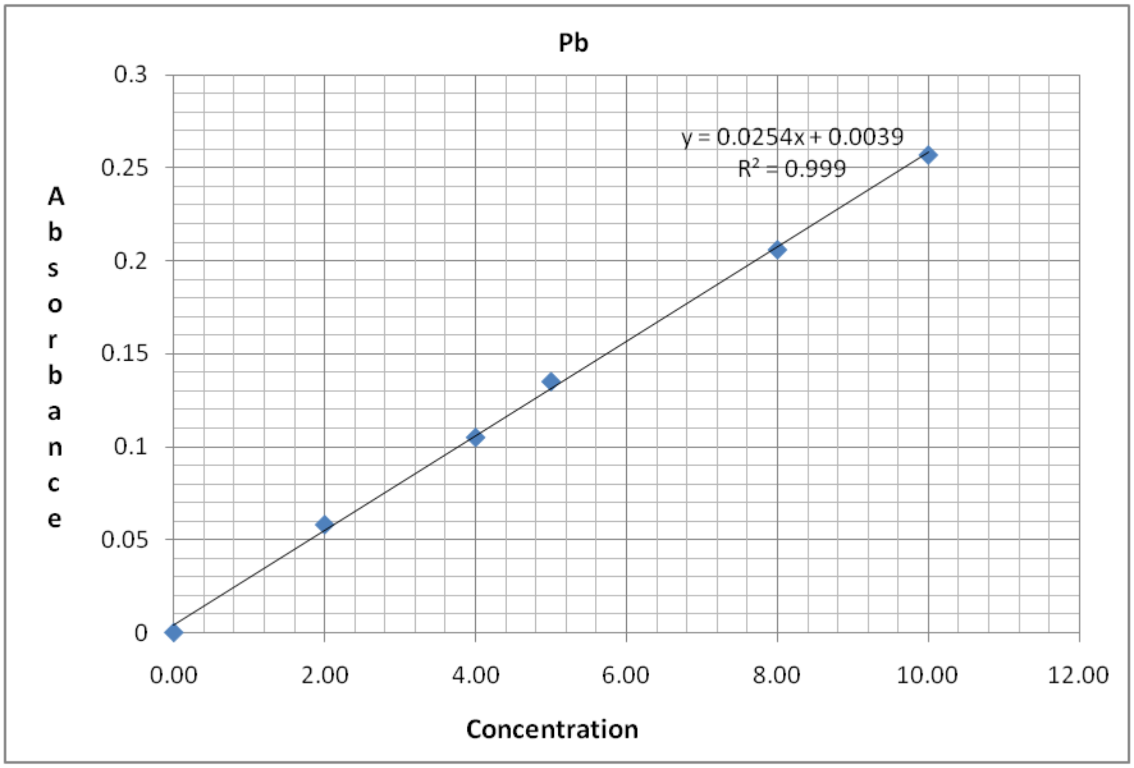
## Appendix VIII: Analytical calibration curves of Nickel

| Concentration (ppm) | Absorbance |
|---|---|
| 0 | 0 |
| 0.5 | 0.019 |
| 1.5 | 0.058 |
| 3 | 0.113 |
| 5 | 0.181 |
| 10 | 0.335 |



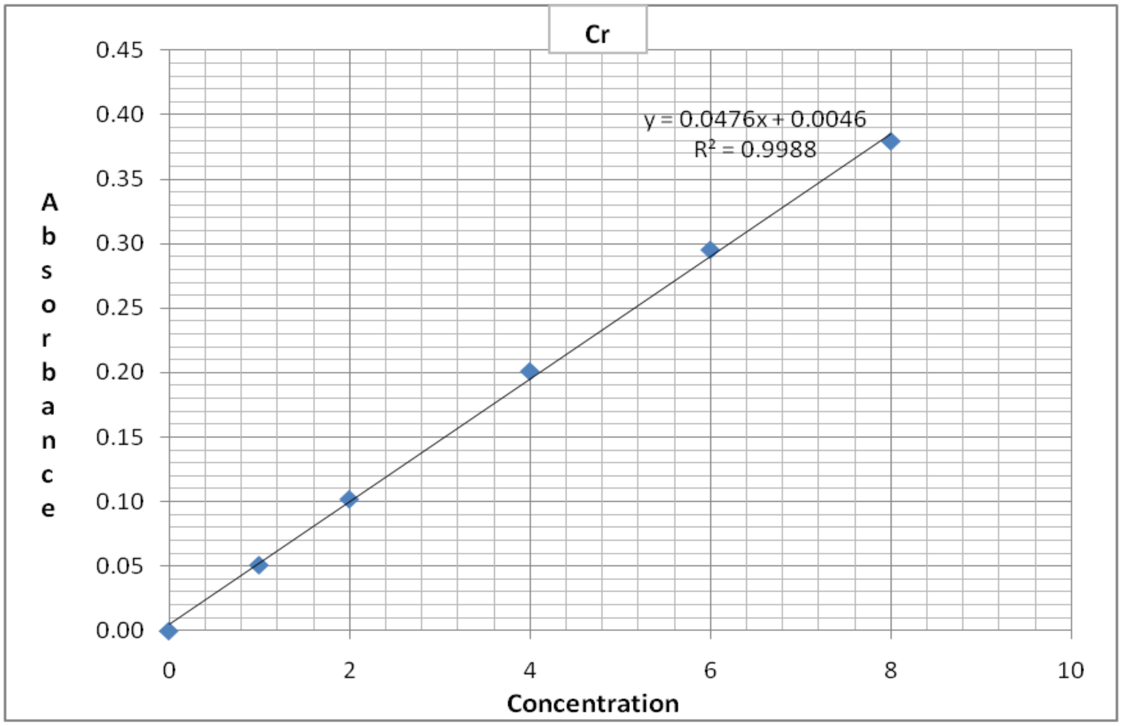
## Appendix IX: Analytical calibration curves of Lead

| Concentration (ppm) | Absorbance |
|---|---|
| 0.00 | 0 |
| 2.00 | 0.058 |
| 4 | 0.105 |
| 5.00 | 0.135 |
| 8.00 | 0.206 |
| 10.00 | 0.257 |



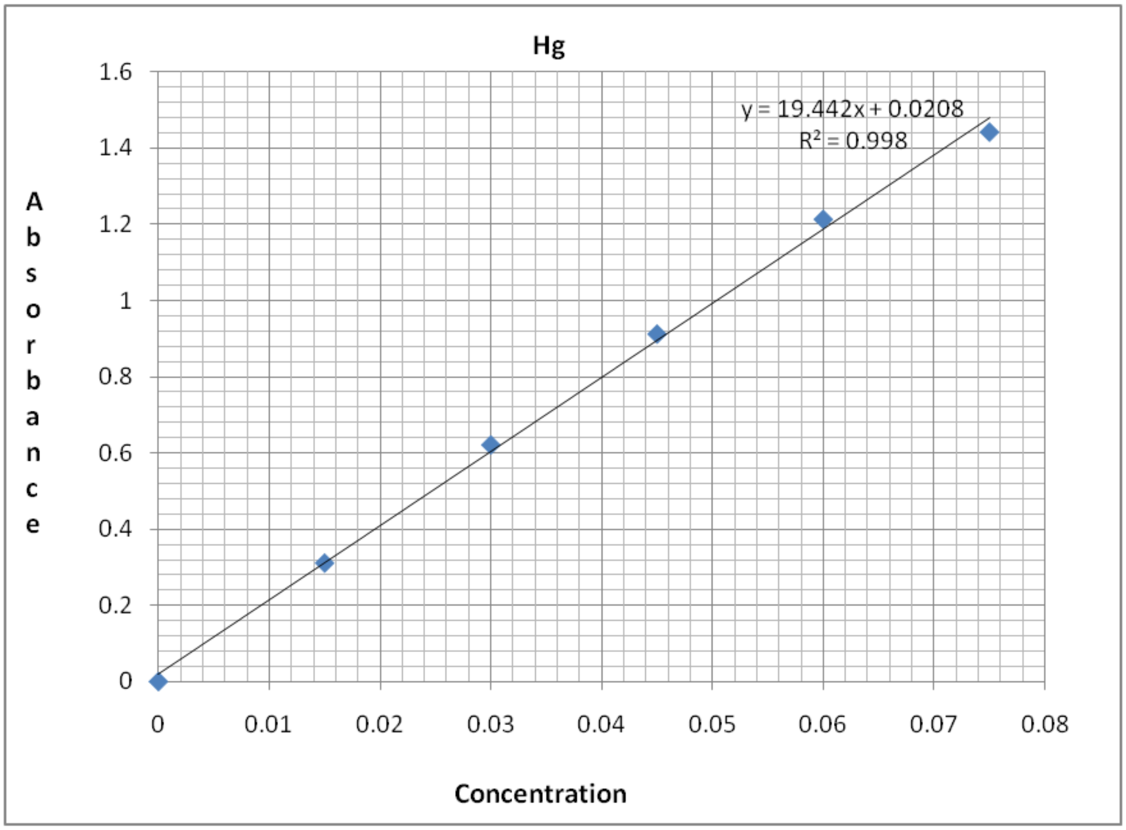
## Appendix X: Analytical calibration curves of Chromium

| Concentration (ppm) | Absorbance |
|---|---|
| 0 | 0.00 |
| 1 | 0.051 |
| 2 | 0.102 |
| 4 | 0.201 |
| 6 | 0.295 |
| 8 | 0.379 |



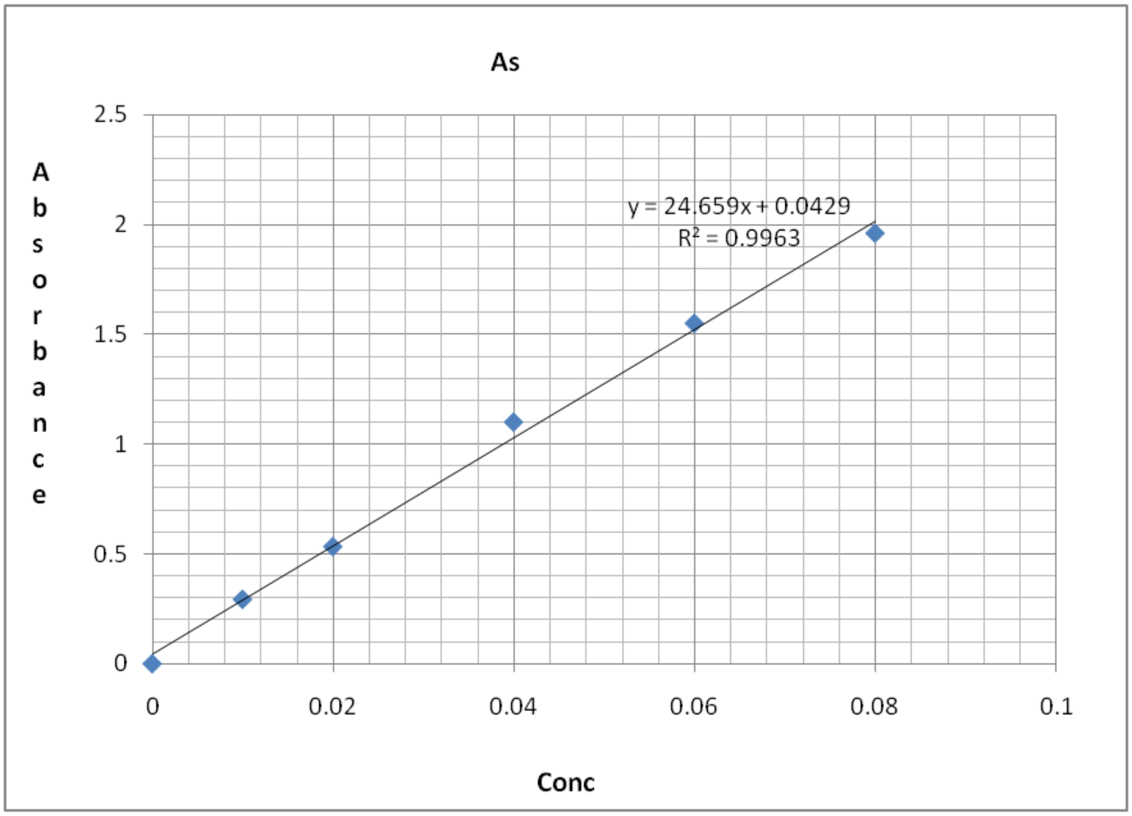
## Appendix XI: Analytical calibration curves of Mercury

| Concentration (ppm) | Absorbance |
|---|---|
| 0 | 0 |
| 0.015 | 0.311 |
| 0.03 | 0.621 |
| 0.045 | 0.912 |
| 0.06 | 1.213 |
| 0.075 | 1.442 |



## Appendix XII: Analytical calibration curves of Arsenic

| Concentration (ppm) | Absorbance |
|---|---|
| 0 | 0 |
| 0.01 | 0.293 |
| 0.02 | 0.533 |
| 0.04 | 1.1 |
| 0.06 | 1.55 |
| 0.08 | 1.96 |



## Appendix XIII: Comparison of current results with the initial data immediately after drilling exercise

| Code | Colour (mg/L) | | Free $CO_2$ (mgPt/L) | | Turbidity (N.T.U) | | TDS (mg/L) | | pH (pH Scale) | | Conductivity (µS/cm) | | Chloride (mg/L) | | Total Alkalinity (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial | Current | Initial | Current | Initial | Current | Initial | Current | Initial | Current | Initial | Current | Initial | Current | Initial | Current |
| K.I.3 | <5 | <5 | - | 2.0 | Clear | 2.87 | 646.0 | 396.0 | 6.6 | 5.88 | 950.0 | 600.0 | 96.0 | 17.0 | 315.0 | 320.0 |
| U.S.4 | - | <5 | 12.0 | 36.0 | - | 4.97 | 450.0 | 592.0 | - | 5.63 | - | 890.0 | 70.0 | 8.0 | 340.0 | 556.0 |
| M.D.6 | <5 | <5 | 6.0 | 0.0 | - | 1.61 | 205.0 | 217.0 | 7.9 | 8.17 | 295.0 | 340.0 | 10.0 | 8.0 | 145.0 | 162.0 |
| T.S.11 | <5 | <5 | - | 0.0 | 1.48 | 16.18 | 443.0 | 473.0 | 9.2 | 5.48 | 626.0 | 730.0 | 45.0 | 52.0 | 282.0 | 256.0 |
| N.C.19 | <5 | <5 | 10.0 | 2.0 | 0.87 | 7.27 | 273.0 | 198.0 | 8.2 | 9.58 | 441.0 | 300.0 | 23.0 | 9.0 | 166.0 | 158.0 |
| R.P.24 | 10.0 | <5 | - | 0.0 | 1.74 | 9.7 | 195.0 | 190.0 | 8.8 | 9.57 | 314.0 | 290.0 | 9.0 | 5.0 | 116.0 | 130.0 |
| C.B.27 | <5 | 5.0 | - | 0.0 | 1.44 | 5.62 | 287.0 | 297.0 | 9.0 | 7.6 | 464.0 | 440.0 | 20.0 | 14.0 | 176.0 | 202.0 |
| A.C.29 | 5.0 | <5 | - | 0.0 | 2.0 | 10.59 | 305.0 | 578.0 | 7.5 | 9.53 | 815.0 | 870.0 | 15.0 | 123.0 | - | 240.0 |
| F.E.30 | - | <5 | - | 0.0 | - | 11.73 | 570.0 | 424.0 | - | 9.37 | - | 660.0 | 52.5 | 51.0 | 330.0 | 250.0 |

| Code | Total Hardness (mg/L) | | $K^+$ (ppm) | | $Na^+$ (ppm) | | $Ca^{2+}$ (mg/L) | | $Mg^{2+}$ (mg/L) | | Sulphates (mg/L) | | Nitrates (mg/L) | | Nitrites (mg/L) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial | Current | Initial | Current | Initial | Current | Initial | Current | Initial | Current | Initial | Current | Initial | Current | Initial | Current |
| K.I.3 | 83.0 | 40.0 | 35.5 | 3.8 | 117.2 | 128.2 | 68.0 | 15.2 | 15.0 | 0.50 | - | 3.43 | - | 0.74 | - | <0.01 |
| U.S.4 | 121.0 | 42.0 | 30.8 | 7.8 | 138.5 | 183.83 | 62.0 | 14.4 | 59.0 | 1.47 | 120.0 | 2.0 | - | 0.43 | 0.7 | 0.02 |
| M.D.6 | 30.0 | 6.0 | 12.7 | 1.9 | 67.5 | 41.0 | 4.0 | 3.2 | 1.2 | 0.49 | 6.0 | 1.14 | - | 0.53 | - | <0.01 |
| T.S.11 | 30.0 | 8.0 | 11.0 | 2.1 | 185.0 | 272.5 | 3.2 | 2.4 | 5.34 | 0.49 | 18.9 | 14.86 | 11.0 | 1.3 | 0.01 | <0.01 |
| N.C.19 | 116.0 | 30.0 | 12.0 | 1.4 | 43.75 | 57.1 | 28.8 | 8.8 | 10.7 | 1.95 | 1.08 | 10.0 | 6.4 | 0.9 | <0.01 | <0.01 |
| R.P.24 | 4.0 | 18.0 | 5.4 | 1.6 | 72.5 | 63.2 | - | 3.2 | 0.97 | 2.43 | 1.17 | 12.0 | 2.32 | 0.25 | <0.01 | <0.01 |
| C.B.27 | 8.0 | 14.0 | 5.6 | 1.8 | 108.0 | 111.75 | - | 4.8 | 1.94 | 0.49 | 9.31 | 2.0 | 2.9 | 0.25 | <0.01 | 0.02 |
| A.C.29 | 120.0 | 18.0 | 10.0 | 4.0 | 135.0 | 180.0 | 37.2 | 3.2 | 13.1 | 2.43 | - | 29.71 | 2.21 | 6.4 | 0.03 | <0.01 |
| F.E.30 | 20.0 | 14.0 | 17.4 | 3.2 | 169.8 | 148.4 | 4.0 | 4.8 | 2.4 | 0.49 | 40.0 | 16.0 | - | 1.1 | 0.04 | 0.02 |

## Appendix XIV: Specific information of boreholes in appendix XIV obtained immediately after drilling exercise

| Zone: | Code | Analyst | Month/Yr | Depth (m) | 1ST STRUCK (m) | Main Aquifer (m) | Water Rest Level | Water Bearing Material | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| **Kasarani/ Roysambu** | K.I.3 | Polucon Ltd | Aug-01 | 202 | 102 | 127 | 95.8 | Lower Athi surface Tuff & Sediments (120-200) | Slightly acidic, soft water |
| | U.S.4 | Govt Chemist | Aug-04 | 198 | 134 | 160 | 95.56 | Old land surface deposits (150-168) | Acidic, moderately hard water |
| **Dagoretti/ Kawangware** | M.D.6 | Govt Chemist | Jun-00 | 304 | 102,150 | 230 | 151 | Sediments | Alkaline, soft |
| **Embakasi** | T.S.11 | CWTL | Jul-02 | 200 | 70 | 110 | 103.83 | Volcanics Sediments (114-128) | Soft, Alkaline |
| **Langata/Karen** | N.C.19 | CWTL | Dec-03 | 289 | 98 | 156 | 95.82 | Fractured Trachytes (156-174) | Moderately soft |
| **City Centre** | R.P.24 | CWTL | Oct-04 | 280 | 212 | 274 | 149 | Agglomerates with clay | Soft |
| **Industrial Area** | C.B.27 | CWTL | Mar-04 | 225 | 168 | 172-174 | 109.14 | Weatherer trachytic and obsideous agglomerates | Soft |
| | A.C.29 | CWTL | Oct-99 | 200 | | | | | |
| | F.E.30 | Govt Chemist | Sep-97 | 217 | 61 | 161 | 89.27 | Fresh volcanics(156-182) | Alkaline, soft |

## Appendix XV: Groundwater occurence, characteristics and simplified stratigraphy in Nairobi area

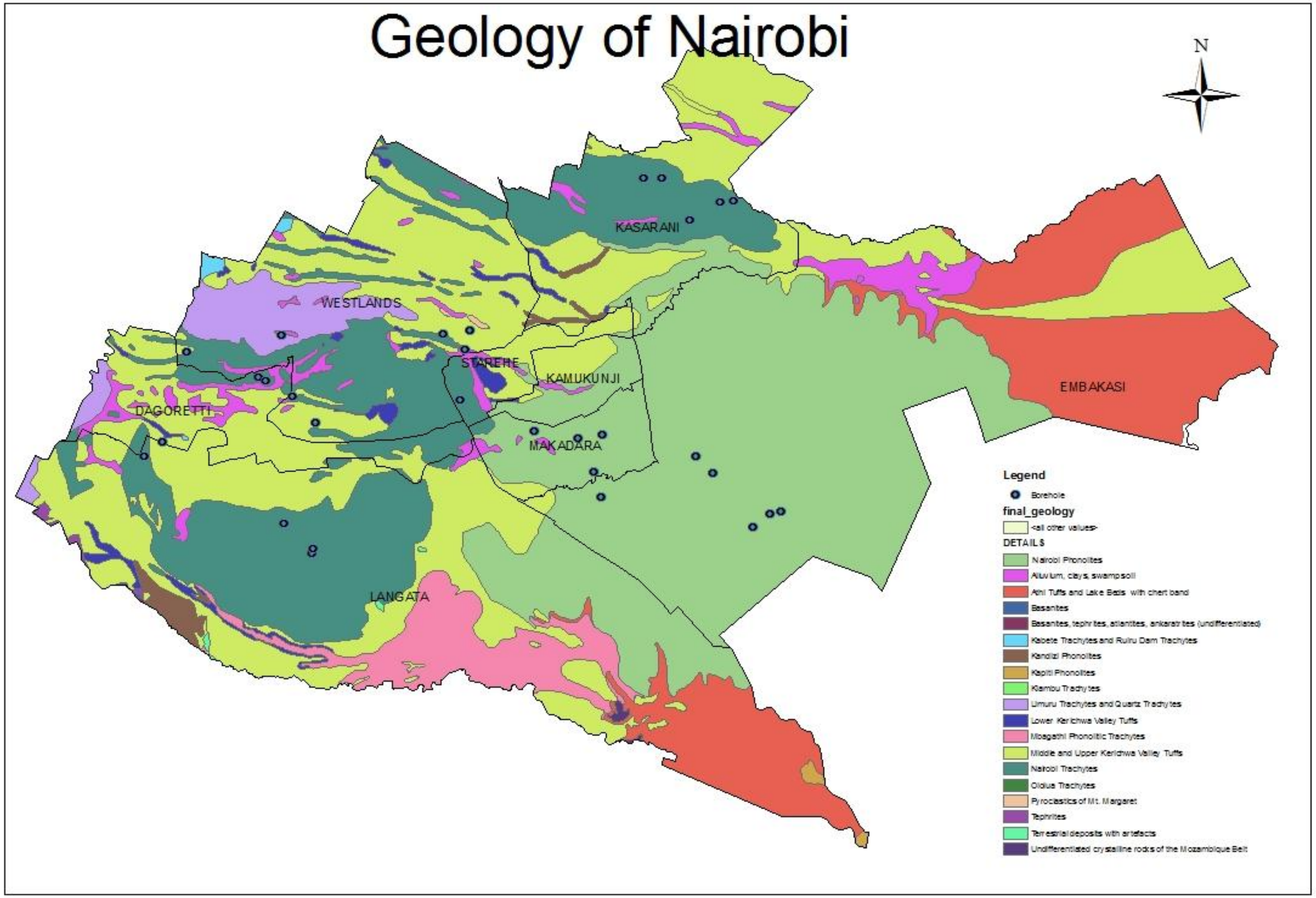
| Rock Type | Age (thickness) | Description | Remarks on Groundwater Characteristics/ Conditions |
|---|---|---|---|
| Kerichwa Valley Tuffs | Tertiary | A group of pumice-rich trachytic tuffs and agglomerates and have some resemblance to some of the Athi Tuffs and Lake Beds | |
| Nairobi Trachyte | Tertiary | Greenish-grey, occasionally porphyritic with tabular phenocrysts of feldspar in a predominantly fine -grained groundmass | Along Mbagathi River small-scale faults were recognized by Saggerson (1967). The faults generally show N-S alignment. Minor cross-faults, the most easterly faults are developed in Kandizi area at Ngoroi cutting across Mbagathi Trachyte and Kandizi Phonolite. Displacements were observed in Athi Sediments and Lake Beds in boreholes. Occurrence of faults was revealed by boreholes in west Langata where two shallow boreholes (Nos. 833 and 1171). They tap from Nairobi Trachyte and apparently struck a fissure into which water is percolating from the nearby Mbagathi River. |
| Nairobi and Kandizi phonolites | Tertiary | Dark- grey, porphyritic lava, and non-porphyritic lava, respectively.<br>Nairobi phonolite forms Athi plains between Athi River and Nairobi. It forms a sarp over soft underlying agglomerates west of Lukenya Hills. | |

**Appendix XV continued**

| | | | |
|---|---|---|---|
| Athi Series Rocks (Upper, Middle and Lower) | Tertiary (305m, maximum at Nairobi station) | Tuffs and lake beds.<br>The Upper Athi Series consist of mainly of sandy sediments, tuffs and welded tuffs, clays being subordinate (includes Mbagathi Trachyte & intercalated basalts)<br>Middle Athi Series consists of basalt flows and basalts sands and agglomerates<br>Lower Athi Series are predominantly clayey deposits | In the area which is underlain by Middle Athi Series, boreholes situated in the valleys had a substantially higher yield than elsewhere which suggests that recharge takes place from local runoff. |
| Kapiti Phonolite | Tertiary (50-100 ft where edge is observed) (absent to over 300 ft under Thika plains) | A rock with large white crystals of feldspar and waxy-looking nephelines set in a fine-grained dark green to black ground mass | In 1940s, borehole 252 and 498 were artesian. In 1961, the rest level stood at 50ft and 1964 65 ft, below the surface after the boreholes had rest periods of 12 hours. As both the area and mode of recharge of the aquifer are not yet known, the loss of head may be due to both loss of storage and deficiency of recharge.<br>the preliminary average recharge estimate (25Mm$^3$/a) is in the same order as annual abstraction |

**Source: Gevaerts (1964).**

## Appendix XVI: Geology of Nairobi area



**Source: Gevaerts (1964); Hydrogeology of the Nairobi Area (Extract)**