DETERMINATION OF ARSENIC CONCENTRATION AND CONTAMINATION FACTOR IN WATER FROM SELECTED BOREHOLES IN NAIROBI CITY COUNTY, KENYA

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June, 2022

DECLARATION

This thesis is my original work and has not been presented for the award of any degree in any university or any other institution of higher learning

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DEDICATION

To my dear husband Nelson Mneria and sons; Kipchumba Kenson and Kiprono Samuel.

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I am greatly indebted to the almighty God for enabling me to pursue this course. My gratitude goes to my supervisors, Prof. Wilson Njue and Dr. Lucy Kiruri for their tireless guidance and counsel through out the study period. Their valuable advice and suggestions contributed to the successful completion of this work.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
AFS	Atomic Furnace Spectrometry
CF	Contamination Factor
DMA(III)	Dimethyl Arsenite
EMCA	Environmental Management and Co-ordination Act
FAO	Food and Agriculture Organization
HGAAS	Hydride Generation AtomicAbsorption Spectrometry
GFAAS	Graphite Furnance AtomicAbsortion Spectrometry
ICP-AES	Inductive Couple Plasma Atomic Emission Spectrometry
IC-PMS	Inductively Coupled Mass Spectrometry
IARC	International Agency for Research on Cancer
MMA(III)	Monomethyl arsenite
NCIDP	Nairobi County Integrated Development Plan
NEMA	National Environmental Management Authority
SPSS	Statistical Packages for Social Sciences
US-EPA	United States Environmental Protection Agency
WHO	World Health Organization
WRMA	Water Resource Management Authority

ABSTRACT

Arsenic is a metalloid, which may be found in surface water, ground water, plants and rocks. In high concentrations, its compounds are considered to be genotoxic and carcinogenic. Arsenic enriched minerals and bearing rocks have been the chief source of arsenic (As) in the ground water. Anthropogenic activities such as improper waste disposal and landfill, excessive use of fertilizers, pesticides and herbicides has also contaminated the groundwater quality to a larger extent. In Nairobi City County, there has been increased number of drilled water boreholes "in thousands," to meet the demand of the scarcity of water resources. However, there is a high possibility of having some of these boreholes in contaminated sites. Thus there is increased concern on the safety and quality of these borehole water due to possible contamination with toxic heavy metals such as mercury, cadmium and in particular arsenic. The objective of study was to determine the concentration and contamination factor of arsenic in water from selected boreholes in Nairobi City, County. Water was randomly sampled from a total of sixty three (n-63) boreholes in five (5) zones (Central, Eastern, Northern, Western and Southern) during the dry and wet seasons. The arsenic was analyzed by Hydride Generation Atomic Absorption Spectrometer (HG-AAS). The results showed that the arsenic content in borehole water during the dry and wet seasons ranged from 0.00455±0.0022 - 0.01007±0.0060 and 0.002057±0.0008 - 0.00744±0.0051 mg/L respectively. There was a significant difference ($P<0.05$) in arsenic content in borehole water samples in Central zone compared to the other zones. The arsenic content in water from ten boreholes (16%) during the dry season and four boreholes (6%) during the wet season was found to be above the WHO recommended and NEMA regulatory limit of 0.01 mg/L. During the dry season, the calculated contamination factor (CF) for the borehole water ranged from moderately contaminated to very severely contaminated (CF 0.26 – 1.0). On the other hand during the wet season, it ranged from slightly contaminated to severely contaminated (CF 0.10 - 0.74). Therefore, the borehole water for domestic purposes requires monitoring in order to mitigate the effect on human health.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Arsenic element is a metalloid with atomic mass of 74.9. It is relatively abundant (20%) in the earth's crust and its compounds exist naturally both in inorganic and organic forms with the inorganic forms being toxic (IARC, 2004; Singh *et al., 2015*; WHO, 2001). Arsenic occurs in more than 200 minerals, 60% being arsenates, 20% sulfosalts and sulphides. Arsenides, arsenites, alloys, oxides and polymorphs making the remaining 20%. High concentration of arsenic minerals are found in areas with transition metals with; arsenopyrite (FeAsS) being the most abundant (Smedley & Kinniburgh, 2002). Table 1.1 shows arsenic mineral groups and their examples (Anthony *et al.*, 2000).

Table 1.1: Arsenic mineral groups and their examples

Arsenides	Arsenic Sulfides	Arsenic Sulfosalts
Domeykite Cu_3As	Arsenopyrite FeAsS	Enargite Cu_3AsS_4
Nickeline (Niccolite) NiAs	Cobaltite CoAsS	Proustite Ag_3AsS_3
Nickel-Skutterudite $(Ni,Co)As_{2-3}$	Gersdorffite NiAsS	
Safflorite $CoAs_2$	Orpiment As_2S_3	
Skutterudite $CoAs_{2-3}$	Realgar AsS or As_4S_4	

Arsenic has four oxidation states, -3, 0, 3 and 5 (Jiang *et al.*, 2014). The inorganic forms of arsenic compounds in oxidation states, 3 and 5 are the most toxic (Zhu *et al.,* 2014; Ratnaike, 2003). The arsenic species in water that have been reported include monomethylarsonic acid (MMA), dimethylarsinic acid (DMA), arsenate and arsenite (Fig. 1.1).

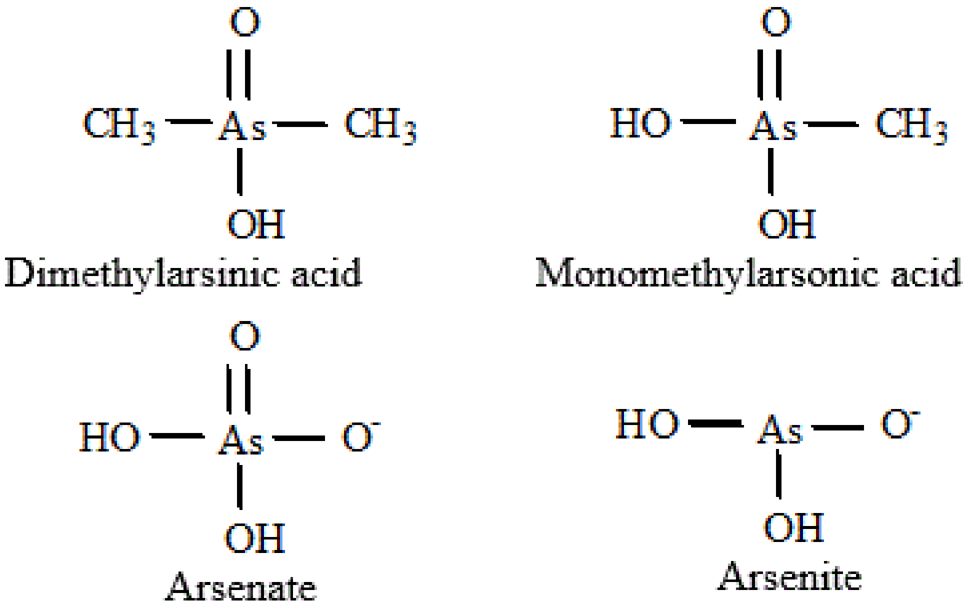

Figure 1.1: Chemical structures of arsenic species in water.

In oxygenated water and sediments, pentavalent state (arsenate) is thermodynamically more stable (David & Hemond, 2002). There are numerous studies around the world on determination of levels of arsenic in water from boreholes and surface water. Many scientists have repeatedly expressed concern about the problem of arsenic pollution (Nriagu *et al*., 2007). Arsenic enriched minerals have been the chief source of arsenic (As) in the environment. Other than the arsenic enriched minerals and bearing rocks, effluents from various industries have found their way into the environment (Hossain & Anantharaman, 2005; Kostal *et al*., 2004; Singh and Sarma, 2010). Anthropogenic activities in agriculture (pesticides, herbicides, fertilizers, additives to livestock feed for poultry), mining and combustion of fossil fuels have also led to the introduction of As to the environment (Smedley and Kinniburgh, 2002). These are among the major sources of groundwater arsenic contamination.

Similarly, population growth and lack of public awareness have been cited as the reason for the increase to a large extent to the chances of water pollution (Singh & Laishram, 2013).

Population growth has been attributed as one of the cause for the many unsafe anthropogenic activities occurring especially in informal settlement in many cities across the world. To mitigate on water pollution, public awareness is therefore needed on anthropogenic activities such as improper waste disposal and landfill. It is imperative therefore to protect the groundwater supply against contamination (Caliman *et al.,* 2011; Srinivas *et al.*, 2011). Thus; the quality of groundwater used by human beings, plants and animals need to be assessed (Tirkey *et al.*, 2013). The overall objective of the study was to determine the concentration and contamination factor of arsenic in water from selected boreholes in Nairobi City, County.

1.2 Statement of the problem

Kenya has experienced severe drought more often than before, which has been blamed on global warming. This has resulted to low levels of surface water, affecting distribution of piped water from rivers to many household across the country. Nairobi County has a population of 4,337,080 (Kenya National Bureau of Statistics, 2019). The daily demand of water in Nairobi City County is 740,000 cubic meters against a supply of 540,000 cubic meters, resulting to rationing of water.

In order to mitigate the shortfall, the Nairobi City, County government has commissioned more boreholes to tap on underground water. However, due to the government’s inability to keep pace with water demand, the private sector has joined in drilling more boreholes in the County. There is thus increased concern on the safety and quality of borehole water due to possible contamination with toxic heavy metals such as mercury, cadmium and in particular arsenic. Studies all over the world have shown that borehole water is usually contaminated with arsenic at various levels, with some above the recommended WHO limit of 0.01 mg/L. Borehole water in Nairobi City County could therefore be contaminated with arsenic.

1.3 Justification

The tremendous increase in human population in Nairobi City County, coupled with industrial expansion and other land uses, water requirements in the city has been overstretched (Thiongo, 2017). This has resulted in increased drilling and commissioning of more water boreholes (Chakava *et al,* 2014). This water could be contaminated with arsenic species leached from arsenic bearing rocks, minerals and effluents from various industries. There is however limited information on levels of arsenic in borehole water in Nairobi County. It was therefore important to conduct a study on the levels of arsenic in borehole water so as to obtain a documented baseline data on its levels and safety.

1.4 Hypotheses

i. There is no significant difference in arsenic levels in water from selected boreholes during dry and wet seasons in Nairobi City County

ii. There is no correlation between the pH values and the levels of arsenic in water from selected boreholes.

iii. There is no significant difference in the contamination factor (CF) of arsenic in borehole water in the two seasons

1.5 General objective

To determine arsenic concentration, pH and contamination factor in water from selected boreholes in Nairobi City, County

1.5.1 Specific objective

i. To determine the levels of arsenic in water from selected boreholes during dry and wet seasons in Nairobi City County.
ii. To determine the pH values of arsenic in water from the boreholes during dry and wet seasons
iii. To assess the contamination factor of arsenic in the borehole water during dry and wet seasons

1.6 Significance of the study

The study provides documented baseline data on levels of arsenic in borehole water in Nairobi City County. The results of the study are useful to policy makers, planners, researchers and decision makers on the quality status of borehole water in the county.

1.7 Scope and limitation of the study

(i) Arsenic levels were determined in water from only 63 selected boreholes out of a total of 2,632 boreholes in Nairobi City County.
(ii) The study determined total arsenic levels but not the species of arsenic. This is because borehole water could be contaminated with all arsenic species leached from arsenic bearing rocks and minerals.

(iii) The study did not focus on the correlation between the levels of arsenic in borehole water and the depth of the boreholes.

(iv) Analysis of other heavy metals like Lead, Mercury and Cadmium were not done.

CHAPTER TWO

LITERATURE REVIEW

2.1. Distribution of arsenic in the world

Areas affected by arsenic contamination span the globe, with a number of significant exposures having been found in countries like Asia and America (IARC, 2002). In United States, India Banglandesh and other developed countries, intensive arsenic investigation has been done on the degree of exposure, spread, occurrence and health effects in ground water (Steinmaus *et al.*, 2005; Bhattacharjee *et al.*, 2005; Appleyard *et al.*, 2006). Studies by Ali *et al*., (2019) revealed that several countries in the world are affected by arsenic contamination in groundwater that exceed the WHO recommended limit of 0.01 mg/L. According to *Ali et al*., (2019) the highest reports were from Asia with thirty two (32) countries and Europe with thirty one (31) countries. Africa has twenty (20) countries, eleven (11) in North America, nine (9) in South America and four (4) countries in Australia as shown in Figure 2.1.

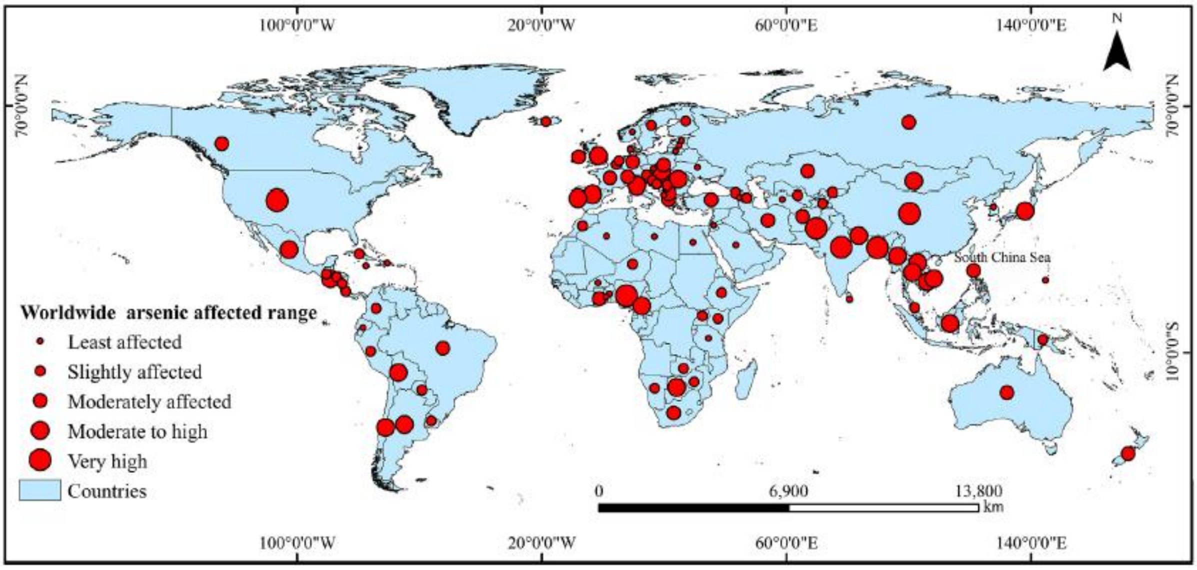

Figure: 2.1: Countries in the world affected by arsenic.
Source: (Ali *et al.*, 2019)

The population that has been mostly affected by ground water arsenic poisoning includes those from India, Cambodia and Bangladesh (Yunus *et al.,* 2016; Shibata *et al.,* 2016; George *et al.,* 2014). Approximately, eighty five (85) million people in Bangladesh and six (6) million people in India were affected by arsenic poisoning of ground water (Sen, 2013). The concentration of arsenic in over forty (40) districts in Bangladesh had arsenic levels exceeding 0.05 mg/L in groundwater (Mukherjee *et al.,* 2006; Ahamed *et al.*, 2006). A study done in China registered concentrations of arsenic in groundwater as high as 1.8 mg/L while those in Cambodia and Vietnam found concentrations of arsenic in borehole water as high as 1.34 mg/L (van Halem *et al.,* 2009).

Many people especially in developing countries consume water with arsenic concentrations that exceed the WHO recommended limit of 0.01 mg/L (George *et al.,* 2014; Mahanta *et al.,* 2015; Niazi *et al.,* 2018). A study conducted in Nigeria established that arsenic levels in borehole water ranged from 0.05±0.008 - 0.10±0.041 mg/L (Nwoke and Edori, 2020). The contamination factor recorded by Nwoke & Edori (2020) revealed the arsenic contamination factor (CF) of borehole waters from Ikono Urban, Akwa Ibom State, in Nigeria was (CF: 0.10 - 0.25) which is slightly contaminated. Studies have shown that arsenic is carcinogenic to both human and animals. There is a strong correlation between infant mortality and maternal exposure to arsenic during pregnancy (Rahman *et al.*, 2010). Depending on the time of exposure, it can either lead to chronic or acute effect (Chen and Olsen, 2016). The effects of acute exposure to arsenic can be noticed immediately after drinking the water and can lead to coma or death, while the chronic exposure causes lesions as shown in Figure 2.2 and can be noticed after a few years later (Chen and Olsen, 2016).

Figure 2.2: Skin Lesions on palm and sole
Source: (Chakrabarti, 2018)

The permitted level of arsenic in drinking water is 0.01 mg/L as per the (2018) WHO guidelines (WHO, 2018). In Kenya, the limit of arsenic in drinking water permissible is 0.01 mg/L (NEMA, 2006).

2.2 Sources of arsenic contaminants

Arsenic trioxide (As_2O_3) was used to treat tooth marrow disease in traditional Chinese medicine (Ratnaike, 2003). Sodium arsenate (NaH_2AsO_4) has been widely used as a insecticide and as a wood preservative but has been banned in most countries due to its arsenic pollution to the environment (Chen and Olsen, 2016) in Figure 2.3. Human exposure to arsenic can be detected in the hair, nails, blood and urine (Ratnaike, 2003).

Arsenic trioxide

Sodium arsenate

Figure 2.3: Chemical structure of some of the arsenic compounds.

2.3 Detoxification mechanism of arsenic in human

Arsenate is reduced to arsenite in the body, this reaction requires glutathione (GSH) given in Figure 2.4, which is a tripeptide and a strong antioxidant (Zhu *et al.*, 2014).

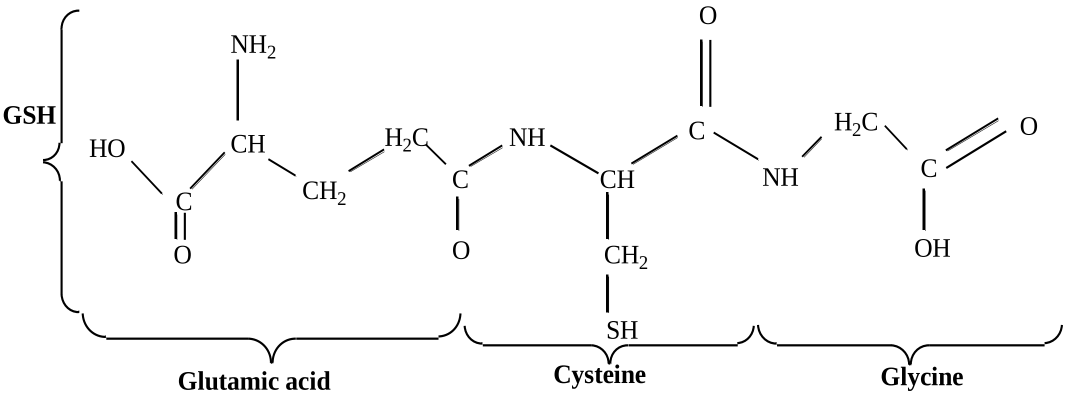

Figure 2.4: Chemical structures of Glutathione

Inorganic arsenate is metabolized in the body bound to proteins in a trivalent form in successive reductive methylation by arsenic methyltransferase (AS3MT) in the presence of S-adenosylmethionine (SAM) and glutathione.

After inorganic arsenic exposure, detoxification occurs in the liver through methylation. Monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA) is formed after methylation of arsenite (Figure 2.5), which are later excreated as they do not bind strongly in human cells. A trimethylated form of arsenic compounds which is more toxic is not excreated because it binds strongly in humans cells (Jaishankar *et al.*, 2014).

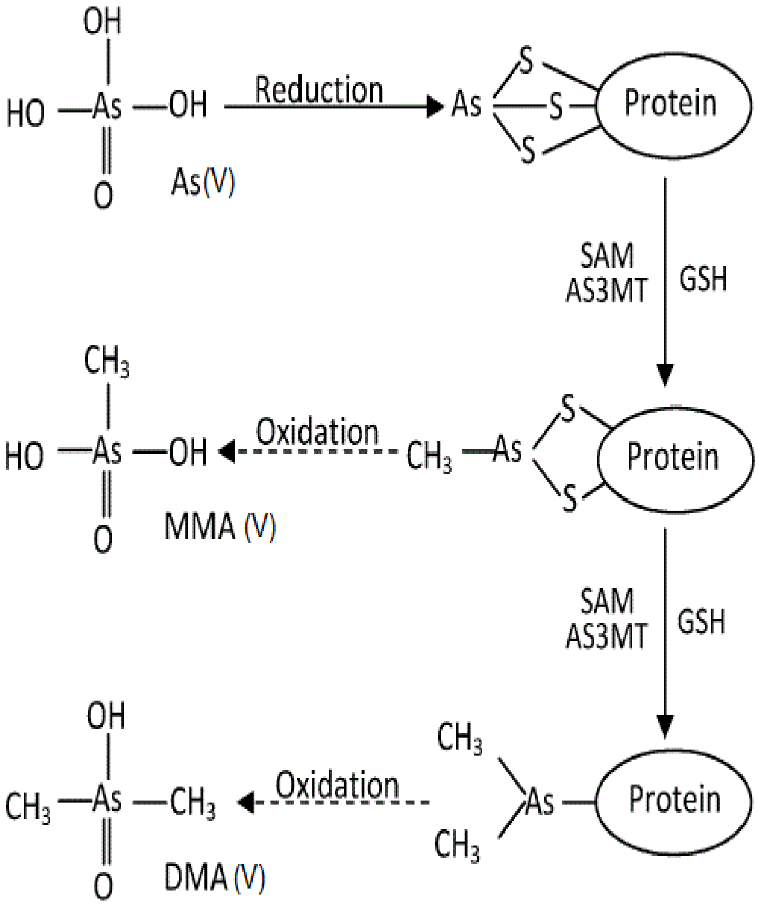

Figure 2.5. Inorganic arsenic metabolic new pathway in mammals.
Source: Naranmandura and Rehman (2012).

2.4 Relationship between arsenic and pH

The correlation between arsenic and pH has been reported in many studies in countries like Argentina (Smedley *et al.*, 2002) and Greece (Katsoyiannis & Katsoyiannis, 2006). According to a study by Smedley *et al* (2002) conditions below pH 7, arsenic is adsorbed by oxide minerals as the arsenate ion. This protects environments from extensive arsenic toxicity problems. At pH above 8.5, arsenic desorbs from the oxide mineral, thus increasing the concentration of arsenic in ground water.

2.5 National water quality regulatory limit

The Environmental Management and Co-ordination Act (EMCA) No. 8 of 1999 was enacted to protect Kenya’s entire environmental system (National Council for Law Reporting, 1999).

Thereafter, a subsidiary legislation was made pursuant to the EMCA, cited as the Environmental Management and Coordination, (Water Quality) Regulations 2006. The regulation in part II ensure protection of sources of water for domestic use. This include prevention of water pollution, standards for sources of domestic water protection of lakes, rivers, streams, springs, wells and other water sources as well as water quality monitoring. National Environment Management Authority (NEMA) is mandated to enforce this regulation (NEMA, 2006).

According to the Environmental Management and Coordination, (Water Quality) regulation the required quality standards for sources of domestic water is captured in the first schedule (NEMA, 2006). The pH and arsenic guideline values for drinking water permissible by NEMA is 6.5 – 8.5 and 0.01 mg/L respectively as given in Table 2.1. The permitted levels of pH and arsenic in drinking water are similar to World Health Organization (WHO, 2018). A number of studies on the quality of water have been conducted in Kenya (Muraguri, 2013).

Table 2.1: Quality standards for sources of domestic water

Parameter	**Guide Value (max allowable)**
pH	6.5 – 8.5
Suspended solids	30 (mg/L)
Nitrate-NO_3	10 (mg/L)
Ammonia –NH_3	0.5 (mg/L)
Nitrite –NO_2	3 (mg/L)
Total Dissolved Solids	1200 (mg/L)
Scientific name (E.coli)	Nil/100 ml
Fluoride	1.5 (mg/L)
Phenols	Nil (mg/L)
Arsenic	0.01 (mg/L)
Cadmium	0.01 (mg/L)
Lead	0.05 (mg/L)
Selenium	0.01 (mg/L)
Copper	0.05 (mg/L)
Zinc	1.5 (mg/L)
Alkyl benzyl sulphonates	0.5 (mg/L)
Permanganate value (PV)	1.0 (mg/L)

Nil means less than limit of detection using prescribed sampling and analytical methods and equipment as determined by the Authority.

Source: (NEMA, 2006).

2.6 Arsenic detection

Numerous methods have been used for determination of total arsenic. The United States Environmental Protection Agency (US-EPA) has documented techniques of detecting and analyzing arsenic concentration (US-EPA, 2001). These methods include inductively coupled plasma atomic emission spectrometry (ICP-AES), inductively coupled plasma mass spectrometry (ICP-MS), graphite furnace atomic absorption spectrometry (GF-AAS), and Hydride generation atomic absorption spectrometry (HG-AAS).

Inductively coupled plasma-mass spectrometry (ICP-MS) is quite sensitive with a detection limit of 0.0001 mg/L, however it has a high cost of instrumentation (Signes-

Pastor *et al.,* 2017) it is not commonly used. On the other hand, although ICP-AES is used for analyzing a multi-element sample (Bose *et al.,* 2011), and has a high detection limit of 0.03 mg/L, thus not commonly used (International Agency for Research on Cancer, 2002). The GF–AAS has been used to analyze arsenic in water (Martínez-Prado *et al.,* 2013). Although it has a low detection limit of approximately 0.00003 mg/L, it is not effictive since its sensitivity reduces with time due to graphite wear (Shahlaei and Pourhossein, 2014).

Though AAS is used for determination of heavy metals in soils and water, it is not suitable for assessment of arsenic as it is a volatile metalloid, making HG-AAS a suitable method (Mestrot *et al.,* 2013; Srivastava *et al.,* 2011; Planer-friedrich *et al.,* 2006). HG-AAS is a method that has been extensively used to determine arsenic in water (International Agency for Research on Cancer, 2002). It is used due to its improved detection limit as a result of hydride generator (Weinber, 2004). The HG–AAS has been used to analyze arsenic in water and soil in Kenya (Makokha *et al.,* 2012). In this study, the HG-AAS has been method of choice for determination of arsenic (As) in water from selected boreholes in Nairobi City County.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Research design

The study adopted an experimental design that involved sampling of borehole water during the dry and rainy seasons followed by sample treatment and analysis.

3.2 Study area description

The study was done in Nairobi City County with an area of approximately 696 Km^2 (Figure 3.1). The County is located at longitudes 36^o 45‘East and latitudes 1^o 18‘South. Rivers found in the county include: Kabuthi, Ngong, and Nairobi river which are highly polluted with industrial waste and open (NCIDP, 2018).

The study area was divided into five zones Western (W) Eastern (E), Northern (N), Southern (S) and Central (C) based on their uses (Figure 3.1). The Western (zone W) has forests, agricultural activities, and is one of the deep percolation for groundwater in the county. The Central (zone C) area is dominated by light and heavy manufacturing industries. Eastern zone (zone E) is on a lower elevation and dominated by residential houses and light industries. The Northern zone (zone N) is dominated by residential houses and has the county’s dump site at Dandora and sewage treatment plant at Ruai. The Southern zone (zone S) has the Nairobi national park, high and middle class residentials houses and the largest informal settlement, Kibra. The total number of boreholes in Nairobi County is approximately 2,632 (Open-Africa, 2015).

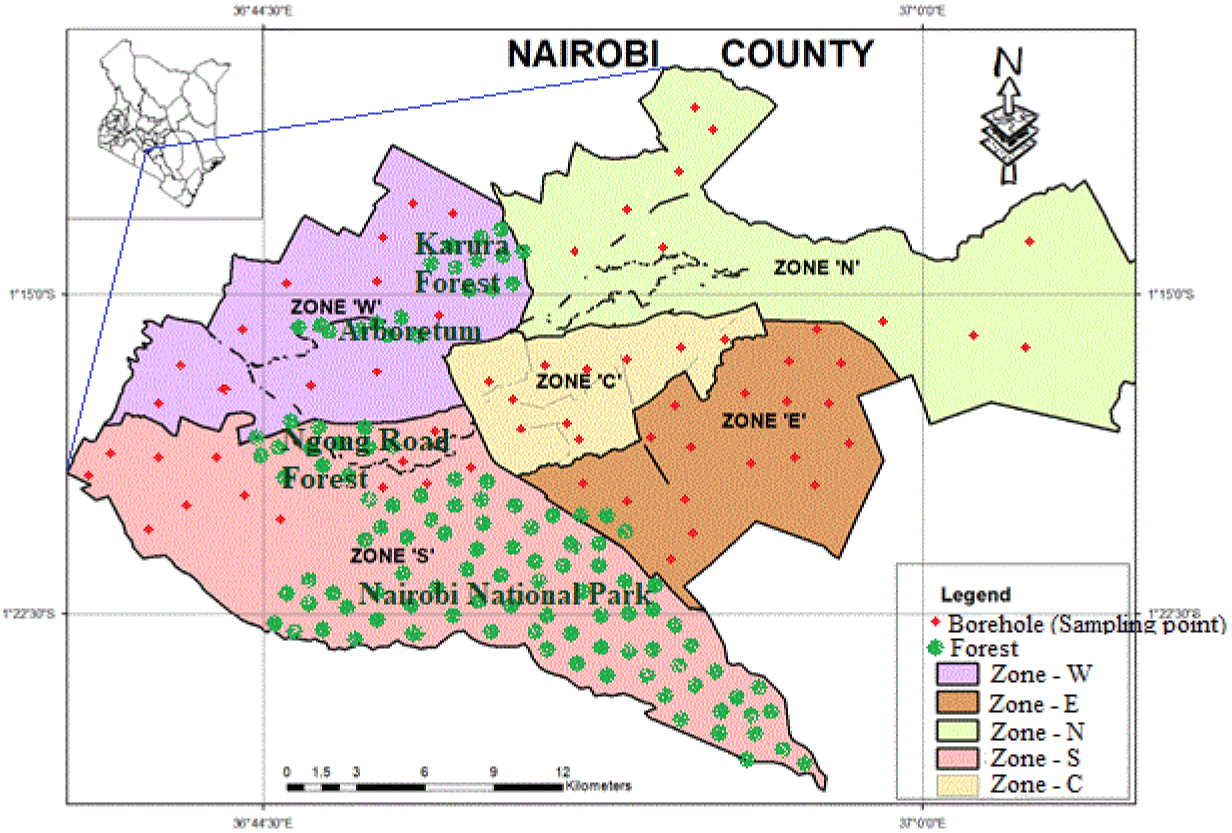

Figure 3.1: Map of Nairobi City ,County showing sampling zones
Source: Author, 2020

3.3 Sampling and sample size

The study area was divided into approximately 4 km^2 blocks (Etyang and Muse, 2016). Nairobi County being approximately 696 km^2 gave rise to (696 km^2/4 km^2) = 174 blocks. For standard distribution, a desired sample size of 30% is required of the total population (Mugenda and Mugenda, 2003). Thus, 30% of 174 resulted to 52 (the sample size desired) and since the population is <10,000 the formula given; was used to estimate the sample size.

Ss = Dss/ (1+Dss/Sp) Where:

Sp = Study population,

Dss = Desired sample size and

Ss = Sample size

Therefore Ss= 52/ (1+52/174) = 40

In each of the blocks, one borehole was randomly selected and assigned unique number. The assumption of the study blocks design was that the land use of each 4 km^2 block was equally uniform and therefore the randomly picked borehole was a representative of the studied block which were selected from the five zones in Nairobi County. A total of sixty three (n=63) boreholes were selected for the study. The samples were collected in three sets from each site and labelled. The 189 samples were collected during dry season (3rd to 28th February, 2020) and 189 samples during wet season (6th to 30th April, 2020).

3.3.1 Sample pretreatment

Plastic sampling bottles of 50mL were soaked in dilute nitric acid and then rinsed with distilled water. At each sampling point, water from boreholes was allowed to run for 2 minutes then sampling bottles rinsed with water from the same borehole before filling it. The pH was then measured immediately on site after collection with a digital portable pH meter. Collection of water samples were done from each borehole between 8.00 am to 2.00 pm at an intervals of two hours. The samples were then treated with 1 ml HCl for preservation before being transported to the laboratory (Iqbal *et al.*, 2006). The samples were stored in a refrigerator at 4°C in the Department of Chemistry Analytical Laboratory at Jomo Kenyatta University of Science and Technology.

3.4 Chemicals

Chemicals used were of analytical grade and included: concentrated hydrochloric acid, concentrated nitric acid, sodium hydroxide, sodium iodide, sodium borohydride pellets and arsenic trioxide. They were procured from Sigma Aldrich (St. Louis, MO) and Merck chemicals (Darmstadt, Germany).

3.5 Preparation of standard solution

Arsenic standard stock solution was prepared daily by dissolving 0.33 g of arsenic trioxide, As_2O_3 in 25 mL of deionized distilled water containing 1 g NaOH. The solution was then acidified with 5 mL conc. HNO_3 and diluted to 250 mL, making a stock solution of concentration, 100 mg/L. Subsequently working standard solutions of 5 mg/L, 10 mg/L, 15 mg/L, 20 mg/L, 25 mg/L, and 30 mg/L were prepared daily by serial dilution of 100 mg/L of the stock solution using ultra pure deionized water then digested.

3.6 Digestion of the sample

One mililitre (1 mL) of 20% NaI and 1 mL of 5 M HCl was added to a 50 mL water sample in a sealed glass container. The mixture was then heated in a microwave at 30 minutes, at 80 °C to allow reduction of arsenic (V) to arsenic (III) then allowed to cool before analysis. Arsenic standards and the blanks were prepared using the same procedure. Sample preparation methods were adopted from theAssociation of Analytical Chemists (AOAC) Method 999.10-2005 for acid digestion using microwave digestion system.

3.7 Instrumentation

Analysis of all the samples for arsenic content was done using Shimadzu Hydride generation atomic absorption spectrometry (HG-AAS) Model (AA-6200 Germany).

The schematic diagram of a HG-AAS flow chart is shown in Figure 3.2

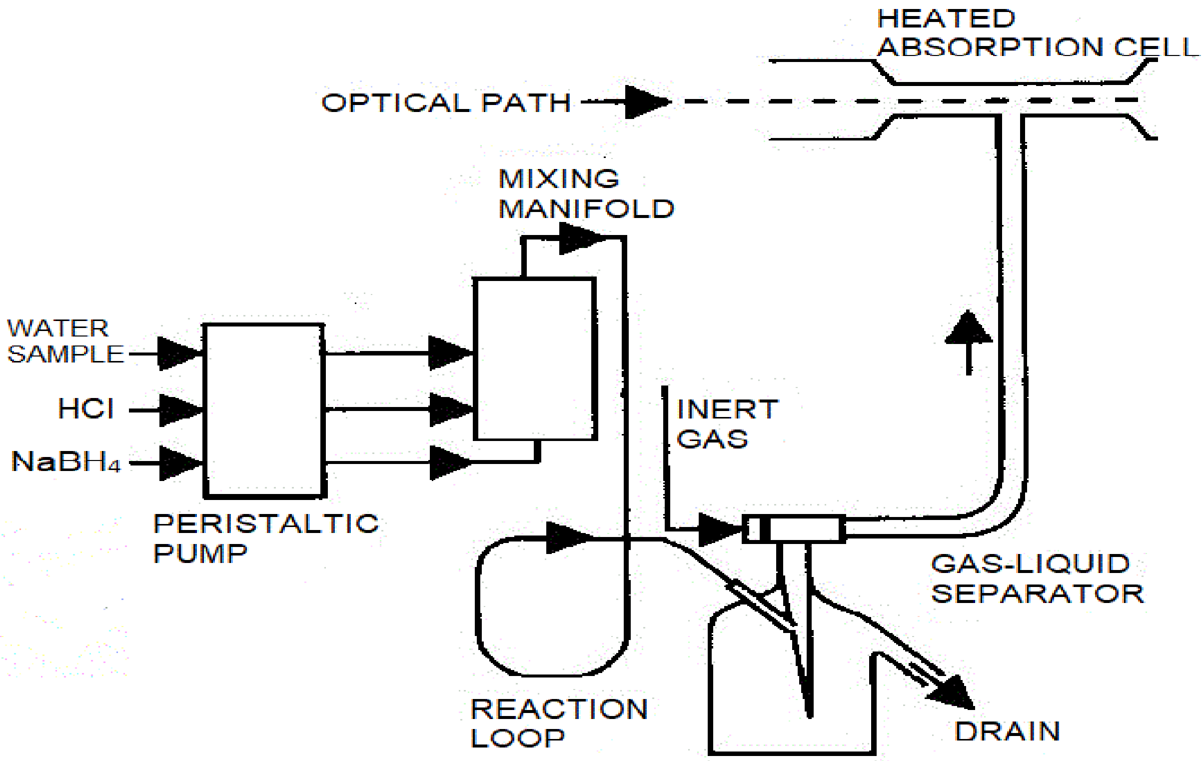

Figure 3.2: Hydride generation – atomic absorption spectrophotometer schematic flow chart diagram.
Source: (Kumar and Riyazuddin, 2007)

3.8 Sample Analysis by Hydride generation atomic absorption spectrometer (HG-AAS)

The treated blanks, standards solutions and water samples was each introduced into a continuous flow of 0.4% $NaBH_4$ and 1-M HCl mixed with 0.1% NaOH in a reaction coil to generate the gaseous hydride by a peristaltic pump (Figure 3.2). Sodium borohydride and the HCl generated the arsine gas, which was transported into a separator where the gaseous phase was carried by Argon gas to the absorption cell. The liquid phase was drained off. Air-acetylene flame was used to pyrolyze hydride to arsenic atoms, absorbance values from the deuterium lamp was recorded and the heights used for quantitative analysis.

3.9 Method validation procedures

Accuracy was tested through recovery experiments. In recovery, four samples of known concentration were spiked with arsenic standards and each analyzed in triplicate after digestion. The amount of spiked arsenic in borehole water was used to determine percentage recovery using the following equation (Al-Weher, 2008).

$$\% \text{ Recovery} = \frac{\text{Recovered concentration (mg/L)} \times 100}{\text{Concentration of the standard used for spiking}}$$

The equation below was used to calculate the precision of the method:

$$\% \text{ Relative Standard Deviation (RSD)} = \frac{SD \times 100}{M}$$

Where

M is the mean of arsenic concentrations recovered from the arsenic spiked samples.

The method validation was done to establish the suitabilty of the method of analysing the levels of arsenic. The standards were read out in a HG-AAS and a calibration curve (Figure 3.3) of good linearity was generated ($R^2 = 0.9986$)

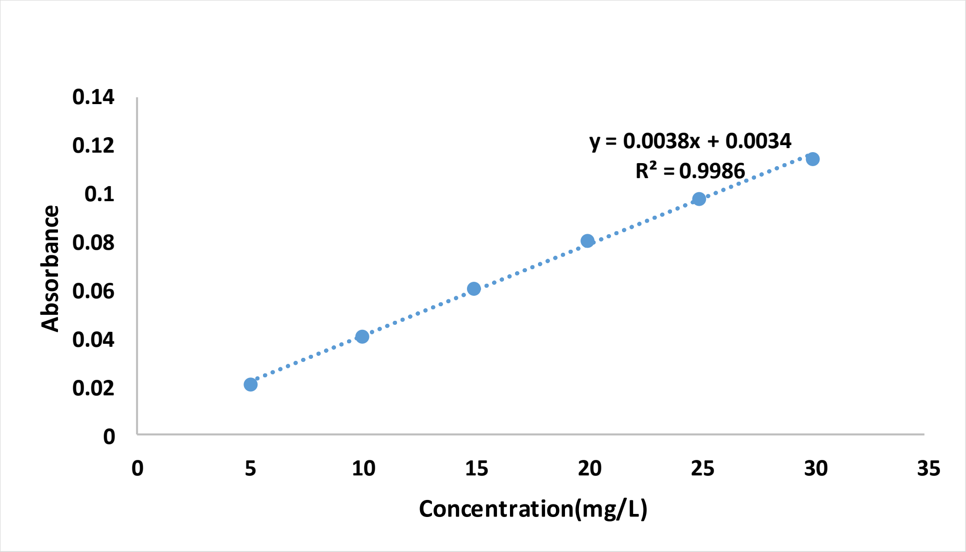

Figure 3.3: Calibration curve for arsenic standard

Table 3.1 below shows the calculated values. The percentage recoveries obtained were close to 100% hence the method was accurate for quantification of arsenic levels in the test samples. The %RSD values were below 5% an indication of good precision.

Table 3.1: Percentage of recoveries and relative standard deviation

Sample	**Concentration of the standards used for spiking(mg/L)**	**Unspiked concentration (mg/L)**	**Recovered concentration (mg/L)**	**% Recovery**	**% RSD**
I	0.01	0.0219	0.0098±0.0003	98	3.1
II	0.015	0.0186	0.0146±0.0002	97	1.4
III	0.02	0.0071	0.0193±0.0005	97	2.6
IV	0.025	0.0123	0.0238± 0.0006	95	2.5

3.10 Statistical analysis

Analysis of data was done using descriptive and inferential statistics. Descriptive statistics used for this study were mean and standard deviation parameters. The inferential statistical procedures used were one-way analysis of variance (ANOVA) and correlation and student t-test. The one-way ANOVA, WINKS SDA Software, 7th edition, was used to determine whether there were significant differences between the means of the levels of arsenic in water. Correlation was used to determine the relationship between pH values and the levels of arsenic in water from boreholes during dry and wet season. The t-test was used to compare the mean levels of arsenic in water from sampled boreholes during dry and wet seasons at statistical significance ($p<0.05$) or ($p>0.05$).

3.11 Contamination factor

The contamination factor (CF) was used to provide a measure of the degree of general contamination in a sampled site (Verma *et al.,* 2015). It requires a minimum of five surficial sediment samples which should be averaged to produce a mean pollutant concentration which is then compared to a baseline pristine reference level (Verma *et al.,* 2015; Srinivas *et al.*, 2011).

CF = Mc /Bv

Where,

Mc = metal concentration

Bv = base line/background value of 0.01

The World Health Organiztion (WHO) and National Environmental Management Authority (NEMA) background value (Bv) for drinking water of 0.01 was used for this work.

The values of CF are as shown in Table 3.1 (Lacatusu, 2000):

Table 3.2: Contamination factor values

Contamination factor	Values
Very slightly	< 0.1
Slightly	0.10 - 0.25
Moderately	0.26 – 0.5
Severely	0.51 – 0.75
Very severely	0.76 – 1.00

3.12 Ethical considerations

After obtaining proposal approval from the Graduate Studies (Appendix XII) a research permit and authorization letter were obtained from the National Commission for Science, Technology and Innovation (NACOSTI) in the Ministry of Education (Appendix XIII). The samples of water from boreholes collected in Nairobi City County during dry and wet seasons were used only for the study.

Anonymity was considered by protecting the identity of the individual borehole through the use of codes and generalised location (Appendix VI to XI). It was only the researcher who was able to link the code to the borehole name in order to collect the sample during both seasons. According to Mugenda & Mugenda (2003) when anonymity is required and yet there is a need for a follow up, an individual borehole code should be used. It is the researcher who is able to link the code to the name in order to do a follow-up (Mugenda and Mugenda, 2003).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This study was set out to determine the levels of arsenic in water from selected boreholes (n=63) in Western, Eastern, Northern, Southern and Central zones of Nairobi City County. The results obtained are presented and discussed using Tables and Figures.

4.2 Levels of arsenic in water from selected boreholes in Nairobi City County

4.2.1 Arsenic content in the borehole water in Central zone

The results for the mean±SD levels of arsenic in water from boreholes sampled from Central zone are (Table 4.1).

Table 4.1: Comparison of mean±SD arsenic levels (mg/L) in borehole water from the Central zone during the dry and wet seasons

Block Code	**Dry season**	**Wet season**
	Mean±SD (mg/L)	**Mean±SD (mg/L)**
C1	0.0017±0.0001	0.0054±0.0001^{p}
C2	0.0066±0.0001^{b}	0.0016± 0.0001^{r}
C3	0.0049±0.0001^{c}	0.0043±0.0001^{pq}
C4	***0.0129±0.0001^{a}**	0.0093±0.0001^{m}
C5	0.0067±0.0008^{b}	0.0013±0.0004^{r}
C6	***0.0219±0.0008**	0.0040±0.0001^{q}
C7	***0.0141±0.0002^{a}**	***0.0130±0.0002^{n}**
C8	***0.0186±0.0002**	***0.0144±0.0002**
C9	0.0062±0.0002bc	***0.0123±0.0001^{n}**
C10	0.0071±0.0001^{b}	0.0084±0.0001^{m}
Overall Mean	0.0101±0.0065	0.0074±0.0048
WHO Guideline Value	0.01	0.01
NEMA Standard	0.01	0.01

Means ± SD with same letter down the column indicate that they are not significantly different at 95% confidence level.

The arsenic levels in borehole water from Central zone ranged from 0.0017±0.0001 to 0.0219±0.0008 mg/L with an overall mean of 0.0101±0.0065 mg/L during the dry season and 0.0006± 0.0001 to 0.0144±0.0002 mg/L with an overall mean of 0.0074±0.0048 mg/L during the wet season. The study revealed that there were significant differences ($p<0.05$) in the levels of arsenic in borehole water during both dry and wet seasons in Central zone. A likely explanation of the high arsenic concentration in during dry seasons could have been attributed to the rapid movement of water into the ground during wet season hence low concentration caused by dilution and higher flow rates within the aquifer (Muraguri, 2013).

Further recharge during the wet season also conveys pollutants into the aquifers, which then concentrate in the dry season hence higher levels (Rasool *et al.,* 2016).

The results obtained during the dry season in Central zone, indicated that arsenic content in water from four boreholes, in a descending order C6, C8, C7 and C4 were 0.0219±0.0008, 0.0186±0.0002, 0.0141±0.0002 and 0.0129±0.00009 mg/L respectively and were above the WHO recommended limit and NEMA regulatory limit (0.01 mg/L) for drinking water. These boreholes were located in industrial area, Viwandani area, Kamukunji and Mukuru Kayaba slums respectively (Appendix I). The arsenic levels in water from borehole C1 was found to be significantly lower compared to the rest of the boreholes in Central zone. This is attributed to less pollution within the Bahati estate where this borehole was located. Arsenic concentrations detected in water from boreholes C2, C5 and C 10 were not significantly ($p> 0.05$) different from each other during the dry season. Similarly, the results obtained at Central zone during the wet season, indicated that arsenic content in water from three boreholes, C8, C7 and C9 were 0.0144±0.0002, 0.0130±0.0002 and 0.0123±0.0001 mg/L respectively and were above the WHO and NEMA regulatory limit.

The high arsenic concentration in C9 during wet seasons could have been attributed to the anthropogenic activities in the zone whereby rapid movement of water into the ground during the wet season caused the untreated wastewater and solid waste into the aquifer. This borehole is in Mukuru Kwa Ruben slums located in the vicinity of industrial area of Nairobi. The study done in Nigeria, reported concentration of the levels of arsenic (0.05±0.008-0.10±0.041mg/L) in water from boreholes at Ikono, Akwa Ibom State, were found to be higher than the WHO recommended levels (Nwoke & Edori, 2020). These levels are far much higher than the levels reported in this study.

4.2.2 Arsenic content in water from boreholes in in Eastern zone

The results for the levels of arsenic in water from borehole sampled from Upper Eastern (UE) and Lower Eastern zone are shown in Table 4.2 and Table 4.3 respectively

Table 4.2: Comparison of mean±SD arsenic levels (mg/L) in borehole water from the Upper Eastern zone during the dry and wet seasons

Block Code	**Dry season**	**Wet season**
	Mean±SD (mg/L)	**Mean±SD (mg/L)**
UE1	***0.0141 ± 0.0020**	0.0076 ±0.0020
UE2	***0.0229 ± 0.0001**	0.0031 ±0.0003^{r}
UE3	0.0082 ± 0.0008^{a}	0.0013 ±0.0002
UE4	0.0031 ± 0.0003	0.0030 ±0.0007^{r}
UE5	0.005 ± 0.0015	0.0031 ±0.0005^{r}
UE6	0.0061± 0.0004	0.0040 ±0.0006
UE7	0.0080 ± 0.0005^{a}	0.0072 ±0.0011
UE8	0.0020 ± 0.0009^{b}	Not detected
UE9	0.0023 ± 0.0002^{b}	0.0030 ±0.0020^{r}
Overall Mean	0.0080±0.0067	0.0036±0.0025
WHO Guideline Value	0.01	0.01
NEMA Standard	0.01	0.01

Means ± SD with same letter down the column indicate that they are not significantly different at 95% confidence level.

The study revealed as shown in Table 4.2, that the arsenic levels of water in the boreholes coded UE1 to UE9 in the Upper Eastern (UE) zone ranged from 0.0020 ± 0.0009 to 0.0229 ± 0.0001 mg/L with an overall mean of 0.0080±0.0067 mg/L during the dry season. During the wet season 0.0013 ± 0.0002 to 0.0076 ± 0.0020 mg/L with an overall mean of 0.0036±0.0025 mg/L. The test for equality of variance (F=7.18) was performed on Upper Eastern zone (Appendix III) to test the assumption whether the two variances were equal and p= 0.01 for this test was small (less than 0.05) indicating that the variances are unequal. The "Unequal variances" t-statistic p-value (p = 0.094) presented evidence that the scores for the two seasons were not significantly different. Arsenic concentration in water from five boreholes, UE1 and UE2, (0.0141 ± 0.0020 and 0.0229 ± 0.0001 mg/L respectively) were above the WHO recommended limits of 0.01 mg/L during the dry season. The UE1 borehole was located around Mukuru Kwa Njega slums while UE2 borehole was located around the airport North road closer to the light industries.

The study indicated that during the dry season there was no significant ($p > 0.05$) difference in the mean of arsenic content in water collected from the four boreholes, UE2, UE4, UE5 and UE9. The arsenic means levels in water from borehole UE8 was significantly lower compared to the rest of the boreholes in UE zone during the dry season. Similarly, during the same season, there was no significant ($p > 0.05$) difference in the mean level of arsenic in water collected from the two boreholes, UE8 and UE9. Further, the results obtained at UE zone during wet season, showed that the arsenic concentration were not detected in water samples from borehole UE8. This could be attributed to less pollution at this area of Nyayo Estate (Appedix VII).

Table 4.3: Comparison of mean±SD arsenic levels (mg/L) in borehole water from the Lower Eastern zone during the dry and wet seasons

Block Code	**Dry season**	**Wet season**
	Mean±SD (mg/L)	**Mean±SD (mg/L)**
LE1	***0.0135 ± 0.0000^{a}**	0.0095 ± 0.0000^{n}
LE2	***0.0122 ± 0.0010**	0.0002 ± 0.0002
LE3	0.0078 ± 0.0000^{b}	Not detected
LE4	0.0082 ± 0.0000^{b}	0.0013 ± 0.0002
LE5	0.0061 ± 0.0000	0.0020 ± 0.0010
LE6	***0.0137 ± 0.0000^{a}**	0.0024 ± 0.0020^{t}
LE7	0.0045 ± 0.0001	0.0027± 0.0000^{t}
LE8	0.0095 ± 0.0000^{c}	0.0059 ± 0.0010
LE9	0.0095 ± 0.0010^{c}	0.0099 ± 0.0000^{n}
Overall Mean	0.0094±0.0032	0.0038±0.0038
WHO Guideline Value	0.01	0.01
NEMA Standard	0.01	0.01

Means ± SD with same letter down the column indicate that they are not significantly different at 95% confidence level.

The study revealed in Table 4.3, that arsenic levels of water in the boreholes, LE1 to LE9 in Lower Eastern zone ranged from 0.0045 ± 0.0001 to 0.0137 ± 0.0000 mg/L with an overall mean of 0.0094±0.0032 mg/L during the dry season. Arsenic concentration in water from three boreholes, LE1, LE2 and LE6 (0.0135 ± 0.0000, 0.0122 ± 0.0010 and 0.0137 ± 0.0000 mg/L respectively) were above the WHO recommended limits of 0.01 mg/L during the dry season. During the dry season there was no significant ($p > 0.05$) difference in the mean level of arsenic in water collected from the two boreholes, LE3 and LE4. The study found out that the arsenic levels in water from borehole LE7 was lower compared to the rest of the boreholes in Lower Eastern zone during the dry season. Similarly, during the same season, the concentrations detected in water from boreholes LE8 and LE9 were not significantly ($p > 0.05$) different from each other.

The study further showed that the arsenic concentration in water sampled from boreholes in Lower Eastern zone zone ranged from 0.0002 ± 0.0002 to 0.0099 ± 0.0000 mg/L with an overall mean of 0.0038±0.0038 mg/L during the wet season. The arsenic levels were not detected in water samples from borehole LE3 during the wet season. This was attributed to less pollution at this General Service Unit (GSU) located in Embakasi (Appendix VIII). The study also found out that arsenic concentration in water from all the boreholes in Lower Eastern zone during the wet season were within the WHO, (2018) guidelines.

The test for equality of variance ($F=1.41$) was performed on Lower Eastern zone during dry and wet season (Appendix III) to test the assumption whether the two variances were equal.

In this case, $p= 0.638$ for this test was large (more than 0.05) indicating that the variances are equal. The "Equal variances" t-statistic p-value ($p = 0.004$) presented evidence that the scores for the two seasons are significantly different. These levels were similar those reported in borehole water (0.01 to 0.015 mg/L) in Eastern zone of Nairobi, Kenya (Muraguri, 2013). However, a study done in in China, found the concentration levels of arsenic (1.8 mg/L) in borehole water, to be higher than the WHO recommended levels. Similarly, the study found that in Cambodia and Vietnam the concentration of the levels of arsenic (1.34 mg/L) in borehole water were also above the WHO recommended levels (van Halem *et al.*, 2009). The levels were far much greater than those reported in this study.

4.2.4 Arsenic content in water from boreholes in Northern zone

The results for the levels of arsenic in water from borehole sampled from this zone are shown in Table 4.4.

Table 4.4: Comparison of mean±SD arsenic levels (mg/L) in borehole water from the Northern zone during the dry and wet seasons

Borehole Code	**Dry season**	**Wet season**
	Mean±SD (mg/L)	**Mean±SD (mg/L)**
N1	0.0063±0.0005	0.0025±0.0001
N2	0.0033±0.0000	0.0019±0.0002
N3	0.0049±0.0001^{a}	0.0029±0.0001^{n}
N4	0.0021±0.0000	0.0009±0.0001
N5	0.0041±0.0002	0.0024±0.0002
N6	0.0023± 0.000	Not detected
N7	0.0086±0.0002	***0.0110±0.0000**
N8	0.0048±0.0000^{a}	0.0027±0.0000^{n}
N9	Not detected	Not detected
N10	Not detected	Not detected
Overall Mean	0.0046±0.0022	0.0021 ± 0.0008
WHO Guideline Value	0.01	0.01
NEMA Standard	0.01	0.01

Means ± SD with same letter down the column indicate that they are not significantly different at 95% confidence level.

The arsenic concentaration in water sampled from boreholes in Northern zone ranged from 0.0021±0.000 to 0.0086±0.0002 mg/L with an overall mean of 0.0046±0.0022 mg/L during the dry season. The mean level ranged from 0.0009±0.0001 to 0.011±0.0000 mg/L with an overall mean of 0.0021±0.0008 mg/L during the wet season. The study indicated that during the dry season there was no significant difference in the mean of arsenic content in water collected from the two boreholes, N3 and N8 ($p > 0.05$). The study found that during the wet season, arsenic concentration were not detected in water samples from borehole N6.

Similarly, during dry and wet seasons, arsenic concentration were not detected in water samples from borehole N9 and N10. These water boreholes were found in two major institutions in Kasarani and Thome area (Appendix IX). The no detection level may be attributed to water treatment methods like reverse osmosis which could have been employed by these institutions to remove arsenic.

The arsenic concentration in water from all the boreholes except in borehole N7 (0.011±0.0000) were below the WHO (2018) recommended levels for drinking water in both seasons. The study revealed that there were significant differences ($p<0.05$) in the levels of arsenic in borehole water in Northern zone during both dry and wet seasons. A likely explanation of the high arsenic concentration in N7 during wet seasons could be attributed to the anthropogenic activities in the zone. N7 is located in an informal settlement (Soweto).The poor drainage system leads to discharge of untreated wastewater and solid into the soil which then percolates into the aquifer during the wet seasons.

4.2.5 Arsenic levels in water from boreholes in Southern zone

The results for the content of arsenic in water from borehole sampled from this zone are shown in table 4.5.

Table 4.5: Comparison of mean±SD arsenic levels (mg/L) in borehole water from the Southern zone during the dry and wet seasons

Block Code	**Dry season**	**Wet season**
	Mean±SD (mg/L)	**Mean±SD (mg/L)**
S1	0.0075±0.0001^{a}	0.0040±0.0000^{n}
S2	0.0025 ±0.0001^{c}	0.0014±0.00013^{pq}
S3	***0.0142±0.0000**	0.0015±0.0000^{pq}
S4	0.0014±0.0000	0.0010± 0.0010
S5	0.0055±0.0001	0.0034±0.0004^{np}
S6	0.0025 ±0.0001^{c}	0.0030±0.0004^{np}
S7	0.0020±0.0000	0.0004±0.0000^{pq}
S8	0.0043±0.0002^{b}	0.0025±0.0001^{np}
S9	0.0044±0.0001^{b}	0.0026±0.0001^{np}
S10	0.0036 ±0.000	0.0044±0.0001
S11	0.0060±0.0010	0.0031±0.0003 ^{np}
S12	0.0071±00001^{a}	0.0030±0.0004^{np}
S13	Not detected	Not detected
Overall Mean	0.0051±0.0035	0.0025±0.0012
WHO Guideline Value	0.01	0.01
NEMA Standard	0.01	0.01

Means ± SD with same letter down the column indicate that they are not significantly different at 95% confidence level.

The arsenic concentration in water sampled from boreholes in Southern zone ranged from 0.0014±0.000 to 0.0142±0.000 mg/L with an overall mean of 0.0051±0.0035 mg/L during the dry season and 0.0011± 0.001 to 0.0044±0.0001 mg/L with an overall mean of 0.0025±0.0012 mg/L during the wet season. The study indicated that during the dry season there was no significant difference ($p > 0.05$) in the mean of arsenic content in water collected from the two boreholes, S1 and S12. Further, the study showed that the concentrations in water from boreholes S2 and S6 during the same dry season were also not significantly different ($p > 0.05$) from each other. The study indicated that during the dry season there was no significant difference ($p > 0.05$) in the mean of arsenic content in water collected from the two boreholes, S8 and S9.

Similarly, during both dry and wet seasons, the arsenic concentration were not detected in water samples from borehole S13. This could be attributed to less pollution at Langata, which is adjacent to Nairobi National Park. Concentrations detected at different water samples from different boreholes during the wet seasons were not significantly different ($p > 0.05$) from each other. The concentrations for the two seasons were below the WHO set limits except for water from borehole, S3 (0.0142±0.0000 mg/L) during the dry season. S3 was located in an informal settlement - Kibra (Appendix X) and the possible cause of high arsenic content could be due to anthropogenic activites within the area.

4.2.6 Arsenic content in water from boreholes in Western zone

The Western zone comprised of agricultural activities, and is one source of the deep percolation of groundwater in the county. The results for the levels of arsenic in water sampled from boreholes from this zone are given in Table 4.6.

Table 4.6: Comparison of mean±SD arsenic levels (mg/L) in borehole water from the Western zone during the dry and wet seasons

Block Code	**Dry season**	**Wet season**
	Mean±SD (mg/L)	**Mean±SD (mg/L)**
W1	0.0001 ± 0.001	0.0023±0.0010
W2	0.0079 ± 0.0000^{a}	0.0019 ± 0.0010^{r}
W3	0.0062 ± 0.0011^{b}	0.0037± 0.0004^{np}
W4	0.0048 ± 0.0012	0.0053 ±0.0040
W5	0.0024 ± 0. 001	0.0022 ± 0.0003^{q}
W6	0.0085 ± 0.001^{a}	0.0025± 0.0020^{pq}
W7	0.0045 ± 0.0003	0.0039± 0.0010
W8	0.0054 ± 0.0004	0.0003± 0.0000^{np}
W9	0.0063 ± 0.0000^{b}	0.0007± 0.0003^{r}
W10	0.0041 ± 0.000	0.0013±0.0010
W11	0.0035 ± 0 .0000	0.0016± 0.0010^{r}
W12	0.0026 ± 0.001	0.0023 ± 0.0000^{q}
Overall Mean	0.0047±0.0024	0.0025±0.0012
WHO Guideline Value	0.01	0.01
NEMA Standard	0.01	0.01

Means ± SD with same letter down the column indicate that they are not significantly different at 95% confidence level.

The arsenic concentration in water sampled from boreholes in Western zone ranged from 0.0001 ± 0.001 to 0.0085 ± 0.001 mg/L with an overall mean of 0.0047 ±0.0024 mg/L during the dry season. The arsenic concentration in water sampled from boreholes in Western zone ranged from 0.00027± 0.0000 to 0.0039± 0.0010 mg/L with an overall mean of 0.0025±0.0012 mg/L during the wet season. Arsenic content in water in all the boreholes in both seasons were below the WHO set standards for dinking water (0.01 mg/L). The study indicated that during the dry season there was no significant difference ($p > 0.05$) in the mean of arsenic content in water collected from the two boreholes, W2 and W6. The study found out that the arsenic levels in water from borehole W1 was lower compared to the rest of the boreholes in Western zone during the dry season.

Similarly, during the same season there was no significant difference (p> 0.05) in the mean of arsenic levels in water collected from the two boreholes, W3 and W9. Further, the results obtained at Western zone during both dry and wet season, indicated that the arsenic content in water for all the boreholes were below the WHO set standards for dinking water.

4.3 The pH values in water from boreholes during dry and wet season

The pH values of water samples were in the range of 5.3 - 8.9 as shown in Appendices VI to XI against WHO (2008) and NEMA regulatory limits for drinking water of 6.5-8.5. The results showed that water samples from three (3) boreholes in the wet season and four (4) of the sampled boreholes water in the dry season did not meet the NEMA regulatory limit requirement. In the wet season, the pH values of borehole water ranged between 6.01±0.04 and 8.64±0.03. The boreholes; W6 and W10 both of Kangemi/ Kawangware had acidic water while boreholes UE of Tasia Embakasi area showed alkaline water. In the dry season, the pH values of borehole water ranged between 5.31±0.63 and 8.94±0.06. The samples of water from LE 7 of Utawala Kibiku area were alkaline while from the boreholes in C6 of industrial area, C8 of viwandani area and UE2 of airport North road area had acidic water during this season. Water with low pH (<6.5) is acidic, corrosive and could contain dissolved metal ions in elevated levels.

4.4 Correlation between pH and level of arsenic in water from boreholes during dry and wet season

There was a linear correlation of ($R^2 = 0.9968$) between the arsenic content and the pH during the dry season (Figure 4.1) suggesting that higher arsenic content occur on high pH values.

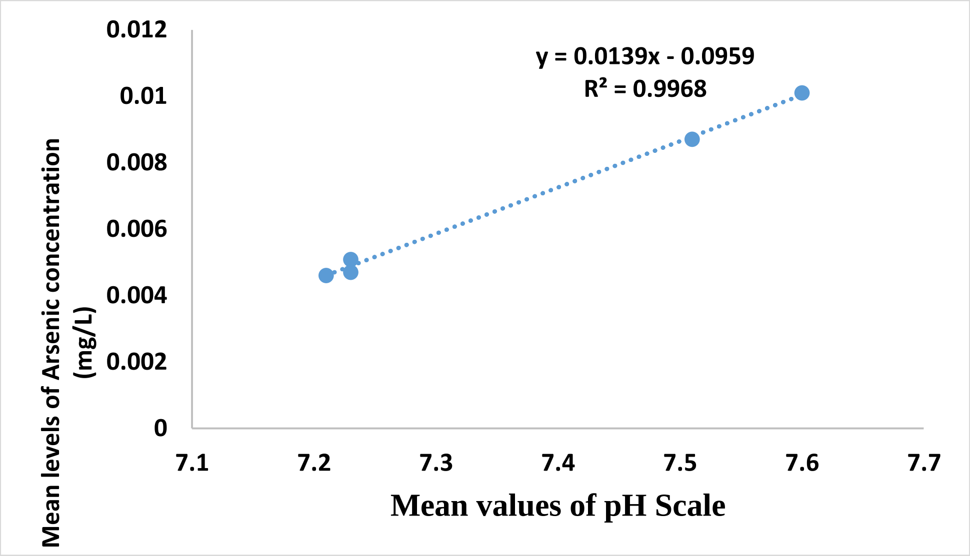

Figure 4.1: Correlation between arsenic content and pH values during dry season.

Similarly, there was a linear correlation of ($R^2 = 0.9750$) between the arsenic content and the pH during the wet season (Figure 4.2) suggesting that higher arsenic content occur on high pH values.

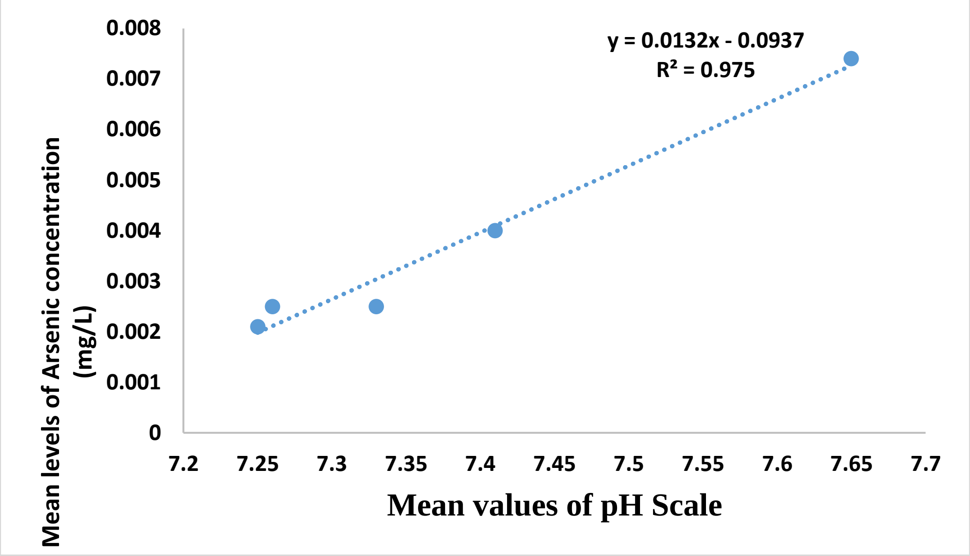

Figure 4.2: Correlation between arsenic content and pH values during wet season.

According to Smedlely *et al.*,(2002), under acidic conditions typically found in a number of natural environments, arsenic is adsorbed by oxide minerals as the arsenate ion. Adsorption protects the environments from arsenic toxicity. As pH increases, arsenic desorbs from the oxide surfaces, thus increasing the arsenic content in water.

4.5 Contamination factor of arsenic in selected borehole water during dry and wet seasons in Nairobi City County

The contamination factor (CF) is generally used to confirm the contamination level owing to the heavy metal contamination effect. The values of contamination factor for different zones are shown in Table 4.7.

Table 4.7: Mean levels of arsenic content and contamination factor of borehole water

Zones	**Seasons**	**Overall Mean Concentration**	**Contamination Factor (CF)**
		Mean±SD (mg/L)	
Central zones	Dry season	0.0101±0.0065	***1.00**
	Wet season	0.0074±0.0048	0.74
Eastern zone	Dry season	0.0087±0.0052	***0.87**
	Wet season	0.0041±0.0022	0.41
Northern zone	Dry season	0.0046±0.0022	0.46
	Wet season	0.0021 ± 0.0008	0.21
Southern zone	Dry season	0.0051±0.0035	0.51
	Wet season	0.0025±0.0012	0.25
Western zone	Dry season	0.0047±0.0024	0.47
	Wet season	0.0025±0.0012	0.25

The borehole water at Central zone had a contamination factor (CF 1.0) during the dry season and contamination factor (0.74) during the wet season. The test for equality of variance (F=1.6) was performed on Central zone during the dry and wet season (Appendix III) to test the assumption whether the two variances were equal. In this case, p= 0.494 for this test was large (more than 0.05) indicating that the variances are equal. The "Equal variances" t-statistic p-value (p = 0.331) presented evidence that the scores for the two seasons were not significantly different. In a study done in Nigeria, the contamination factor revealed that Arsenic (As) ranged from 5.0 – 10 in water from boreholes at Ikono, Akwa Ibom State (Nwoke and Edori, 2020). The levels were far much higher than those reported in this study.

An explanation of high contamination factor at Central zone during both seasons could be attributed to an uneven distribution of arsenic within ores which changes the arsenic content in the groundwater (Roy and Saha, 2002). Similarly, the study showed that the borehole water at the Eastern zone had a contamination factor of (CF 0.87) during dry season and a contamination factor of (0.41) during wet season. Test for equality of variance (F=5.59) was also performed in Eastern zone (Appendix IV) to test the assumption whether the two variances were equal. In this case, p= 0.001 indicated that the variances were unequal. The "Unequal variances" t-statistic p-value (p = 0.002) presented evidence that the scores for the two seasons were significantly different. A possible explanation of low contamination in the wet season compared to dry season could be attributed to the rapid movement of water into the ground hence low contamination in the wet season caused by dilution and higher flow rates within the aquifer (Muraguri, 2013). Further recharge during the wet season also conveys pollutants into the aquifers, which then concentrate in the dry season hence higher levels (Rasool *et al.,* 2016).

The water from boreholes at Northern zone (Table 4.7) had a contamination factor (CF 0.46) during dry season and a contamination factor (0.21) during wet season. The test for equality of variance (F=7.93) was performed in Northern zone (Appendix V) to test the assumption whether the two variances were equal and p= 0.014 for this test was found to be small (less than 0.05) indicating that the variances are unequal. The "Unequal variances" t-statistic p-value (p = 0.014) presented evidence that the scores for the two seasons are significantly different. In a study done by Nwoke & Edori (2020) in Nigeria, the contamination factor (CF 5.0 – 10) were many folds higher than the levels reported in this study.

As shown in Table 4.7, the water from boreholes at Southern zone had a contamination factor of (CF 0.51) during dry season and a contamination factor of (0.25) during wet season. The test for equality of variance (F=8.36) was performed in Southern zone

(Appendix VI) to test the assumption whether the two variances were equal and p= 0.001 indicated that the variances were unequal. The "Unequal variances" t-statistic p-value (p = 0.03) presented evidence that the scores for the two seasons were significantly different.

The results further shows that the borehole water at Western zone had a contamination factor of (CF 0.47) during dry season and a contamination factor of (CF 0.25) during wet season. The test for equality of variance (F=3.96) was performed on Western zone (Appendix VII) to test the assumption whether the two variances were equal and p= 0.031 for this test was small (less than 0.05) indicating that the variances are unequal. The "Unequal variances" t-statistic p-value (p = 0.012) presented evidence that the scores for the two seasons are significantly different.

The low contamination factor in Southern and Western zone could be as a result of the Aboretum, Karura forests and the Nairobi National park respectively. According to Santiago and Bolan, (2010) plants get rid of contaminants existing in solution neighbouring the root zone by adsorption or absorption of toxins into their roots from the solution. This is one of the phytoremediation technique known as rhizofiltration which is used to clean contaminated underground water (Mahmood *et al.,* 2007; Hussain *et al*., 2018).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

i. The levels of arsenic in water from ten boreholes (16%) during dry season and four boreholes (6%) during wet season had arsenic concentration above the WHO guidelines and NEMA regulatory limit for drinking water. The implication is that water from these boreholes is unsafe for human consumption. The levels of arsenic in water from fifty three boreholes (84%) during dry season and fifty nine boreholes (94%) during wet season were found to be below the NEMA regulatory limit. This imply that the water from these boreholes are safe for drinking.

ii. There was a linear correlation (R^2 = 0.9968) of arsenic content and pH of borehole water during dry season and wet season (R^2 = 0.9750) implying that higher concentrations of arsenic occur at high pH values.

iii. The contamination factor of arsenic in the borehole water from Northern, Southern and western zones ranged from slightly contaminated to moderately contaminated (CF 0.10 – 0.5) during both dry and wet seasons, impling that the water is safe. The contamination factor of arsenic in the borehole water from Eastern and Central zones ranged from severely to very severely contaminated (CF 0.26 – 1.00). The implication is that water from boreholes in these two zones is potentially unsafe for drinking.

5.2 Recommendations

Based on potential arsenic levels in water from boreholes the following measures can be undertaken by the relevant authorities;

i. There is need to use methods such as reverse osmosis for the treatment of arsenic in borehole water in Nairobi City County.
ii. The NEMA regulatory limit of 0.01 mg/L should be enforced.
iii. Frequent monitoring of borehole water for arsenic levels is necessary.

5.3 Suggestions for further research work

i. The study determined the level of arsenic in water from selected boreholes in Nairobi City County. Further research should be conducted to determine levels arsenic in borehole water in other towns and cities in Kenya.

ii. Depth of boreholes was not considered in this study. Research should be done to determine whether there is a correlation between the levels of arsenic in borehole water and the depth of the boreholes and wells.

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LIST OF APPENDICES

Appendix I: Statistical analysis of Central zone per season

Independent Group Analysis/Dunnett's Test

Group Means and Standard Deviations

Season	Mean	S.d	n
Dry	.0101	.0065	10
Wet	.0074	.0051	10

Mean Difference = .00262 Pooled S.E. = .00262

Equality of Variance Test

F	D.F.	P
1.6	9,9	0.494

Summary Data of Independent Group t-test

Variance	Calculated t	D.F.	P
Equal variance	1.	18	0.331 (two-tail)
Unequal variance	1.	17.1	0.332 (two-tail)

Appendix II: Statistical analysis of Northern zone per season

Independent Group Analysis/Dunnett's Test

Group Means and Standard Deviations

Season	Mean	S.d	n
Dry	.0046	.0022	8
Wet	.0021	.0008	8

Mean Difference = .00249 Pooled S.E. = .00081

Equality of Variance Test

F	D.F.	P
7.93	7,7	0.014

Summary Data of Independent Group t-test

Variance	Calculated t	D.F.	P
Equal variance	3.08	14	0.008 (two-tail)
Unequal variance	3.08	8.7	0.014 (two-tail)

Appendix III: Statistical analysis of Eastern zone per season

Independent Group Analysis/Dunnett's Test for Upper Eastern zone per season

Group Means and Standard Deviations

Season	Mean	S.d	n
Dry	.008	.0067	9
Wet	.0036	.0025	9

Mean Difference = .0044 Pooled S.E. = .00238

Equality of Variance Test

F	D.F.	P
7.18	8,8	0.011

Summary Data of Independent Group t-test

Variance	Calculated t	D.F.	P
Equal variance	1.85	16	0.084 (two-tail)
Unequal variance	1.85	10.2	0.094 (two-tail)

Independent Group Analysis/Dunnett's Test for Lower Eastern zone per season

Group Means and Standard Deviations

Season	Mean	S.d	n
Dry	.0094	.0032	9
Wet	.0038	.0038	9

Mean Difference = .0056 Pooled S.E. = .00166

Equality of Variance Test

F	D.F.	P
1.41	8,8	0.638

Summary Data of Independent Group t-test

Variance	Calculated t	D.F.	P
Equal variance	3.38	16	0.004 (two-tail)
Unequal variance	3.38	15.5	0.004 (two-tail)

Independent Group Analysis/Dunnett's Test for the overall Eastern zone per season

Group Means and Standard Deviations

Season	Mean	S.d	n
Dry	.0087	.0052	18
Wet	.004	.0022	18

Mean Difference = .00473 Pooled S.E. = .00133

Equality of Variance Test

F	D.F.	P
5.59	17,17	0.001

Summary Data of Independent Group t-test

Variance	Calculated t	D.F.	P
Equal variance	3.57	34	0.001 (two-tail)
Unequal variance	3.57	22.9	0.002 (two-tail)

Appendix IV: Statistical analysis of Southern zone per season

Independent Group Analysis/Dunnett's Test

Group Means and Standard Deviations

Season	Mean	S.d	n
Dry	.0051	.0035	12
Wet	.0025	.0012	12

Mean Difference = .00258 Pooled S.E. = .00107

Equality of Variance Test

F	D.F.	P
8.36	11,11	0.001

Summary Data of Independent Group t-test

Variance	Calculated t	D.F.	P
Equal variance	2.42	22	0.024 (two-tail)
Unequal variance	2.42	13.6	0.03 (two-tail)

Appendix V: Statistical analysis of Western zone per season

Independent Group Analysis/Dunnett's Test

Group Means and Standard Deviations

Season	Mean	S.d	n
Dry	.0047	.0024	12
Wet	.0025	.0012	12

Mean Difference = .00217 Pooled S.E. = .00077

Equality of Variance Test

F	D.F.	P
3.96	11,11	0.031

Summary Data of Independent Group t-test

Variance	Calculated t	D.F.	P
Equal variance	2.81	22	0.01 (two-tail)
Unequal variance	2.81	16.2	0.012 (two-tail)

Appendix VI: Block code, location and comparison of pH levels in borehole water from the Central zone during the dry and wet seasons

Block code	Location of the borehole water	Dry season	Wet season
		pH Scale	pH Scale
C1	Bahati	7.04±0.42	7.55±0.75
C2	Makongeni	7.31±0.14	7.34±0.61
C3	Kariobangi	7.15±0.23	7.43±0.76
C4	Mukuru Kayaba	7.84±0.32	7.94±0.56
C5	Makadara	7.42±0.44	7.22±0.06
C6	Industrial area	8.82±0.63	7.12±0.16
C7	Kamukunji	7.91±0.23	8.01±0.15
C8	Viwandani	8.73±0.17	8.03±0.39
C9	Mukuru kwa Reuben	7.31±0.43	8.00±0.24
C10	Maringo	7.81±0.42	7.87±0.15
WHO Guideline Value		6.5-8.5	6.5-8.5
NEMA Standard		6.5-8.5	6.5-8.5

Appendix VII: Block code, location and comparison of pH levels in borehole water from the Upper Eastern zone during the dry and wet seasons

Block code	Location of the borehole	Dry season	Wet season
		pH Scale	pH Scale
UE1	Mukuru kwa Njenga	7.92±0.33	7.44±0.03
UE2	Airport North road area	8.94±0.06	7.64±0.27
UE3	Imara Daima	7.61±0.00	7.14±0.08
UE4	Donholm	7.11±0.00	7.04±0.01
UE5	Pipeline	7.17±0.00	7.24±0.01
UE6	Tasia	8.01±0.02	8.64±0.03
UE7	Mradi	7.55±0.09	7.41±0.09
UE8	Nyayo Estate	7.10±0.28	7.41±0.10
UE9	Fedha	7.11±0.63	7.09±0.08
WHO Guideline Value		6.5-8.5	6.5-8.5
NEMA Standard		6.5-8.5	6.5-8.5

Appendix VIII: Block code, location and comparison of pH levels in borehole water from the Lower Eastern zone during the dry and wet seasons

Block code	**Location of the borehole water**	**Dry season**	**Wet season**
		pH Scale	**pH Scale**
LE1	Ruai	7.75±0.12	7.76±0.44
LE2	Njiru	6.68±0.22	6.86±0.02
LE3	GSU Embakasi	7.52±0.23	7.38±0.61
LE4	Jua Kali	7.56±0.01	7.11±0.06
LE5	Kamulu	6.07±0.34	7.57±0.77
LE6	Mihango	7.82±0.67	7.22±0.43
LE7	Utawala Kibiku	5.31±0.63	6.08±0.21
LE8	Utawala Benedicta area	7.63±0.27	7.39±0.63
LE9	Jomo Kenyatta International Airport	7.62±0.61	7.81±0.43
WHO Guideline Value		6.5-8.5	6.5-8.5
NEMA Standard		6.5-8.5	6.5-8.5

Appendix IX: Block code, location and comparison of pH levels in borehole water from the Northern zone during the dry and wet seasons

Block code	**Location of the borehole**	**Dry season**	**Wet season**
		pH Scale	**pH Scale**
N1	Kariobangi	7.42±0.08	7.27±0.08
N2	Babadogo	7.15±0.22	7.19±0.02
N3	Kayole	7.25±0.43	7.42±0.06
N4	Kahawa	7.07±0.05	7.06±0.31
N5	Githurai	7.19±0.12	7.22±0.20
N6	Komarock	7.11±0.16	7.02±0.03
N7	Soweto slums	7.52±0.09	7.90±0.01
N8	Mwiki	7.21±0.01	7.31±0.07
N9	Kasarani	7.02±0.02	7.03±0.11
N10	Thome	7.04±0.06	7.04±0.17
WHO Guideline Value		6.5-8.5	6.5-8.5
NEMA Standard		6.5-8.5	6.5-8.5

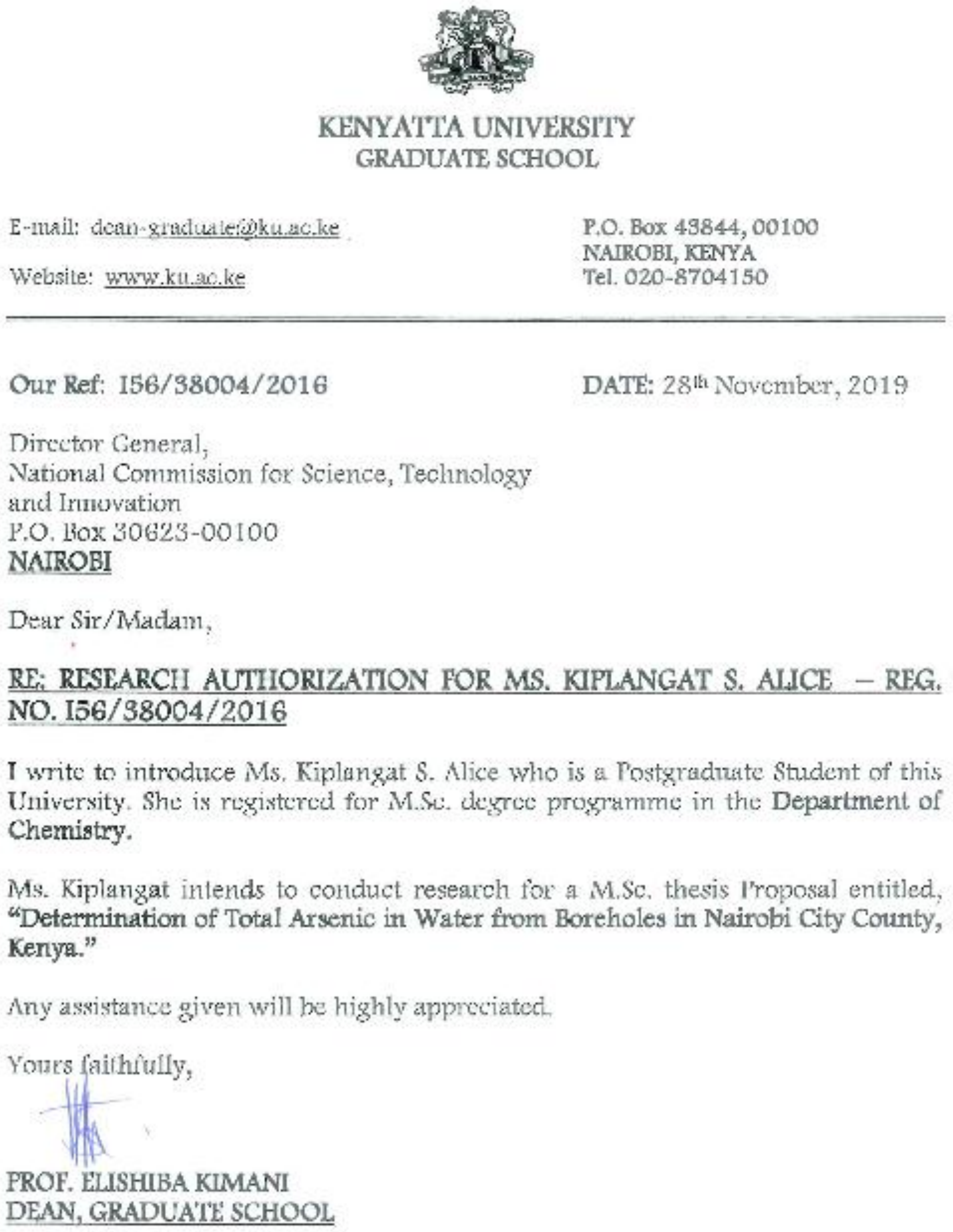
Appendix X: Block code, location and comparison of pH levels in borehole water from the Southern zone during the dry and wet seasons

Block code	Location of the borehole water	Dry season	Wet season
		pH Scale	pH Scale
S1	Wilson	7.21±0.45	7.30±0.00
S2	Nairobi West	7.12±0.70	7.14±0.12
S3	Kibra	7.95±0.00	7.94±0.08
S4	High Rise estate	7.02±0.04	7.04±0.11
S5	Woodley	7.07±0.25	7.38±0.12
S6	Ayany	7.11±0.11	7.08±0.02
S7	Uhuru Garden	7.19±0.19	7.01±0.19
S8	Nairobi Dam Estate	7.21±0.05	7.37±0.08
S9	South C	7.27±0.14	7.54±0.24
S10	Karen	7.16±0.29	7.74±0.09
S11	Otiende	7.24±0.04	7.44±0.08
S12	Lenana	7.19±0.06	7.02±0.07
S13	Langata	7.19±0.09	7.29±0.12
WHO Guideline Value		6.5-8.5	6.5-8.5
NEMA Standard		6.5-8.5	6.5-8.5

Appendix XI: Block code, location and comparison of pH levels in borehole water from the Western zone during the dry and wet seasons

Block code	Location of the borehole	Dry season	Wet season
		pH Scale	pH Scale
W1	Upper Hill	7.31±0.17	7.28±0.31
W2	Kileleshwa	7.15±0.03	7.16±0.02
W3	Riruta	7.22±0.69	7.42±0.40
W4	Loresho	7.12±0.03	7.57±0.07
W5	Lavington	7.22±0.11	7.24±0.05
W6	Kangemi	6.08±0.01	6.01±0.04
W7	Hurlingham	7.22±0.02	7.49±0.06
W8	Kilimani	7.18±0.06	7.04±0.00
W9	Westlands	7.31±0.01	7.07±0.61
W10	Kawangware	6.05±0.09	5.44±0.41
W11	Spring Valley	7.06±0.01	7.19±0.27
W12	Parklands	7.26±0.01	7.25±0.09
WHO Guideline Value		6.5-8.5	6.5-8.5
NEMA Standard		6.5-8.5	6.5-8.5

Appendix XII: Graduate studies research approval letter



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P.O. Box 43844, 00100
NAIROBI, KENYA
Tel. 020-8704150

Our Ref: I56/38004/2016

DATE: 28th November, 2019

Director General,
National Commission for Science, Technology
and Innovation
P.O. Box 30623-00100
NAIROBI

Dear Sir/Madam,

RE: RESEARCH AUTHORIZATION FOR MS. KIPLANGAT S. ALICE – REG. NO. I56/38004/2016

I write to introduce Ms. Kiplangat S. Alice who is a Postgraduate Student of this University. She is registered for M.Sc. degree programme in the **Department of Chemistry.**

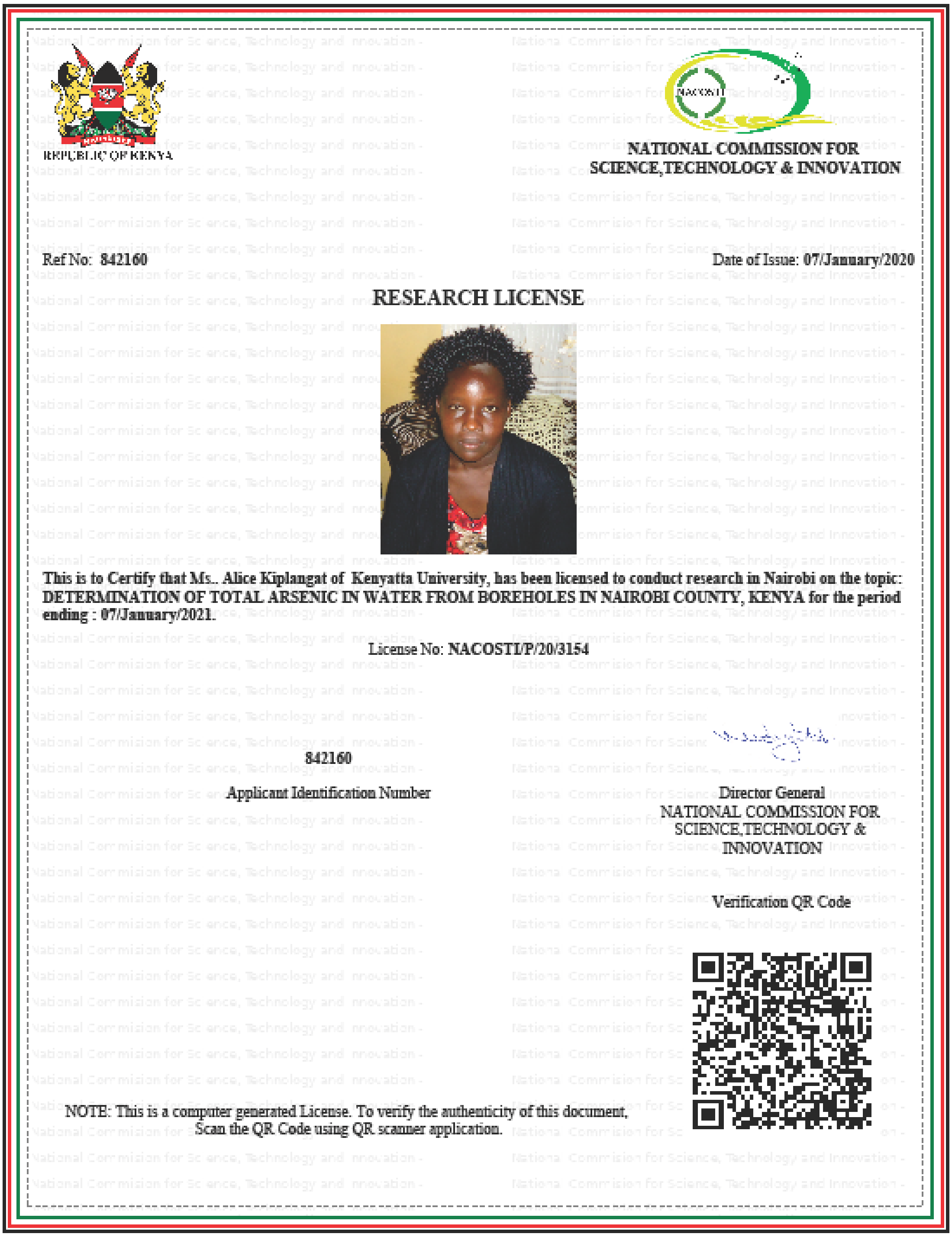
Ms. Kiplangat intends to conduct research for a M.Sc. thesis Proposal entitled, **"Determination of Total Arsenic in Water from Boreholes in Nairobi City County, Kenya."**

Any assistance given will be highly appreciated.

Yours faithfully,

PROF. ELISHIBA KIMANI
DEAN, GRADUATE SCHOOL

Appendix XIII: National Commission for Science, Technology and Innovation research permit and authorization



REPUBLIC OF KENYA

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

Ref No: 842160

Date of Issue: 07/January/2020

RESEARCH LICENSE

This is to Certify that Ms.. Alice Kiplangat of Kenyatta University, has been licensed to conduct research in Nairobi on the topic: DETERMINATION OF TOTAL ARSENIC IN WATER FROM BOREHOLES IN NAIROBI COUNTY, KENYA for the period ending : 07/January/2021.

License No: NACOSTI/P/20/3154

842160

Applicant Identification Number

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