FACULTY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF CHEMISTRY

ASSESSMENT OF WATER QUALITY IN SOME DISTRIBUTION TANKERS AND BOREHOLES IN SELECTED AREAS OF NAIROBI COUNTY

BY

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DECLARATION

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

Signature: … ………… Date: 10th May 2024

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DEDICATION

I dedicate this thesis to my parents, my husband, supervisors, friends, and those who supported me in my education journey.

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I'm grateful to God for providing me with life, health, education, wisdom, and the tools I needed to complete this work. My heartfelt thanks go to my supervisors, Professor Amir O. Yusuf and Dr. Farida W. Hussein, as well as Mr. Godfrey A. Wafula, for their encouragement, time sacrifice, and guidance during the project. I'd like to thank Mr. Mwangi Ephantus and the academic and technical staff at the University of Nairobi's Department of Chemistry, including the chairman. In addition, I'd like to thank my family, friends, and fellow students, particularly Stephen Kioko, for their inspiration and aid in completing my thesis. I am incredibly grateful to my parents, spouse, and kids for their unwavering support and patience while I sacrificed precious time doing this study.

ABSTRACT

The health of any community entirely depends on the availability of sufficient safe and clean water which helps in preventing waterborne diseases. This study's primary goal was to determine whether water from distribution tankers and boreholes in a few locations in Nairobi County complied with the World Health Organization and National Environment Management Authority’s established guideline values. Samples were collected from boreholes and distribution tankers as follows: Dandora Boreholes (DB) and Dandora Tankers (DT); Kayole Boreholes and Kayole Tankers; Pangani Boreholes and Pangani Tankers; Eastleigh Boreholes and Eastleigh Tankers; South B Boreholes and South C Tankers in Nairobi County. The parameters determined included: pH, Total suspended solids (TSS), Total dissolved solids (TDS), Electrical conductivity (EC), fluoride, chloride, ammonia, nitrate, *Escherichia coli,* total count and analysis of some selected heavy metal ions. The measurements of pH, fluoride, and electrical conductivity were made by an ion-selective electrode. The determinations of TDS and TSS were made through the gravimetric method. The titration method was used to quantify chloride, while ultraviolet-visible spectrophotometer was used to measure ammonia and nitrate. *E. coli* and total counts were ascertained by the biological method. Heavy metals were measured using atomic absorption spectrophotometer. All boreholes and tankers met the guideline values of NEMA, KEBS and WHO with regard to pH, EC, TDS, chloride and ammonia. Total suspended solids were above the recommended limits of KEBS and WHO for the borehole and tanker sites. Nitrate values in all the borehole sites conformed to the WHO, NEMA and KEBS guidelines except at site PB1, while nitrate values for tanker sites conformed to the WHO except at site ET3. It also conformed to NEMA and KEBS guidelines except at sites KT1, KT2, ET3 and SCT1. *Escherichia coli* in all boreholes conformed except at Pangani Borehole 2. *E-coli* in tankers conformed except at sites KT1, PT1 and SCT1. Total coliforms for both water samples from boreholes and Tankers did not conform to the set limit values. The concentration of zinc in boreholes conformed with the set limit values except that of PB1, PB2, PB3 and EB2. In tankers, all conformed to the set limit except STT3, PT1, ET1, and ET2. Concentrations of lead, copper and cadmium in both boreholes and distribution tankers did not conform to the limit values.

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LIST OF ABBREVIATIONS AND SYMBOLS

UNICEF	United Nations Children's Fund
WHO	World Health Organization
MEWR	Ministry of Energy and Water Resource
GPS	Global Positioning System
GIS	Geographic Information System
TDS	Total Dissolved Solids
F^-	Fluoride Ion
mg	Milligram
L	Liter
NEMA	National Environment Management Authority
KEBS	Kenya Bureau of Standards

CHAPTER ONE

INTRODUCTION

1.1 Background Study

Water is a vital, life-sustaining resource that is frequently taken for granted in terms of its existence and availability for human use. Apart from meeting direct human needs, water allows all living species to survive and it is a renewable natural resource (Annison, 2011). The supply of food is related to the availability of water that is needed for the fast-growing populations. Furthermore, access to clean water is essential for maintaining human health (Pimentel *et al.*,2004).

Both terrestrial and aquatic ecosystems are also influenced by water shortages, which lead to decreased biodiversity in their surroundings. According to Albert *et al.* (2021), many countries across the globe are facing water shortages due to changes in climate and population. Major biological processes cannot proceed in the absence of water. However, water is not distributed evenly around the globe (Kılıç, 2020).

An adequate supply of water must be available to sustain life processes of living things. Improving accessibility to clean water can directly influence health. Our priority should be to make sure that water for domestic purposes is free of contaminants as much as possible. According to the WHO, NEMA and KEBS guidelines, water that is suitable for drinking is water that poses no significant danger to health when consumed (WHO, 2022). The most susceptible groups to waterborne illnesses include young children, the elderly and those who live in unhygienic dwellings. People who are normally prone to waterborne diseases need to boil water for domestic consumption.

Research conducted by Bremmer *et al.* (2010) showed that about 43% of Kenyans lack access to clean and safe drinking water. Recurrences of drought, pollution of water sources, growth of population and poor management of water supply have been the key issues in the scarcity of water over the years. The inability to obtain food is also hampered by the lack of rainfall. In the Rural areas of Kenya, water scarcity has been exacerbated in many areas by insufficient investment in water. As a result, many urban residents end up being affected by water-borne diseases like cholera. There is a substantial rural-urban disparity in terms of the availability of safe water, notwithstanding the acute shortage of clean water in Kenya's urban slums. A report published by Marshall (2011) showed that almost 85 % of urban settlers globally have no access to clean water, unlike rural residents.

This research study enabled me to assess the quality of water that was distributed by tankers and from boreholes in Nairobi County for domestic use. Within the span of the study, samples were taken from five regions in Nairobi and analyzed on-site and in the laboratory. Electrical conductivity, pH, TDS, TSS, fluoride, chloride, ammonia, nitrate and some selected heavy metals were assessed. In addition, bacteriological studies were also undertaken.

1.2 Statement of the problem

Studies on improving urban water supply services will continue to be undertaken around the world due to the importance of safe water supply. However, freshwater resources are under increasing strain in all regions due to rising demand and the effects of a changing climate. It has been found from studies done that some Sub-Counties of Nairobi County have experienced an acute water shortage. This made many households to rely on underground water sources (boreholes) and also water supplied by water tankers (water bowsers). This helped to supplement the city's insufficient water supply (Ochungo *et al.*, 2019). Research conducted by Muraguri (2016) on borehole waters found high concentrations of Ni and Pb, which were above WHO guideline values during the dry season. It was also found that studies on assessment of water from bowsers that supply water to Nairobi County residents has been rare. Access to clean and quality water has been a problem in Nairobi County and this has created health challenges to the residents. Water has been found to be contaminated with heavy metals, bacteriological contaminants and other physical-chemical parameters in various regions of Nairobi Country. This was brought about by urbanization that led to increased population. Therefore, this has posed a great challenge to accessing safe water for human consumption (Rezaei *et al.*, 2019). In the areas selected for these studies, it was found that studies on borehole waters and waters from tankers was lacking. Hence, there was a knowledge gap in relevant studies to ascertain the level of pollutants in underground water and water tankers. In Nairobi County there have been an increasing number of boreholes that have been drilled to supplement other sources. There has also been an increase in the number of water tankers that are used to supply water for residents for domestic consumption. This study on borehole water and water tankers was therefore done at some selected sites in Nairobi County which included Dandora, Kayole, Pangani, Eastleigh, South B and South C. This involved Borehole water samples and samples from Water Tankers.

1.3 Objectives of the study

1.3.1 Main objective

The main aim of this study was to assess the quality of water from some selected water tankers and boreholes in Nairobi County.

1.3.2 Specific objectives

The study's specific aims were as follows:

1. To assess the physical-chemical properties of some water distribution tankers and boreholes in selected areas of Nairobi County (TDS, TSS, pH, electrical conductivity, fluoride, chloride, ammonia, nitrate and *Escherichia coli*).
2. To assess the content of some selected heavy metals in some water distribution tankers and boreholes in selected areas of Nairobi County (copper, zinc, cadmium, and lead).

3. To determine the bacteriological water quality (*E-coli* and total count) in some selected areas of Nairobi County.

1.4 Justification

The ecosystem has continued to decline because of population development and rapid industrialization, since both surface and subsurface water have been contaminated. Industrial effluent disposal and/or waste on land, air, and water bodies has exposed humans and livestock to various diseases. This has also affected aquatic life and caused harm to other organisms. Assessment of the quality of water in these Sub-Counties of Nairobi will therefore assist in mapping out the affected areas which will lead to setting out mitigation steps by the Nairobi County.

Nkonge (2012) discovered that fluoride, iron, and manganese levels in borehole water in some regions of Nairobi County were above the WHO recommended limit in a previous study on the organic, inorganic, and microbiological elements. In another study by Kiplagat et al (2021) on the levels of arsenic in selected boreholes in Nairobi County, it was found that arsenic level in 16 % of the boreholes in Central Kenya region were found to be above WHO recommended limit. This therefore necessitated my study on borehole waters in some areas of Nairobi County.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water pollution

Water contamination has become an international problem and eliminating it requires constant review of water resource policy. This is an issue in both industrialized and developing nations. Water pollution negatively affects people all over the world and about 14,000 people die every day (Chaudhry & Malik, 2017). Agricultural, industrial and domestic effluents are the major cause of pollutants that contaminate the water. Water contamination can be classified into two: Surface water pollution and groundwater pollution (Turner, 2014). In a study done by Nkonge (2012) on analysis of organic, inorganic and microbiological constituents of borehole water in Kibera, Dagoretti, Embakasi, Kasarani and Westlands. It was found that fluoride, iron and manganese were found to be above WHO recommended limit. In a study by Kiplagat et al (2021) on the levels of arsenic in selected boreholes in Nairobi County, it was found that arsenic level in 16 % of the boreholes in Central region were found to be above WHO recommended level.

2.1.1 Water Pollutants

Water pollutants are compounds that can alter the chemical, physical, and biological properties of water. They are compounds that, when introduced into the environment, have negative health consequences. Pollution can cause long-term or short-term damage to the environment. Biodegradable pollutants are only harmful in the short term, while some pollutants, such as dichlorodiphenyltrichloroethane (DDT), degrade to form other pollutants, such as dichlorodiphenyldichloroethane (DDD) and dichlorodiphenyldichloroethylene (DDE) (Chaudhry & Malik, 2017). These degraded products can also cause other health challenges. Nonbiodegradable polymers, synthetic chemicals and heavy metals are examples of pollutants that accumulate in the environment as time passes. Their damage grows in direct proportion to their content. As a result, these contaminants are a threat on the future generations. Other contaminants in the environment like carbon dioxide that have absorptive characteristics can be a threat only when their abundance surpasses the environment's absorption capability. Only by recycling or diluting these pollutants can they be converted into other non-harmful compounds (Chaudhry & Malik, 2017).

2.1.2 Sources of water pollution

Pollutants in rivers, streams, and lakes are a result of surface water contamination. Surface water pollution sources can well be described in terms of nonpoint and point sources, as they directly discharge effluents into freshwater bodies. This category includes household and industrial waste. According to Ritter *et al.* (2002), it is very possible to control pollution at its source effectively (Baluch & Hashmi, 2019). When the source of water contamination is identified as coming from identifiable sources such as storm water, industrial sources and sewage treatment plants, then point source pollution occurs. It is distinguishable from other sources of contamination (Chaudhry & Malik, 2017).

Non-point sources are those that are spread out across a large area. It happens when the source of the water contamination is unknown or when the pollution does not come from a single, distinct source. It is difficult to control and can be caused by pesticides, industrial waste and fertilizers, just to name a few. In many countries this is the leading source of water contamination. This contamination source accounts for the high levels of contaminants in lakes and streams. Runoff from polluted water from construction sites, farms, and mines also finds its way to lakes and streams. Controlling non-point sources is extremely difficult (Cantonati *et al*., 2020; Turner, 2014).

2.1.2.1 Anthropogenic and natural pollution sources

The main causes of water pollution are global warming, industrial discharge, agricultural runoff, livestock farming and sewerage discharge, maritime traffic, fuel spillages and deforestation. Pollution is defined as the presence or introduction of a substance that is damaging or poisonous to the environment. Pollution can be introduced through siltation (soil), wind deposition and runoff due to the hydrological cycle. Natural sources may have a great impact on physical-chemical properties. Agricultural waste, waste from domestic processes, mining and other industrial effluents are some of the human activities that influence the quality of drinking water by increasing levels of pollutants like heavy metals (Khatri & Tyagi, 2015).

Table 2.1 shows different sources of ground water pollution.

Table 2.1: Different sources of ground water pollution

Anthropogenic Sources	Natural Sources
• Mining activities	• Withering of rocks
• Waste dumps	• Intrusion of sea water
• Extended urban development	• Chemical reactions in the atmosphere
• Use of fertilizers, insecticides and pesticides	• Volcanic activities
• Processing of radioactive materials	
• Chemical dumping	
• Sewage spillage	
• Climate change	

Source; Khatri & Tyagi, 2015.

2.2 Ground Water Pollution

Groundwater pollution occurs mostly when polluted surface water seeps into the earth and into the aquifer. In other words, it occurs when pollutants present on the ground reach the underground water bodies. When pathogen-infested fecal water seeps into the earth, it renders it unfit for human consumption. Groundwater polluted with pathogens can contain viruses, protozoa, bacteria, and, in rare situations, helminth eggs. When this water is consumed, it causes diseases such as diarrhea and cholera (Jablecki, 2005).

Groundwater pollution is becoming one of the most important environmental and human health issues. Rapid population growth, climate change and a variety of human activities jeopardize the availability of freshwater resources and degrade groundwater quality (Pimentel *et al.*, 2004). Because water is a consumable resource and a major component of the life cycle, excessive usage of freshwater resources reduces the available amounts for future generations. Contamination of water resources has a direct impact on all living organisms that rely on the hydrologic cycle.

Most rural and urban regions rely on groundwater as their primary drinking water supply. Research conducted in Romania and Bulgaria showed that rural populations were affected by “blue baby syndrome’’ as a result of consuming polluted groundwater (Chaudhry & Malik, 2017). Different practices, such as the release of untreated sewage, contribute adversely to the contamination of groundwater. Research done by Hinga (2016) gives the mechanism of leaching untreated sewage to the groundwater table. Likewise, industrial emissions and nitrogenous fertilizers have rampant effects on human health when they find their way into the groundwater. This becomes a serious threat, especially where the water table is near the surface (Turner, 2014).

2.2.1 Potential sources of ground water contamination

Pollution of the groundwater is a prevalent problem that has a negative impact on human health. The world's population relies heavily on groundwater as a supply of fresh water for domestic, commercial and industrial purposes. Groundwater supplies provide drinking water for around a third of the world's population. Due to the existence of natural mineral reserves inside the Earth's crust, many of the pollutants in the groundwater are of geologic origin. The problem of anthropogenic pollutants is currently a challenge because of the world's rapid population growth, urbanization, industrialization and agricultural production (Li *et al.*, 2021).

Table 2.2 represents the category and the source of contamination in water.

Table 2.2: Category and the source of contamination of water

Category	Pollution Sources
Agricultural activities	Waste from animals, sludge re-use, irrigation sites, feedlots from animals
Commercial activities	Gas stations, airports, car washes, construction sites
Industrial processes	• Hazardous spills • Mining drainage • Metal fabrication • Manufacturing of electronics • Chemical industries
Residential sources	• Waste from household • Furniture fabrication • Waste water from household
Municipal activities	• Sewer lines • Municipal sludge • Effluents from treatment plants • Municipal incinerators

Source: Li *et al.*, 2021

2.3 Heavy metals contamination of water

Toxic substance contamination of the environment is increasing, which is causing major concern among local consumers of water. A wide variety of contaminants are frequently introduced into aquatic ecosystems, mostly because of increased industrial activities, technical advancement, growing population, resources exploitation, domestic waste spillage and agricultural run-off. Because of their toxicity, persistence, propensity to accumulate in living things and cause food chain amplification and non-biodegradability, heavy metals are among the most hazardous classes of pollutants. Heavy metals present clear health risks due to their environmental persistence. One of the main contributors to ecological damage is the presence of heavy metals in fish, water, vegetation and other marine foods. As a result, detecting heavy metals and their harmful effects on humans is always a scientist's top priority.

Heavy metals have long-lasting toxic effects because of their non-biodegradability. Research conducted by Ganagaiya *et al.*, (2001) showed that small amounts of these metals have hazardous effects. These metals are widely found in industrial, municipal, and urban runoff and have an impact on humans and other living things. Heavy metal levels in our waterways are rising as a result of increased urbanization and industrialization. Abida *et al.* (2009) found that numerous heavy metal ions concentrate in aquatic sediments and soil after being introduced into the environment.

Studies by Bagul *et al.,* (2015) indicate that excessive levels of trace metals can occur in nature due to geological phenomena such as volcanic eruptions, weathering of rocks and the introduction of these products into rivers, oceans and lakes. When ores and huge volumes of metal are smelted over open flames, the introduction of these heavy metal compounds will occur. Heavy metal ions are introduced into the atmosphere during industrial procedures (Sankhla *et al.*, 2016). Heavy metals are defined as elements with an atomic number larger than 20 and a density greater than $5g/cm^3$ .They should exhibit metallic characteristics. These can be categorized into two:

a: Essential heavy metals are those that live organisms require to carry out biological functions such as growth and metabolism. Plants often require tiny levels of essential heavy metals. Copper, iron, manganese, cobalt, zinc, and nickel are among the examples.

b: Non-essential heavy metals such as Cr, Pb, Hg, and Cd are not required by plants, even at minute levels. Essential metals need to be present in trace levels ranging from 10–15 mg/kg. These nutrients are also known as micronutrients. (Sankhla *et al.*, 2016).

2.3.1 Copper

Depending on concentrations of copper, it can be used as an essential nutrient, but enhanced contamination can lead to contamination of drinking water. It finds numerous commercial applications, especially in the manufacture of valves, pipes and fittings, as well as alloys and coatings (Oketola *et al.*, 2013). The addition of copper sulfate pentahydrate to surface waters is done to control algal growth. Copper lining in pipes can increase the levels of copper in drinking water (Pizzi, 2010). Research showed that copper accumulations increase during the distribution of water, especially in acidic or alkaline media. Water and food are considered to be the major sources of copper, especially in developed countries (Cho, 2019). The WHO guidelines indicate that the permitted quantity of copper in bottled water for consumption shouldn't go above 2 mg/L (WHO, 2019) and the NEMA Guideline value is 0.05 mg/L (Brossard, 2000).

2.3.2 Cadmium

Cadmium is a heavy metal that occurs normally in the earth's crust. It is used in the manufacture of batteries, electroplating, making of alloys and in coatings. The oxidation state of cadmium is always +2, although a few compounds have +1 oxidation state. The toxicity of Cd, which is present in marine water, surface water and ground water, when introduced into the food chain, it causes antagonistic changes in living organisms (Mahmood *et al.,* 2019). Following the Itai-Itai illness epidemic in Japan, which was brought on by wastewater irrigation in agricultural regions, scientists started studies on it. The environment is exposed to cadmium from both natural and artificial sources. The physical-chemical characteristics of the soil impact its bioavailability. Cadmium is harmful to plants, people, and soil microorganisms due to its high mobility in the soil. Humans can be exposed to cadmium through consumption of water and smoking. As shown by Mahmood et al. (2019). Ingestion of Cd is a substantial cause of risk. Cadmium is used in the steel and plastics industries. Compounds of cadmium are used in battery manufacture. It is released into the environment through wastewater, fertilizer contamination and through air pollution. Food contributes to the increase in cadmium in our bodies. The recommended daily oral intake is 0.0002 mg/kg. Research conducted by Oyem *et al.,* (2015) showed that cigarette smoking increased cadmium exposure. The highest allowed concentration of cadmium by WHO is 0.003 ppm (WHO, 2019) and 0.01 ppm by NEMA (Brossard, 2000).

2.3.3 Lead

Lead Compounds are found in the mineral’s crocoite, cerussite, anglesite and galena. The latter is the main source of lead. Lead was used in paints, hair dyes, insecticides and glassware. Lead can exist in the +2 and +4 oxidation states. Lead can be used in the manufacture of batteries, bullets, bearing, alloys, protective shield in nuclear plants and pigments in paints. There are several ways in which lead may enter the human body. It can be introduced through consumption of polluted water. Leaded gasoline when burnt can deposit it in the air. It is also found in seafood. Over a period of time lead ingestion may lead to accumulation, particularly in children. Over time, lead poisoning can cause death or long-term harm to the kidneys, brain, and the central nervous system. In addition to behavioral and learning issues (such as hyperactivity), this damage commonly results in memory and attention loss, high blood pressure, hearing loss, headaches, slower development effect on reproductive systems of humans and discomfort in the muscles and joints (Sankhla *et al*., 2016).

The effects of lead poisoning can last a lifetime, making lead the leading health danger for children, leading to retardation of a child's development, and nervous system damage. Although their usage is declining in many nations. Some organic compounds contain lead. Tetraethyl and tetramethyl lead have been extensively utilized as antiknocks in gasoline (Clark *et al.*, 2015).

Lead can be present in piped water when the pipe is made of lead. Temperature, pH, water hardness, and water standing time are just a few of the variables that might determine how much lead dissolves in the plumbing system. Drinking water should have a lead concentration maximum of 0.01mg/L (WHO, 2019), and 0.05 mg/L as the NEMA guideline value (Brossard, 2000).

2.3.4 Zinc

Zinc is a metallic element with atomic number 30. It can exist in oxidation state +2. Zinc is an essential element for life as a structural compound or reaction site in proteins. Although zinc concentrations in surface and groundwater are less than 0.05 and 0.01 mg/L respectively, tap water concentrations can be significantly higher due to zinc dissolution in pipes. In 1982, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) proposed a zinc Provisional Maximum Tolerable Day Consumption (PMTDI) of 1 mg per kg of body weight. However, zinc levels in drinking water greater than 3 mg/L may be unpalatable to consumers (Poddalgoda et al., 2019). According to the WHO, zinc levels greater than 15 mg/L would drastically reduce water portability. Zinc levels in drinking water should not go over 3 mg/L (WHO, 2019). The NEMA recommendation value should not exceed 1.5 mg/L (Brossard, 2000).

2.4 Human exposure to heavy metals

Significant soil pollution is caused by heavy metal contamination of both subsurface and surface soils. This problem is made worse when mined ores are dumped on the ground. Metal ores exposed on the ground can dissolve in acids which causes a significant quantity of acid mine drainage (AMD). These metal ions when taken up by plants can build up in their tissues. Animals that consume these contaminated plants and water will have a buildup of these heavy metals in their tissues. Heavy metals are regarded as environmental toxins that can adversely impair health (Kapoor & Singh, 2021).

2.5 Health effects of heavy metals in groundwater

Heavy metal ions exist naturally and are found in trace amounts throughout the environment. Larger amounts of these heavy metal ions may be harmful. Usually, these metals are introduced to animals when ingested or inhaled by humans. One's risk of exposure rises if they work or live near an industrial facility that utilizes these metals and their compounds (Martin & Griswold, 2009). Although each metal has its own unique set of symptoms, mercury, cadmium, aluminum, copper, arsenic and lead poisoning have been linked to the following general symptoms: gastrointestinal (GI) disorders, tremor, paralysis, vomiting, convulsions, depression, hemoglobinuria, (which causes rust-red stools), ataxia, diarrhea, stomatitis and pneumonia. These ions can have toxic (chronic, acute, or sub-chronic), carcinogenic, teratogenic, neurotoxic, or mutagenic effects (Verma & Dwivedi, 2013).

A particularly harmful consequence of lead intoxication is teratogenicity. Acute and long-term central nervous system damage, impairment of the cardiovascular and reproductive systems, impairment of the kidneys and suppression of hemoglobin production are further effects of lead poisoning. Zinc has been associated with lead-like symptoms and is readily mistaken for lead poisoning. When taken orally. Zinc is rather non-toxic. However, excessive amounts can interfere with growth and reproduction (Nolan *et al.*, 2003). Zinc toxicosis symptoms have been characterized as diarrhea, vomiting, bloody urine, and icterus (yellow mucous membrane). Additionally, failure of the liver, anemia, and kidney damage may occur (Verma & Dwivedi, 2013).

Even in extremely low quantities, cadmium is hazardous. Humans who have long-term exposure develop renal failure marked by tubular proteinuria. As a result of inhaled dust and fumes, high exposure levels can result in obstructive pulmonary disease, commonly known as cadmium pneumonitis. It is distinguished by chest pain, coughing that generates frothy blood sputum, and lung tissue deterioration caused by excessive accumulation of watery liquids. In addition to excessive blood pressure and cardiac dysfunction, cadmium is also connected to bone deformities such as osteocalcin, spontaneous fractures and osteoporosis (Verma & Dwivedi, 2013).

2.6 Physical parameters in determining water quality.

Total dissolved solids, pH, electrical conductivity and total suspended solids were studied in this research.

2.6.1 Total Dissolved Solids (TDS)

Total dissolved solids are the total amount of organic and inorganic components suspended in a liquid as molecules, ions, or micro-granular colloids. The solids must be small enough to pass through a two-micrometer-mesh sieve. TDS is used for a range of applications, including low-level water quality examinations for streams, rivers, and lakes, as well as drinking water. It is a drinking water quality indicator as well as a general measure of dissolved organic and inorganic compounds. TDS in surface rivers is caused by the solvent action of water on interaction with minerals in the soil, agriculture and domestic runoff, soil leaching, industrial effluent, and discharges. The most prevalent chemical elements in nutrient runoff and stormwater are calcium, chloride, potassium, phosphates, and nitrates. It serves as both a drinking water quality indicator and a general chemical content measurement. Total dissolved solids are one of the most accurate indicators of nutrient availability for hydroponic plants. These enhanced levels may cause the following environmental setbacks: Displeasing color and odors, depletion of dissolved oxygen, laxative effect and distress to livestock. The concentrations of these dissolved ions in water change greatly across geological locations due to a lack of uniformity in mineral solubility. The World Health Organization recommends that the acceptable limit for human ingestion be less than 1000 ppm (Kang *et al.,* 2019), while the NEMA guideline value is 30 mg/L (Brossard, 2000). Muraguri (2016) reported on analysis of some borehole waters in Langata and Industrial area. It was found that in all those areas TDS were within the WHO limit.

2.6.1.1 Methods for measuring TDS.

Total dissolved solids can be measured in two ways: gravimetrically and conductively. The most precise method is gravimetric analysis. A thoroughly combined sample is filtered through a conventional glass fiber filter, and the filtrates evaporate to dryness in a weighted dish before drying to a consistent weight at 105°C. The rise in dish weight indicates the total dissolved solids. Despite its slowness and problems caused by low-boiling-point compounds that evaporate with the water, this method is widely considered to be the best. TDS is made up of dissolved anions, cautions and non-ionic species.

2.6.2 Electrical Conductivity (EC)

Electrical conductivity is a measure of water's ability to conduct electric current. The electrical conductivity of water increases with the concentration of dissolved salts. Water contains naturally occurring charged ions such as calcium, potassium, chloride, sulfate, and nitrate. These ions contribute to electrical conductivity. Water's ability to conduct a charge of electricity rises with temperature. As a result, electrical conductivity is constantly measured at 25 degrees Celsius as a reference temperature. The measurement unit is µS/cm. Electrical conductivity in a river might vary substantially, but it is always within acceptable limits. The normal values of a river range from 100 to 2000 µS/cm. The availability of dissolved ions in a certain sample lead to good electrical conductivity. Pure water does not conduct electricity due to the absence of ions; therefore, it acts as an insulator. Hence, the concentration of ions in the samples determines the electrical capability of certain samples. Increased ion concentration improves water's electrical conductivity. The allowed guideline limit for electrical conductivity by WHO standards in drinking water should be 1,500 µS/cm (Logesh *et al.*, 2015).

2.6.3 pH

The pH of a solution is a measurement that indicates whether it is acidic or alkaline. It is rated from 0 to 14 on a scale of 1 to 14. pH is formed by combining the mathematical symbol "p," which represents the negative logarithm, with the chemical sign "H," which represents hydrogen. pH is defined in technical terms as the negative logarithm of hydrogen ion activity. The pH of a substance is determined by the amount of hydrogen ions [H+] and hydroxyl ions [OH-] present. If the concentration of H+ exceeds that of OH-, the material is acidic and has a pH less than 7. When the amount of H+ and OH ions is equal, the pH is 7. If the OH exceeds the H+, the pH will be greater than 7. Free protons and hydroxyl ions are examples of acidic and basic components. Knowing one allows you to determine the other because the interaction between hydrogen and hydroxyl ions in a solution remains constant under specific conditions. Even though pH is, by definition, a selective measure of hydrogen ion activity, it also measures acidity and alkalinity. Because pH is a logarithmic function, a tenfold change in pH results in a tenfold change in hydrogen ion concentration. According to Gilca *et al*. (2020), monitoring pH is critical at all stages of life to ensure water disinfection and clarity. Because hydrogen is an operational water characteristic, its potential is regarded as critical. The pH range authorized by the NEMA Guideline value is 6.5–8.5 (Brossard, 2000). Very acidic and basic mediums can cause corrosion, particularly in water conveyance pipelines (Nas and Berktay, 2010).

2.6.4 Total Suspended solids

Total suspended solids refer to particles large enough to pass through the filter that separates them from the water. A thoroughly combined sample is filtered through a weighted standard glass fiber, and the residue on the filter is dried to a constant weight at 103–105 degrees Celsius. The increased weight of the filter shows the total amount of suspended solids. High concentrations of suspended particles can settle to the bottom of a stream or lake, covering aquatic creatures, eggs, and macro-invertebrate larvae. High quantities of suspended particles limit the efficiency of disinfection agents in drinking water. TSS, the world's most frequent pollutant, is the most common contaminant. Pollutant concentrations on solids are high because many organic and inorganic pollutants are adsorbed onto the soils. TSS acceptable levels should not exceed 1000 ppm, according to WHO regulations (Ayegbo *et al.,* 2021). The NEMA Guideline value is 30 mg/L.

2.7 Anions and cations in water

Enhanced levels of anions and cations in water for domestic consumption can influence the quality of the water. This can have a detrimental impact on human health.

2.7.1 Fluoride

Fluoride occupies around 0.3 g/kg of the earth's crust. It appears in a number of minerals. Fluoride-containing minerals are used in industry for a variety of purposes, including aluminum production. Fluoride can be released into the environment from phosphate-containing rocks. The phosphate deposits contain about 4% fluoride. In most cases, food appears to be the primary source of fluoride intake, with drinking water and toothpaste making minor contributions. In some areas, fluoride levels can be high, contributing to fluoride pollution (Abdeljawad, 2019). Drinking water with 1 ppm fluoride can prevent dental cavities, boost tooth strength, and have no detrimental effects on enamel. (Abdeljawad, 2019).

Water fluoridation has both advantages and disadvantages. The benefits of fluoride in water include improved oral health. Dental fluorosis is a developmental disorder of enamel that occurs during the formation of enamel. This is visible as white patches on the teeth, indicating dental fluorosis. According to studies, the main cause of dental fluorosis is ingesting fluoride through water or food. The production of aluminum is associated with inorganic fluoride-containing minerals (Choudhary *et al.*, 2019). According to WHO guidelines, the allowed levels of fluoride in drinking water is 1.5 mg/L (Sarvaiya *et al.,* 2012) while that of NEMA is also 1.5 mg/L (Brossard, 2000).

Food is the chief source of fluoride accumulation in most cases, with minor additions from toothpaste and drinking water. These studies clearly show that fluoride has the greatest impact on skeletal tissues (bones and teeth). Fluoride is a major cause of morbidity in many areas with high fluoride exposure. Low concentrations protect against dental caries, especially in children (Mukherjee & Singh, 2018).

2.7.2 Chloride

Chloride in drinking water is derived from sources that are natural, such as sewage discharge, industrial effluents, urban runoff, and saltwater intrusion. Food is the most common source of human chloride exposure, and it is usually ingested in larger proportions than in drinking water. Excessive chloride levels accelerate the corrosion of metals in distribution networks. Concentrations of chloride greater than 250 mg/l have been shown to produce a perceptible taste in water. There are various other man-made salt sources that contributes to increased chloride levels. The usage of sodium chloride and calcium chloride on roadways in temperate climates contributes greatly to elevated chloride levels. Chloride levels in a community's wastewater are usually increased by chlorinated water and sodium chloride added to water softeners. The level of chloride in drinking water shouldn't go above 250 mg/L, according to WHO (2019). Chloride is a necessary ingredient for the body's key extracellular actions. It is a highly adaptable ion that easily travels across cell membranes, contributing to correct osmotic pressure, water balance, and acid-base balance. Until lately, it was considered that the chloride ion's physiological function was mostly that of a passive counterion. Several recent studies have suggested that the chloride ion plays a more active and autonomous part in renal function, nutrition and neurophysiology. It has been proposed that chloride has a role in sodium-sensitive hypertension. According to the evidence, a hypertensive effect requires both sodium and chloride ions. Despite the fact that red blood cells from hypertensive humans have altered chloride processing, chloride does not appear to promote hypertension in rats. Despite research into the function of sodium in hypertension, there is no indication that high levels of chloride are any more hazardous than high sodium content.

2.7.3 Ammonia

Ammonia enters the environment through metabolic, agricultural, and industrial processes, as well as chloramine disinfection. Natural levels in groundwater and surface water are typically less than 0.2 mg/l. Ground water undergoing an anaerobic process may contain up to 3 mg/L. Animal excrement may increase the concentration of ammonia. The high percentage of ammonia in water indicates bacterial sewage and animal waste pollution. There is no proposed health-based ammonia guideline value. However, its presence can reduce disinfection efficiency (Kumar *et al.*, 2022). Toxicological effects are only observed at doses greater than 200 mg/kg body weight (Rietjens *et al.*, 2022). As stipulated by WHO (2019), the maximum levels of ammonia in water used for drinking is 2 mg/L. On the other hand, NEMA guideline value is 0.5 mg/L (Brossard, 2000).

2.7.4 Nitrate

The nitrogen cycle produces nitrate and nitrite ions. Nitrate is largely utilized in inorganic fertilizers, but sodium nitrite has a wide range of applications in food preservation, particularly in cured meats. The levels of nitrate in groundwater and surface water are typically low, but they can rise due to leaching, runoff, or pollution from human or animal waste, which comes from ammonia oxidation. WHO (2019) recommended nitrate levels in drinking water at 50 mg/L; however, NEMA recommends 10 mg/L. (Brossard, 2000).

2.8 Total Coliforms of bacteria

All warm-blooded creatures, including humans, excrete coliform bacteria. Coliform bacteria are unlikely to cause harm. The presence of pathogens (disease-causing organisms) in drinking water can cause human illness. The great majority of microorganisms that may harm water systems are found in human or animal waste. It is expensive to test drinking water for every possible pathogen. Coliform bacteria testing is easy and inexpensive. If coliform bacteria are discovered in a water sample, the source of the contamination should be identified, and safe drinking water restored. The presence of pathogens suggests a decline in drinking water quality. Total coliforms are a large class of bacteria. Total coliforms seen in feces are referred to as fecal coliforms. *E. coli* belongs to the fecal coliform subgroup. Drinking water samples are tested to determine total coliform levels. If total coliform is found, then one must look for *E. coli* as well. Total coliform bacteria are common in the environment (soil and plants) and are generally harmless. If total coliform bacteria are present in drinking water, their source is most likely ecological, with fecal contamination unlikely. In contrast, polluted settings may allow diseases to infiltrate the system. It is critical to identify and remove the source of contamination. Fecal coliform bacteria can be found in both human and animal intestines. *E. coli* belongs to the fecal coliform group. The overwhelming majority of E. coli bacteria are harmless and can be found in the intestines of both humans and warm-blooded animals. However, some strains can make people ill. *E. coli* in drinking water is usually a sign of recent fecal contamination; therefore, pathogens are more likely to be present (Mohsen & Dughial, 2020).

2.9 *Escherichia coli*

Fecal coliforms are single-celled microorganisms, always linked with fecal impurities in water. Escherichia coli is a thermo-tolerant coliform bacterium that contains the enzymes β-glucuronidase, β-galactosidase and hydrolyzed 4-methyl-umbelliferyl-β-D-glucoronidase. It is expected that Escherichia coli is found in up to 95% of human waste. Normally, in the typical water environment, Escherichia coli cannot increase and therefore is not used as an indicator for fecal contamination. Aquatic microbiota plays a significant role in the sustainability of the natural ecosystem (Jang et al., 2017). It can, however, endanger the lives of animals and humans by transporting pathogens that cause waterborne diseases. Total coliform, *E. coli* and fecal coliform can be used to determine the quality of drinking water. The introduction of pathogens into the gastrointestinal tract of mammals is referred to as fecal pollution of water. It is detected using fecal indicator bacteria (Zaghloul *et al.*, 2020).

Water pollution is thought to spread pathogenic diseases such as typhoid and cholera. Ingestion of pathogenic organisms or infection of the nasal cavity, skin, ears, and eyes allows pathogenic organisms to enter the gastrointestinal tract. Vomiting, diarrhea, anemia, hepatitis, amoebic dysentery and respiratory diseases are some of the health effects associated with fecal pollution.

The presence of Escherichia coli can produce nausea, diarrhea, and other problems in society, including for children and minors. Hemorrhagic Colitis is an acute disease caused by *Escherichia coli*. Hemorrhagic Colitis illness can cause watery diarrhea, lower intestinal bleeding, fever, vomiting and serious abdominal cramps, while in some circumstances renal disorder or hemolytic uremic syndrome can occur. These troubles can be hazardous for minors, but not for the elderly. Escherichia coli is scattered by fecal-oral consumption through drinking of water, swimming, or fishing (PCRWR, 2007). Guidelines for *Escherichia coli* is 0 CFU/100 mL for safe drinking water and the NEMA guideline value is also Nil/100 mL (Brossard, 2000).

2.10 Instrumentation techniques

Various methods are used to analyze the various samples under investigation.

Described below are key instruments used in the analysis of water samples.

2.10.1 Atomic absorption spectroscopy (AAS) and its working principle

Atomic absorption spectroscopy (AAS) is a useful analytical technique that uses radiation absorption by atoms. Almost all metallic elements may be directly detected with high precision, exact quantification and low limits of detection.

Fig 2.1 shows the AAS spectrophotometer.

Fig 2.1: Schematic diagram of atomic absorption spectrophotometer

In the ground state, each element's atoms have a distinct electron configuration. These atoms can absorb light energy quanta if the energy precisely matches the energy associated with any of the atom's allowable electronic transitions. Energy is absorbed by atoms in an excited state. Their electrons absorb specific quantities of energy, rise to higher energy levels, and then return to the ground state, producing light photons. Because it corresponds to the energy released when electrons return to their ground state, this light has a definite wavelength. This wavelength corresponds to the energy of one of the permitted transitions in the atom. As a result, the light emitted produces an emission spectrum made up of certain wavelengths that may be seen as Fraunhofer Lines (Brossard, 2000).

Fig 2.2 illustrates the working principle of the AAS.

The absorbance is directly proportional to the concentration of the analyte and the pathlength traversed. The equation is shown below.

$A = \varepsilon CL$

Where:

A= Absorbance

ε = molar absorption coefficient $M^{-1}\ cm^{-1}$

C=molar concentration M

L= optical path length

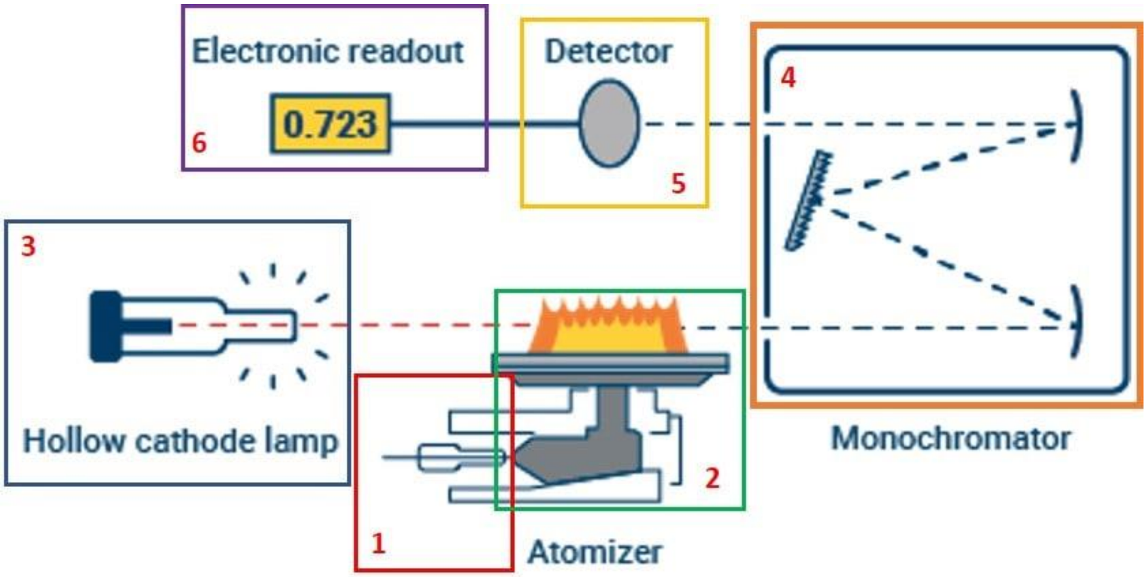

Fig 2.2: Illustration of the working principle of AAS

Source: (Lagalante, 2004)

Atomic absorption spectrometry (AAS) detects elements in liquid or solid samples by employing a light source to emit certain wavelengths of electromagnetic radiation. Individual elements absorb wavelengths in different ways, which are assessed in comparison to standards. In essence, AAS makes use of the varying wavelengths of radiation absorbed by different atoms. Analytes are first atomized in AAS before being emitted and recorded at various wavelengths. Excitation occurs when electrons in atoms go up one energy level after receiving a specific amount of energy. This energy corresponds to the element's specific wavelength. Specific components are then identified (Majeed *et al.*, 2021).

2.10.2 Ultraviolet-visible spectrophotometer

This apparatus uses a light source to illuminate a sample in the ultraviolet-to-visible wavelength range (190-900 nm). The sensor then determines the amount of light the sample absorbs, transmits, and reflects at each wavelength. A precise amount of energy is necessary to move electrons in a substance to a higher energy state, which is known as absorption.

Fig 2.3 shows a ultraviolet-visible (UV-VIS) instrument.

Fig 2.3: Ultraviolet-visible instrument

Source: Department of Chemistry, Analytical Laboratory, University of Nairobi

A UV-VIS spectrophotometer operates by sending light at a certain wavelength interval via a solvent-filled cell and then through a photoelectric cell. This cell turns radiant radiation into electrical energy, which is measured using a galvanometer. The absorbance spectra of a substance in solution can be obtained using a UV-visible spectrophotometer. Spectroscopy detects the absorbance of light energy or electromagnetic radiation that excites electrons from a chemical or material's ground state to its first singlet excited state. A single xenon lamp is frequently employed as a high-intensity light source in ultraviolet and ultraviolet-visible bands. Other lamps used are halogen and tungsten lamps for visible light. Deuterium lamps are mostly used as a source of ultraviolet light. The light then passes through a sample and another through a reference sample.

Fig 2.4 is a diagram of the components of an ultraviolet-visible spectrophotometer.

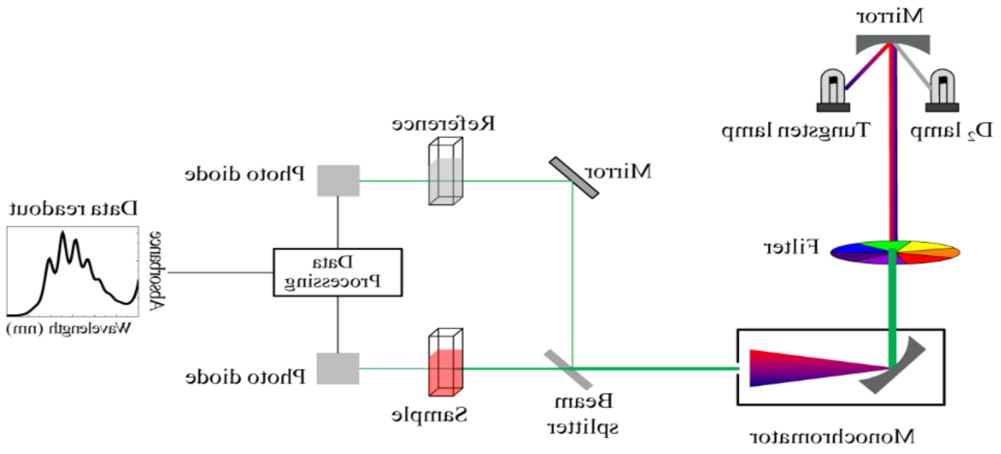

Fig 2.4: The components of an ultraviolet-visible spectrophotometer

Source: (Verma & Mishra, 2018)

There are two approaches to determining the concentration of an unknown solution. The first approach entails developing a standard calibration curve, which is a graph of absorbance against concentration for a variety of standard solutions. The absorbance of the unknown solution is then compared with that of the standard. The second way is to use Beer's law, which states that a solution's absorbance is proportional to the concentration of the absorbing species and the route length. Thus, ultraviolet-visible spectroscopy can be used to calculate the amount of an analyte in a solution for a particular path length (Verma & Mishra, 2018).

2.10.3 Fluoride ion selective electrode

The Orion fluoride ion selective electrode (ISE) is one of the ways used to assess total ionic strength adjustment buffer (TISAB), a fluoride-adjusted buffer that offers consistent background ionic strength, de-complexes fluoride ions and modifies solution pH (Thermo Fisher Scientific, 2016).

Fig 2.5 shows a fluoride ion selective electrode.

Fig 2.5: Fluoride ion selective electrode

The fluoride-ion selective electrode consists of a single crystal of lanthanum fluoride that serves as the membrane and is attached to a glass or epoxy body. Only fluoride ions travel through the ionic conductor crystal. When the membrane encounters a solution containing fluoride ions, an electric potential is formed across it. This electrode potential is compared to a continuous reference potential using an ISE amplifier and a computer connection.

The Nernst equation gives the level of fluoride ions in the solution corresponding to the measured potential $E = E_0 - S\log x$

Where E= measured electrode potential

E_0 = reference potential

S= electrode slope

X= concentration of fluoride ions a solution

CHAPTER THREE

MATERIAL AND METHODS

3.1 Study area and sampling points

The research was carried out in five regions of Nairobi County (Fig 3.1). The areas were located at longitude 36° 49′50.328″E to 36°54′19.629″E and latitude 1°15'26.386″S to 1°19'21.149"S. Water samples were collected in December 2021 from water distribution tankers (Water Bowsers) and boreholes in five regions in Nairobi. The samples were analyzed in the Department of Chemistry, the University of Nairobi laboratories. The areas covered were Dandora, Kayole, Eastleigh, Pangani, South B and South C.

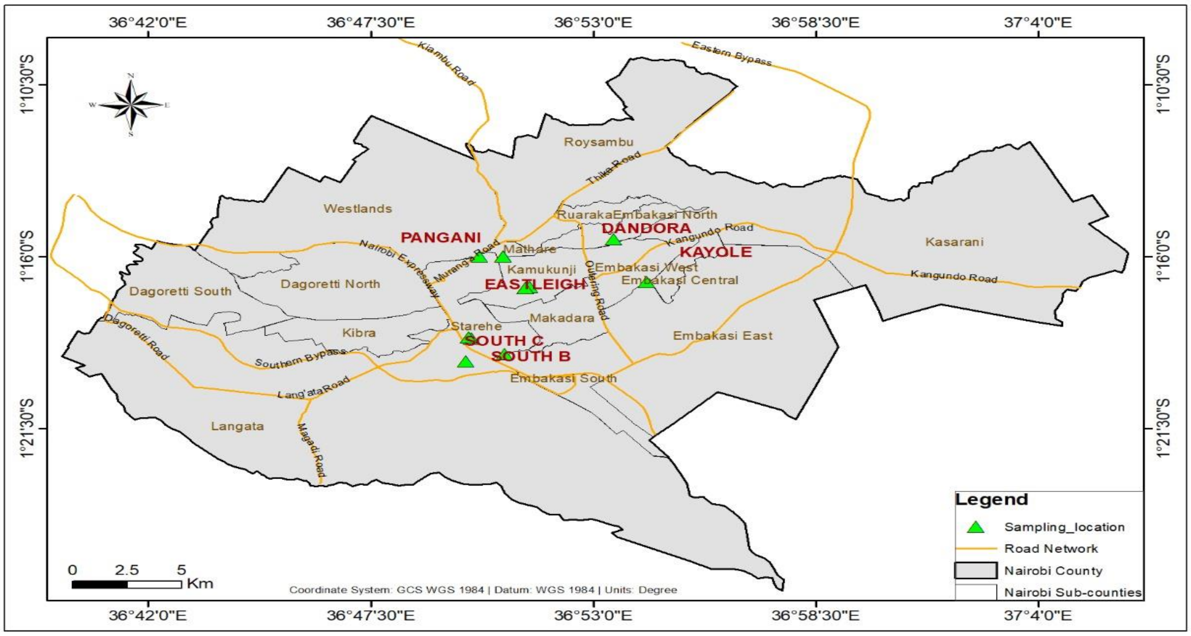

Fig 3.1: Location of the sampling points in the Nairobi region

During sample collection, the following were taken into account: characteristics of the water sources, population density near the water intake and the access routes. The mapping of the various sites was done using GPS to determine their spatial location and later used for GIS evaluation. Groundwater sampling was carried out in accordance with the groundwater sampling guidelines (Keith, 2017). Water samples were collected from designated boreholes in triplicate using sterilized plastic bottles. Sampling of water tankers were also done in triplicate either at the sampling borehole point or any other place within the same sampling region. The collected samples were transported in controlled conditions in cooler boxes to Chiromo Campus, Department of Chemistry laboratory. These were stored in appropriate conditions while awaiting analysis. Some parameters which fluctuate with different environmental conditions were measured on site (Barsegech, 2014). A geographical information system was used in mapping of the area. The depth of the boreholes at Dandora, Pangani, Eastleigh, South B, South C and Kayole ranged from 200-400 m.

3.2 Coordinates of the sampling points in Nairobi County

Table 3.1 shows various sampling points and their longitudes and latitudes.

Table 3.1: Sampling points with the corresponding GPS coordinates

Sampling point	Longitude	Latitude
Dandora	E 36°53'30.1434"	S 1°15'26.38692"
Kayole	E 36°54'19.62936"	S 1°16'48.93888"
Eastleigh	E 36°51'19.42236"	S 1°16'59.87172"
Pangani	E 36°50'22.5006"	S 1°16'4.5858"
South C	E 36°49'50.32848	S 1°19'21.14904"
South B	E 36°49'55.35588"	S 1°18'34.73676"

3.3 Chemicals used in analysis.

Potassium chromate, sodium chloride, silver nitrate, Nessler's reagent, sodium hydroxide, borate buffer, hydrochloric acid, ammonium chloride, phenol sulphonic acid, potassium nitrate, ammonium hydroxide, nitric acid, CTDA (trans-1,2-diaminocyclohexane N,N,N´,N´-tetraacetic acid), sodium fluoride and glacial acetic acid were used in the analysis of water samples.

3.4 Apparatus and Equipment used for analysis.

Atomic absorption spectrophotometer (AAS-6300, Shimadzu, Japan), EC/ pH /TDS multi parameter meter (model 15, Fisher Scientific), ultraviolet-visible spectrophotometer (UV-1700, Shimadzu, Japan), pH meter (model MI306), fluoride ion-selective electrode (SN. X28312), analytical balance (No.C12970), hot plate, burette, beakers, volumetric flasks, conical flasks and filter papers no 4.

3.5 Collection and storage of samples

In sampling water from each borehole or Tanker, three 1-litre plastic bottles were first cleaned with soap and thereafter sterilized with distilled water. The plastic bottles were then filled to the brim and caped. The samples were then placed in a cooler box with ice for immediate delivery to the Department of chemistry laboratory, University of Nairobi. Some physical parameters like pH were determined on site. The rest were determined in the laboratory. Bacterial measurement of *E-coli* and total coliforms were also carried out on the samples.

3.6 Physical-chemical parameters determination

The physical-chemical parameters studied included total dissolved solids, total suspended solids, electrical conductivity, pH, fluoride, chloride, ammonia and nitrate.

3.6.1 Total dissolved solids (TDS)

Total dissolved solids determination was done through the gravimetric method. The beakers were cleaned and dried for one-hour at 105 °**C** before being placed in a desiccant to cool slowly before taking the weight of the cooled beakers. The process of drying was done three times until a constant weight of the coded beakers were achieved. Using a measuring cylinder, 100 mL of filtered sample was placed in the coded beakers, dried for 2 hours in an oven at 105°C to ensure all the water evaporated, and then placed in a desiccator to cool. An analytical balance was used to weigh the beakers and the processes of drying were repeated to ensure a constant weight was achieved before determining the weight difference. The procedure was repeated for all water samples (Gilmore & Luong, 2016).

3.6.2 Total Suspended Solids (TSS)

A sample (100 mL) was passed through a weighted, standardized glass fiber filter, and the residue on the filter was dried to a constant weight at 103–105 °C. The rise in filter weight indicated the total amount of suspended particles. This was then converted into milligrams per liter.

3.6.3 Determination of electrical conductivity and pH

At room temperature (25°C), the EC and pH meters were calibrated with various calibration standards and confirmed with known solution concentrations. pH calibration was carried out using a buffer solution with pH values of 4 and 10. Initially, the electrode was submerged in a pH-7 buffer solution. After about a minute, the measurement stabilized, and the reading was recorded. The electrode was then cleaned with deionized water and submerged in a pH-4 buffer solution. These processes were repeated until a consistent measurement was obtained. A beaker was filled with 20 mL of borehole or tanker water, and the pH electrode was dipped into it. A reading was then taken.

In the calibration of electrical conductivity meter, the electrode was placed in the 0.001 M KCl conductivity buffer solution. This buffer solution gives a conductivity value of 146.9 μS/cm. After approximately one minute the measurement was stable and the reading was taken. This step was repeated until a reliable measurement was obtained. 20 mL of the borehole water sample or Tanker water sample was placed in a beaker and the electrode placed in the sample. The reading was then taken. The pH/EC meter used was Hanna model 08655183.

3.6.4 Determination of fluoride

3.6.4.1 Apparatus

An ion selective electrode for fluoride ion (Thermo Scientific-Orion Star Series) coupled with a reference electrode Ag/AgCl was used for fluoride measurement.

3.6.4.2 Chemicals used

CTDA (trans-1,2-diaminocyclohexane N,N,N´,N´-tetra acetic acid), sodium chloride, sodium fluoride, sodium hydroxide, and glacial acetic acid were graded as analytical reagents. The reagents were bought from Merck (Germany) and Kobian Kenya Limited.

3.6.4.3 Sampling

Water was gathered from chosen locations in Nairobi County at three sample points for boreholes and tankers. These were then placed in a cooler box and delivered to the Department of Chemistry laboratory. The samples were kept in plastic bottles composed of polyethylene terephthalate (Massoud *et al.*, 2009).

3.6.4.4 Fluoride standards and analysis

A variety of fluoride standards, ranging from 0.1 to 5.0 mg/L, were developed. These standards were created from sodium fluoride and deionized water. The total ionic strength adjusting buffer II (TISAB II) was prepared by combining 4 g CDTA, 57 mL glacial acetic acid, and 58 g NaCl in 500 mL deionized water. To adjust the pH to 5-5.5, a few drops of 5M NaOH (200 g/L) was added and diluted to 1 liter. This range of fluoride ion concentrations ensured that the meter was calibrated correctly for quantitative fluoride measurements in water samples.

3.6.4.5 Fluoride determination

A sample bottle was obtained, and 10 mL of the sample was mixed with 10 mL of TISAB II; then, the fluoride levels of all the samples were evaluated in duplicate using a fluoride ion selective electrode (Onipe *et al.*, 2021).

3.6.5 Determination of chloride

The chloride solution containing chromate was titrated with silver nitrate. Silver chromate precipitated and at the end point, red silver chromate was formed. The following reagents were made to determine chloride concentration:

3.6.5.1 Preparation of 0.25M potassium chromate solution

1.0g of K_2CrO_4 was placed in a 20-mL volumetric flask. Distilled water was then added with shaking and the volume made to the mark. This then gave 5 % potassium chromate solution.

3.6.5.2 preparation of 0.01M sodium chloride

0.5843g of sodium chloride was taken and placed in a 100-mL volumetric flask. That was followed by topping up of solution with deionized water with shaking to the mark.

3.6.5.3 Standardization of silver nitrate ($AgNO_3$) solution with 0.1M sodium chloride (NaCl)

16.987g of silver nitrate was put into a 500-mL volumetric flask. Deionized water was then added with shaking to the mark. Titration of 10 mL of sodium chloride solution with silver nitrate was done using a chromate indicator until the end point (red color). The process of titration was continued four times to ensure precision was achieved and the average titer was calculated.

3.6.5.4 Chloride concentration determination

25 mL of the sample was taken and placed into a porcelain dish. 1 mL of 0.25 M potassium chromate (5 % potassium chromate) was then added into the dish and titrated with standard silver nitrate solution until the slightest reddish color (due to the excess formation of silver chromate) appeared.

3.6.6 Ammonia

The following reagents were prepared to determine the ammonia concentration in the borehole and tanker water samples: Nessler's reagent: 100 g mercury I chloride (HgI) and 70 g potassium chloride (KI) were placed in a 1000-mL volume flask, and a small volume of distilled water was added to dissolve the solutes. A chilled solution of 160 g of sodium hydroxide (NaOH) diluted in 500 mL of filtered water in a 1-liter volumetric flask was progressively added to this. This was then diluted with distilled water to a liter and stored away from sunlight.

Borate Buffer: A measured volume of 0.1M sodium hydroxide solution (88 mL) was added to 0.5 liters of 0.025 M sodium tetraborate heptahydrate in a 1-liter volumetric flask (borate was made by weighing 9.5g of $Na_2B_4O_7.10H_2O$ dissolved and diluted with distilled water in a 1-litre volumetric flask and made up to the mark).

3.6.6.1 Preparation of the sample

25 mL of distilled water was added to a volumetric flask containing boiling chips (previously treated with diluted NaOH). After adjusting the pH to 9.5 with 0.1M NaOH, a few drops of 1.25M borate buffer was added, followed by 15 mL of distilled water for a period of 2 to 3 minutes, and finally 2.5 mL of 1M HCl was added. Because of the hydrochloric acid solution level, the condenser tip was extended. After diluting the distillate to 25 mL with distilled water, an aliquot was Nesslerized to estimate the concentration of ammonia in the sample.

3.6.6.2 Ammonium chloride stock solution preparation

2.9871 g of ammonium chloride (NH_4Cl) was dissolved in distilled water and filled to the mark in a 1-liter volumetric flask to produce ammonium ions (NH_4^+). Working standards were prepared using Nessler's reagent, and serial dilutions were performed. The absorbance values for the standards were measured. The samples were examined with a 425-nanometer ultraviolet-visible spectrophotometer.

3.6.7 Nitrate

Nitrate ion concentrations in borehole and tanker water samples were determined using the phenol-sulfonic acid procedure. In an alkaline solution, nitrate reacted with phenol sulfonic acid to form a yellow nitro derivative. The yellow tint was created by a change in the nitro derivative's structure. According to Beer's rule, the color intensity of a water sample is proportional to its nitrate (NO_3) concentration. The concentration of nitrate was determined using an ultraviolet-visible spectrophotometer (Shah *et al.*, 2019).

3.6.7.1 Preparation of 1000 ppm potassium nitrate standard

3.5 g of potassium nitrate was weighed using an analytical balance and dried in a 105°C oven before being stored in a desiccator to cool. 1.65 g of potassium nitrate was dissolved in 10 mL of water before being diluted to 1000 mL to give 1000 ppm. Serial dilutions were performed using the dilution formula C1V1 =C2V2.

3.6.7.2 preparation of 100 ppm of potassium nitrate stock solution.

10 mL of 1000 ppm potassium nitrate solution was taken and placed into a 100-mL volumetric flask. This was then made to volume with distilled water. This gave 100 ppm solution. 100 ppm stock solution was used to make 1ppm, 2 ppm, 4 ppm, 6 ppm and 8 ppm of potassium nitrate. 25 mL of 1 ppm of potassium nitrate was added to a 100-mL beaker. 2mL of phenol sulphonic acid and 10 mL of concentrated ammonium hydroxide were added to the beaker with stirring. Repeat preparations were done for 2 ppm, 4 ppm, 6 ppm and 8 ppm. The samples were thereafter measured using an Ultraviolet-Visible spectrophotometer set at a wavelength of 410 nm.

3.6.7.3 Preparation of the sample

The sample was prepared by pipetting 25 mL of water sample (borehole or tanker) into a 150 mL beaker. 2 mL of phenol sulfonic acid was added and 10 mL of concentrated ammonium hydroxide was also added with care. A blank was prepared by adding 25 mL of distilled water into a 150-mL beaker, 2 mL of phenol sulphonic acid and 10 mL of ammonium hydroxide were added. Ultraviolet-Visible spectrophotometer was then used to measure the absorbance.

3.7 Determination of heavy metals

Atomic Absorption spectrophotometer was used to determine heavy metal concentrations.

3.7.1 Procedure for digestion of water samples

The aqua-regia preparation was done by adding 75 mL of hydrochloric acid and 25 mL of nitric acid. This was done in a fume chamber. 25 mL of nitric acid was slowly added to 75 mL of hydrochloric acid. The aqua-regia is unstable and therefore, it was prepared and used immediately. In a 200-mL conical flask, 50 mL of water sample was added followed by 10 mL of aqua-regia solution. This was then stirred for complete mixing. 1 mL of perchloric acid was added to each of the samples. The flask was then heated to boiling on a hot plate magnetic stirrer until the sample was reduced to about 15 mL and then allowed to cool. Filtration was carried out, and the filtrate transferred to a 50 mL volumetric flask. Distilled water was then added to volume. A blank was also prepared by adding 50 mL of distilled water and mixing with 10 mL aqua-regia and 1mL of perchloric acid.

3.7.2 Analysis of samples using Atomic Absorption Spectrophotometer

Calibration standards were prepared for each metal under study. These standards were then aspirated, and the corresponding absorbance recorded (García & Báez, 2012). A blank was also aspirated and the difference of the standards absorbance and the blank recorded. The difference gave the actual absorbance of the corresponding standard. The absorbance versus concentration of the standards was therefore used to give a straight-line equation. The sample was then aspirated and from the absorbance, the corresponding concentration was then calculated.

3.8 *Escherichia coli*

3.8.1 sample collection, preservation and storage

Water samples were taken using sterile polypropylene containers with leak-proof lids. The residual chloride in drinking water (or chlorinated effluent) samples was neutralized with sodium thiosulfate (1 mL of a 10% solution) at the time of collection.

3.8.2 Storage temperature and handling conditions

During transit to the laboratory, the samples were kept refrigerated at 1-4°C. Insulated containers were used to ensure proper temperature maintenance during storage. During transit or storage, bottles were kept from becoming completely immersed in water from melted ice.

3.8.3 Holding Time Limitations

The samples were examined as soon as possible after collection. Drinking water samples were analyzed within 30 hours of collection. Filter control: Place one or more membrane filters onto Tryptic Soy Agar (TSA) plates and incubated for 24 hours at 35°C. The absence of growth indicated sterility in the filters.

3.8.4 Phosphate-buffered dilution water controls

Before starting the sample filtrations, 50 mL of sterile dilution water was filtered, followed by another 50 mL of dilution water once the filtrations were finished. The filters have been set on TSA plates and incubated for 24 hours at 35°C. The absence of growth indicated sterility in the dilution water.

3.8.5 Agar or Broth Controls: Before starting the sample filtrations, 50 mL of sterile dilution water was filtered, followed by another 50 mL of dilution water once the filtrations were finished. The filters were placed on TSA plates and incubated for 24 hours at 35°C. The absence of growth indicated sterility in the dilution water.

3.8.6 Procedure

Total coliforms (TC) are bacteria that produce fluorescent colonies when exposed to longwave ultraviolet light (366nm) after initial incubation on MI agar or broth. Fluorescent colonies can be totally blue, white (except for E. coli), or blue green (E. coli), with fluorescent halos visible around the blue edges. This experiment used premade MI agar or MI broth, as well as TSA. If dishes were prepared ahead of time and stored in the refrigerator, they were removed and allowed to warm to room temperature. The crystals that had formed on MI agar after chilling dissipated when the plates warmed up. The funnel was filled with approximately 30 mL of sterile dilution water. The sample container was aggressively shaken twenty-five times. A hundred milliliters of water were measured and put into the funnel. The suction was turned on and left running while the funnel was cleaned twice with approximately 30 mL of sterile dilution water. The funnel was taken from the filter unit's base. In between filtrations, the funnel was held and cleaned using a germicidal UV (254 nm) light box. To decontaminate the funnel, at least 2 minutes of exposure time were required. UV irradiation was kept away from the eyes via glasses, goggles, or an enclosed UV chamber. Using flamed forceps, gently lift the membrane filter at its edge and set it on the filter grid-side-up MI agar or MI broth pad plates. To prevent air bubbles from forming between the membrane filter and the underlying agar or pad, the filter was rolled onto it. The forceps were designed to run around the outside edge of the filter, contacting the agar or pad. If there were any unwetted areas created by air bubbles, the membrane was adjusted. The agar petri dish was inverted, and the plate was left at 35°C for 24 hours. Pad plates containing MI broth were incubated grid-side up at 35°C for 24 hours. All blue colonies on each MI plate were counted and documented in either normal or ambient illumination conditions. This was the count of E. coli. Each MI plate was exposed to longwave UV light (366nm), and all fluorescent colonies were counted: blue/green, fluorescent E. coli, blue/white, fluorescent TC other than E. coli, and blue/green with fluorescent borders (containing E. coli). Any blue, non-fluorescent colonies found on the same plate were included in the TC count.

3.8.7 Data Analysis and calculations

E. coli /100 mL = {Number of blue colonies/ volumes of sample filtered (mL)} × 100

TC/100 mL = 100*{Number of fluorescent colonies + Number of blue, non-fluorescent colonies (if any) } /volume of sample filtered (mL).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical–chemical values of borehole water samples

The results of the values of the physical-chemical parameters of water samples in boreholes is presented in Table 4.1.

Table 4.1: The values of physical-chemical parameters of borehole water from Dandora, Kayole, Eastleigh, Pangani and South B sampling sites

coded Sampling site	physical - chemical values of parameters in boreholes			
	pH	EC (µS/cm)	TDS (mg/L)	TSS (mg/L)
DB	8.20±0.00	241.00±10.00	31.50±0.71	9.50±0.71
KB1	8.06±0.06	230.00±0.50	101.00±1.41	11.00±0.00
KB2	7.50±0.04	473.30±5.60	73.00±0.70	7.00±0.15
PB1	7.70±0.06	246.60±5.80	93.00±1.23	6.00±0.14
PB2	7.80±0.20	236.60±4.61	175.50±1.30	10.5±0.74
PB3	7.80±0.31	256.6±3.60	41.50±0.62	2.00±0.03
EB1	7.80±0.10	260.00±10.00	30.00±0.12	10.00±0.18
EB2	7.90±0.13	260.00±8.17	171.50±2.30	10.00±0.22
EB3	7.50±0.19	260.00±17.41	20.50±0.91	9.00±1.11
SBB1	8.00±0.10	260.00±2.40	163.50±1.60	10.00±0.20
SBB2	8.03±0.06	260.00±4.38	51.50±0.29	8.00±0.26
SBB3	7.90±0.22	260.00±10.00	40.50±0.40	5.00±0.05
NEMA	6.5-8.5	no set guideline	1200	30
WHO	6.5-8.5	2500	1000	NIL
KEBS	6.5-8.5	no set guideline	1500	NIL

Key: DB= Dandora Borehole; KB1, KB2= Kayole Boreholes (1 and 2); PB1, PB2, PB3= Pangani Boreholes (1,2, and3); EB1, EB2 and EB3= Eastleigh boreholes (1,2 and 3); SBB1,SBB 2,SBB 3 = South B Boreholes (1,2 and 3); ±SD = standard deviation

According to Table 4.1, the values of the physical- chemical parameters in borehole water samples ranged from 7.5 to 8.2. Kanyole borehole 2 (KB2) had the lowest pH value, whereas Dandora boreholes, South C and South B had the highest values. The recommended pH guideline values of WHO, KEBS and NEMA in drinking water was in the range of 6.5–8.5. The pH of all boreholes was within the guideline established by several organizations (Islam *et al.*, 2017; Sila, 2019; Wamalwa & Mutia, 2014); the pH value was within the NEMA/WHO/KEBS guideline limit in drinking water.

A histogram whose pH values were derived from Table 4.1 is shown in Fig. 4.1. It compares all pH values in borehole waters at various sites in Nairobi County.

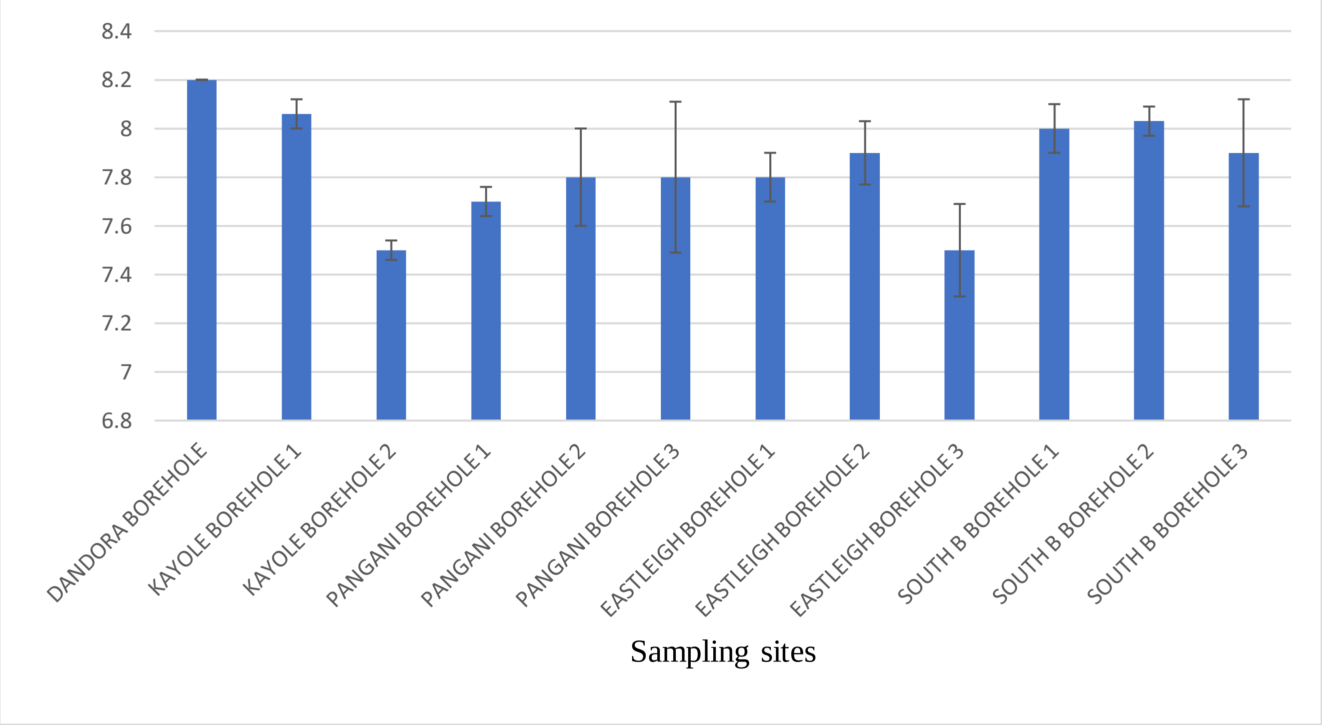

Fig 4.1: A histogram of values of pH of boreholes of some sites in Nairobi County

The electrical conductivity values in borehole water ranged from 230 to 473.3 µS/cm.The largest and lowest values of electrical conductivity were reported at site KB1and KB2 respectively.The readings varied from 230 ± 0.5 to 473.3 ± 5.6 µS/cm. According to WHO regulations, the permissible limits for electrical conductivity in drinking water should be not be more than 2,500 µS/cm. There is no KEBS guideline value. Electrical conductivity of all boreholes values were within WHO acceptable limit (Logesh et al., 2015; Sila, 2019).

A histogram whose values of electrical conductivity were derived from Table 4.1 is shown in Fig. 4.2. It compares all the electrical conductivity values in borehole waters at various sites in Nairobi County.

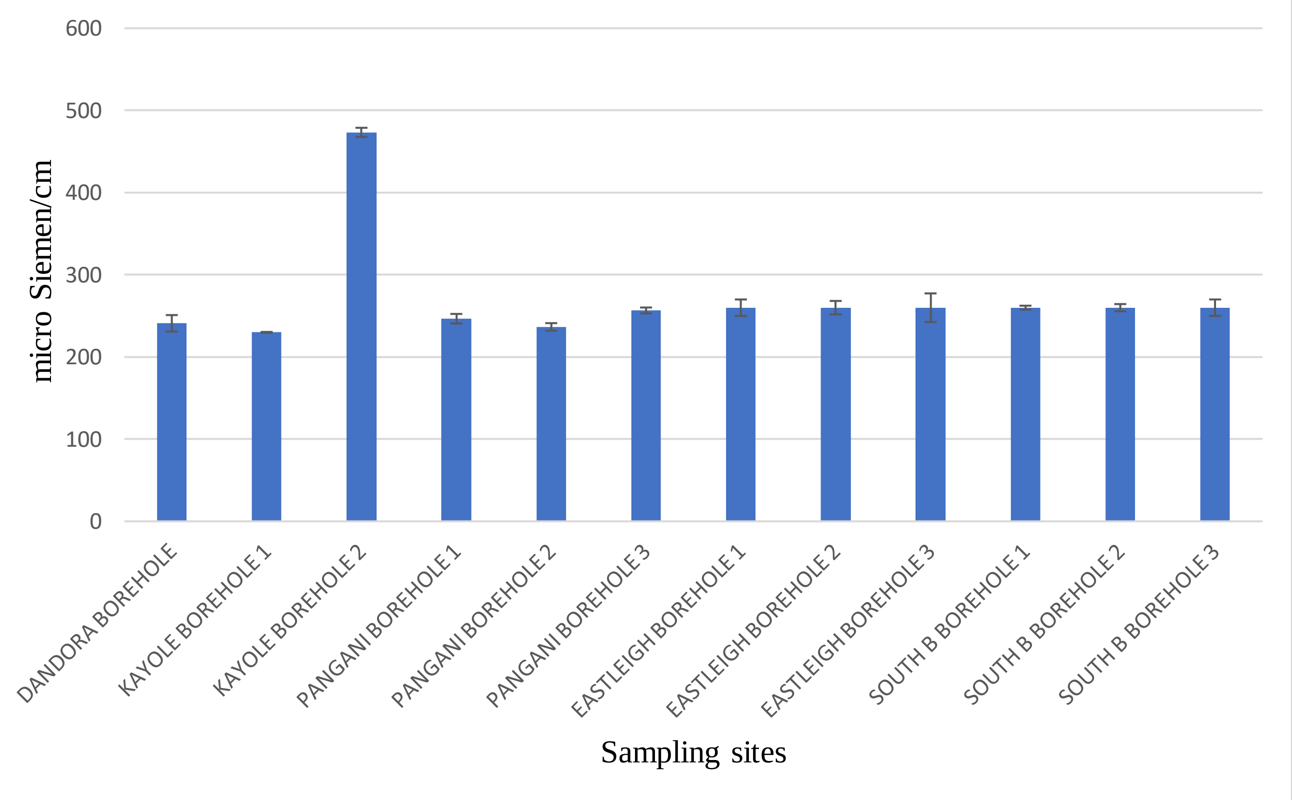

Fig 4.2: A histogram of values of Electrical conductivity of boreholes of some sites in Nairobi County

TDS levels were determined to be between 20 and 175 ppm. TDS concentrations in borehole water samples were highest in PB2 and lowest in EB3. The concentrations ranged from 20.5 to 175.50 mg/L. The WHO recommends that the acceptable level for human consumption be not more than 1000 ppm. The NEMA and KEBS maximum guideline values in Kenya are 1200 mg/L and 1500 mg/L respectively. All borehole results complied with WHO, KEBS and NEMA guidelines (Kang *et al.*, 2019; Wekesa & Otieno, 2022).

A histogram whose values of total dissolved solids were derived from Table 4.1 is shown in Fig. 4.3. It compared all the TDS values in borehole waters at various sites in Nairobi County..

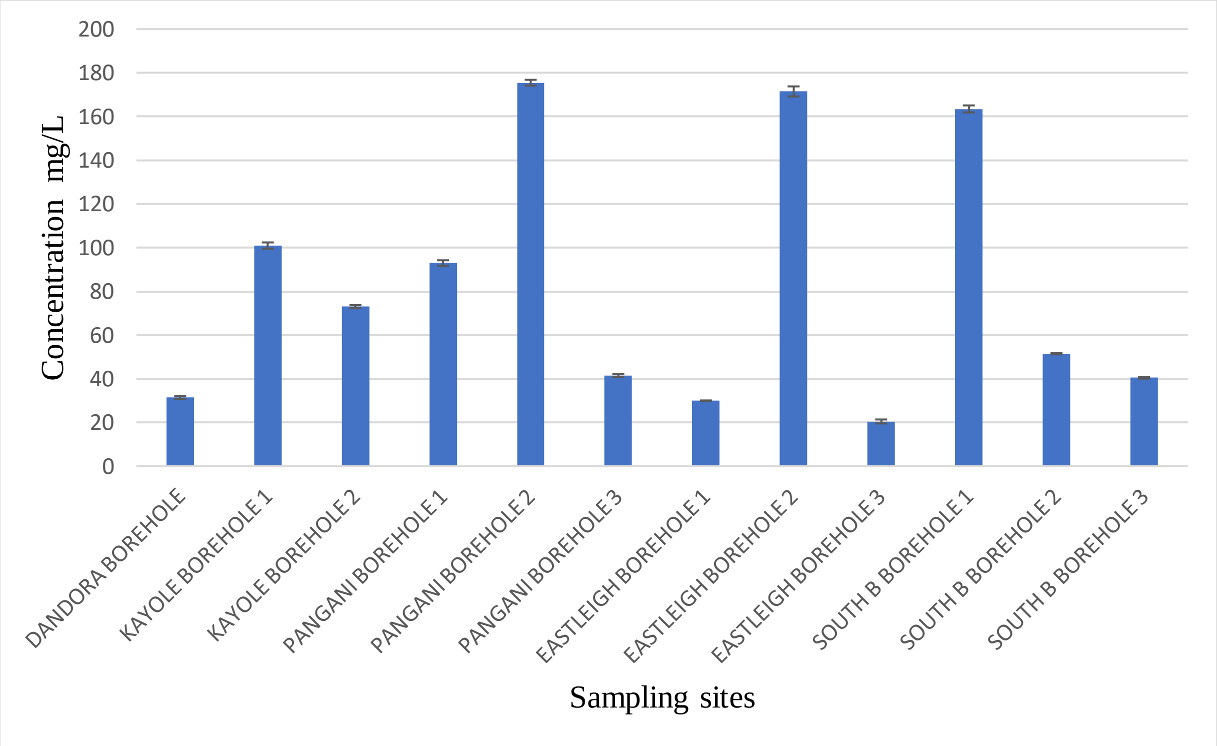

Fig 4.3: A histogram of values of Total dissolved solids of boreholes of some sites in Nairobi County

TSS levels varied from 2-11.0 ppm. The concentrations at all the sampling sites exceeded WHO and KEBS guidline values . All the values for all sites for TSS were within the NEMA guideline value of 30 mg/l

A histogram whose values of total suspended solids were derived from Table 4.1 is shown in Fig. 4.4. It compared all the TSS values in borehole waters at various sites in Nairobi County.

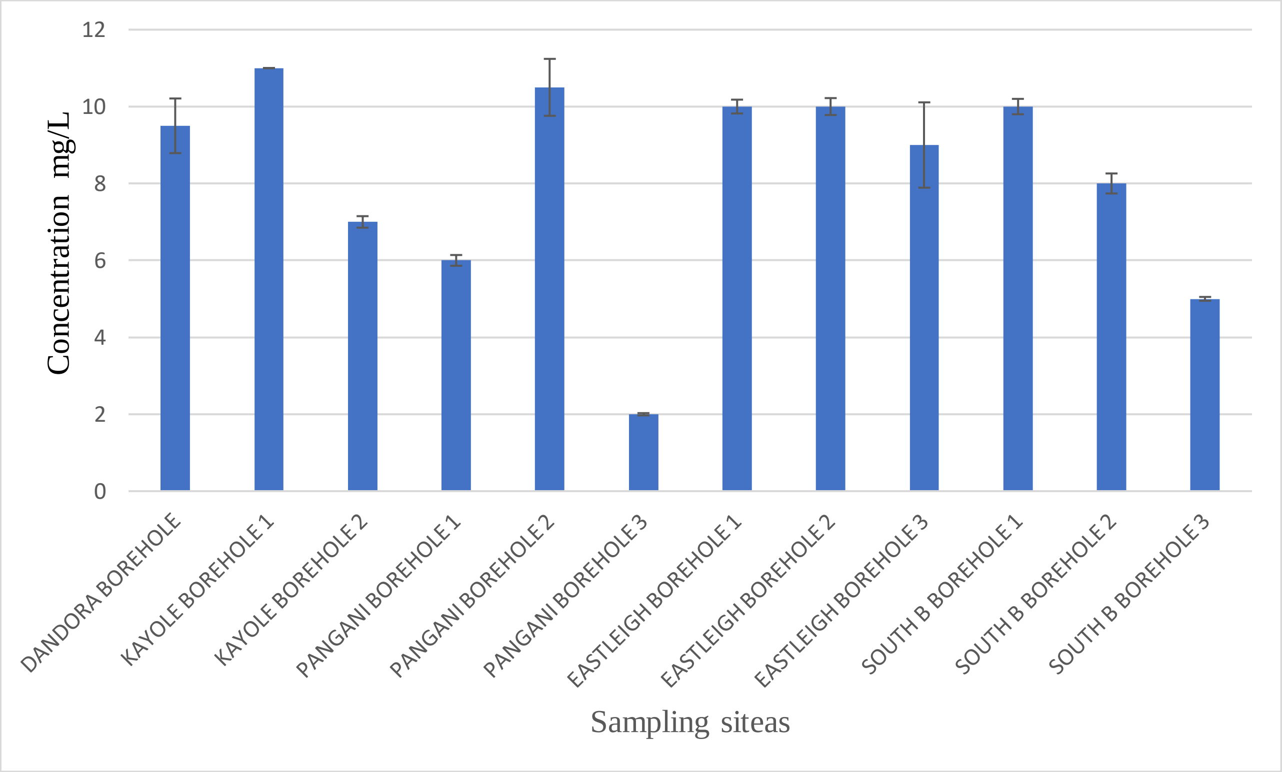

Fig 4.4: A histogram of values of Total Suspended solids of boreholes of some sites in Nairobi County

4.2 Physical-chemical values of water distribution tanker samples

The results of the levels of the physical-chemical parameters of water samples in distribution tankers is given in Table 4.2.

Table 4.2*:* Values of pH, EC, TDS and TSS of tankers water samples from Dandora, Kayole, Eastleigh, Pangani and South C sites

coded Sampling site	physical-chemical values of parameters in tankers water samples			
	pH	EC (µS/cm)	TDS (mg/L)	TSS (mg/L)
DT	8.10±0.04	216.60±5.80	6.50±0.71	11.00±0.13
KT1	8.06±0.08	263.30±6.20	40.50±2.30	10.00±0.21
KT2	8.06±0.16	249.60±2.17	51.50±1.68	10.00±0.20
PT1	7.80±0.10	236.60±4.90	240.50±4.10	9.50±0.77
PT2	7.80±1.20	243.30±7.23	90.50±2.11	2.50±0.30
PT3	7.80±1.10	216.60±6.90	237.50±4.19	4.50±0.10
ET1	8.00±0.10	300.00±4.60	31.50±1.40	6.50±1.12
ET2	7.83±0.12	290.00±10.00	175.50±3.60	10.00±2.31
ET3	7.93±0.18	253.30±3.10	198.00±5.90	5.50±0.22
SCT1	7.70±0.16	483.30±8.90	260.50±4.66	5.50±1.10
SCT2	8.10±0.05	410.00±7.30	220.50±4.02	10.50±3.30
SCT3	8.10±1.31	383.30± 5.30	236.00±7.90	10.00±1.29
C	7.30±0.10	70.00±0.00	21.50±0.05	0
NEMA	6.5-8.5	No set guideline	1200	30
WHO	6.5-8.5	2500	1000	NIL
KEBS	6.5-8.5	No set guideline	1500	NIL

Key: DT= Dandora Tanker; KT1, KT2= Kayole Tanker (1 and 2); PT1, PT2, PT3= Pangani Tanker (1,2 and 3); ET1, ET2 and ET3= Eastleigh Tanker (1,2 and 3); SCT1,SCT2,SCT3=South C Tanker (1,2 and 3); C is a Control; ±SD = standard deviation
The control C was Nairobi Water and Sewerage Company water.

The pH of tanker water samples ranged from 7.3 to 8.1, according to Table 4.2. The pH values were highest at DT,SCT2 and SCT3 and lowest at SCT1 sampling sites. The control had a pH of 7.30. The maximum pH limit, according to WHO, KEBS and NEMA, is 6.5 to 8.5. All water samples from tankers had levels that were within the ranges established by WHO, KEBS and NEMA (Islam *et al.*, 2017; Sila, 2019; Wamalwa & Mutia, 2014).

The histogram in Fig. 4.5 was derived from Table 4.2. It compared all the values of the pH values in distribution tankers at various sites in Nairobi County.

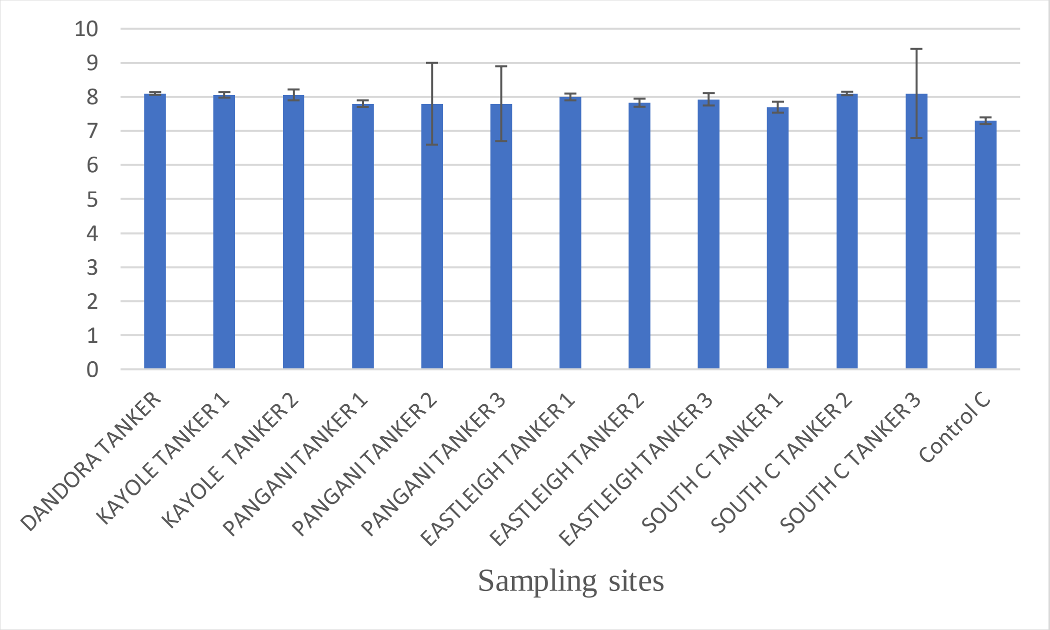

Fig 4.5: A histogram of the values of pH of tankers water samples of some sites in Nairobi County

The electrical conductivity levels in the tankers ranged from 70 to 483.3 µS/cm According to the World Health Organization (WHO) regulations, the permissible limits for electrical conductivity in drinking water should be not more than 2,500 µS/cm; This prameter does not have NEMA and KEBS guideline value. All tankers water samples were within WHO allowed limit (Logesh *et al.*, 2015; Sila, 2019).

The histogram in Fig. 4.6 was derived from Table 4.2. It compared all the electrical conductivity values in distribution tankers at various sites in Nairobi County.

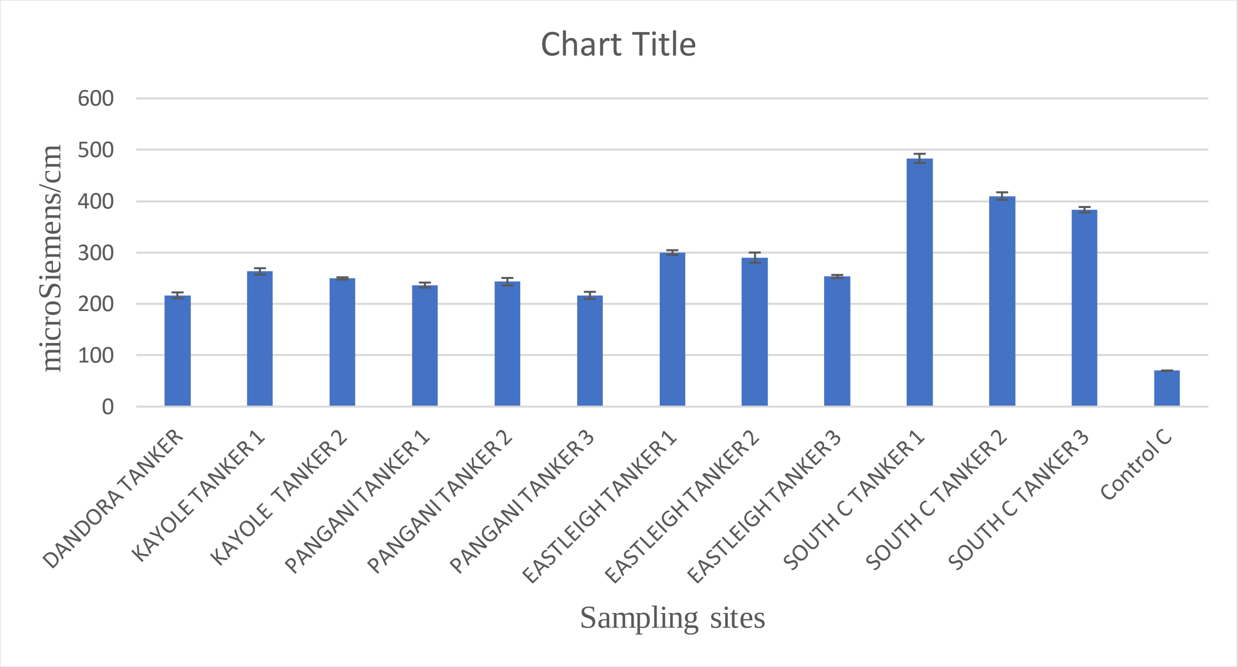

Fig 4.6: A histogram of the values of Electrical conductivity of tankers water samples of some sites in Nairobi County

TDS levels in tanker water samples ranged from 6.50 to 260.50 mg/L. According to the WHO, the recommended limit for human consumption should not be more than 1000 ppm. In Kenya, the NEMA and KEBS Guideline values (max permissible) are 1200 mg/L and 1500mg/L, respectively. All tanker water samples were within WHO, KEBS and NEMA set limits (Kang *et al.*, 2019; Wekesa & Otieno, 2022). The values of TSS in tankers ranged from 2.50 to 11.00 mg/L.

The histogram in Fig. 4.7 was derived from Table 4.2. It compared all the values of total dissolved solids in distribution tankers at various sites in Nairobi County.

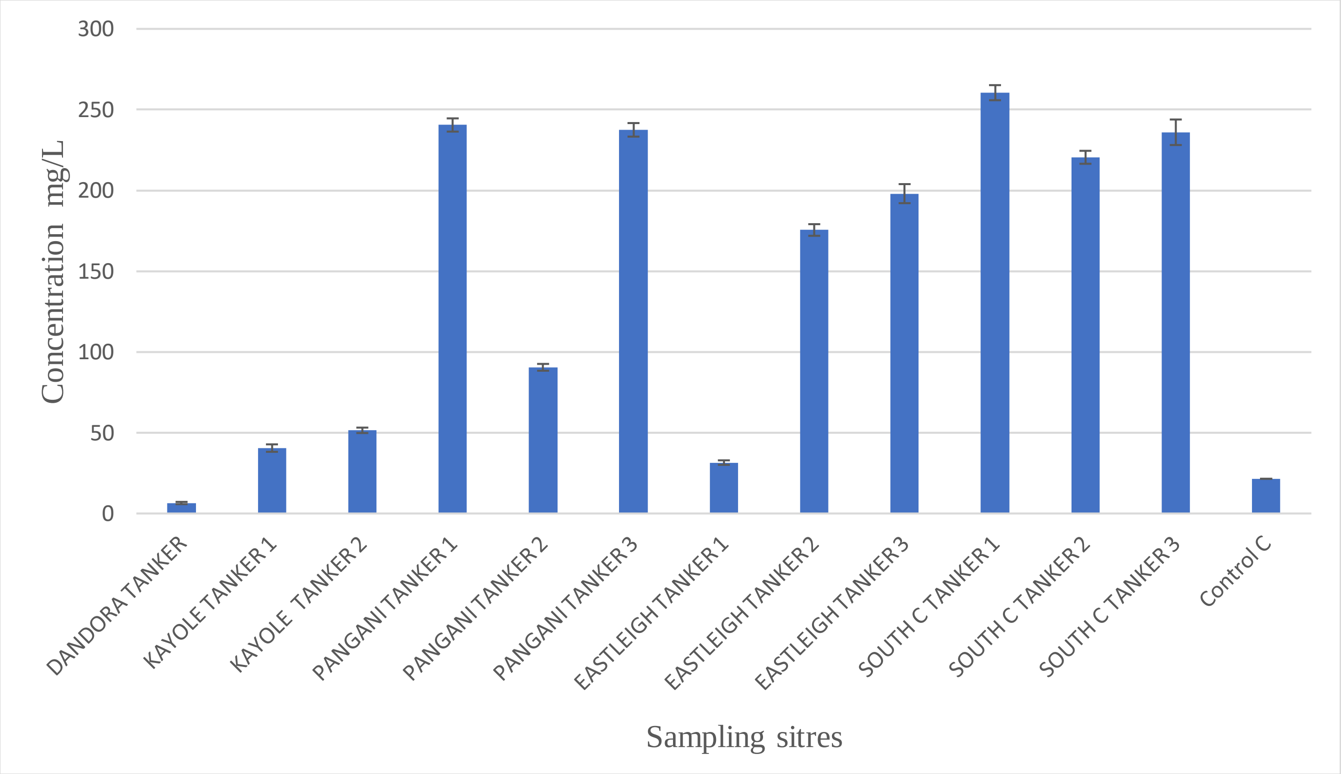

Fig 4.7: A histogram of the values of Total dissolved solids of tankers water samples of some sites in Nairobi County

The values of TSS in all sites exceeded exceeded the WHO and KEBS permitted limits for water quality. All values in all the sites were within the set guideline linit set by NEMA.

The histogram in Fig. 4.8 was derived from Table 4.2. It compared all the values of the total suspended solids in distribution tankers at various sites in Nairobi County.

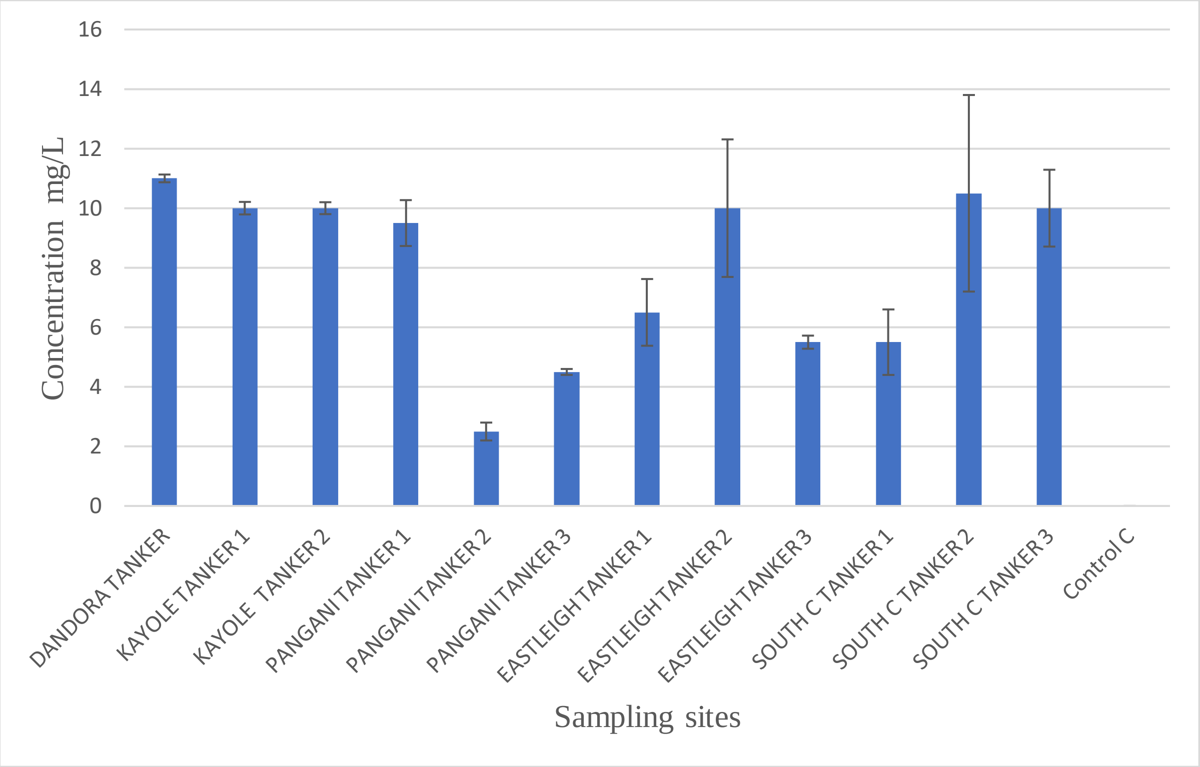

Fig 4.8: A histogram of the values of Total Suspended solids of tankers water samples of some sites in Nairobi County

4.3 Anion and ammonia values of physical-chemical parameters in borehole water samples

Table 4.3 shows the values of anions and ammonia parameters in borehole water samples.

Tables 4.3: Concentrations of anion and ammonia in borehole water samples

coded Sampling site	Concentration of Anions/ammonia in Boreholes			
	Chloride	Fluoride	Nitrate	Ammonia
DB	5.70±0.04	0.50±0.10	0.38±0.10	<0.01 mg/L
KB1	17.07±0.07	3.00±0.14	0.38±0.12	<0.01 mg/L
KB2	28.44±0.12	1.00±0.01	0.38±0.03	<0.01 mg/L
PB1	22.76±0.16	2.00±0.06	25.09±0.01	<0.01 mg/L
PB2	11.37±0.04	4.00±0.17	0.38±0.06	<0.01 mg/L
PB3	5.70±0.25	0.53±0.10	2.10±0.04	<0.01 mg/L
EB1	5.67±0.10	0.86±0.20	1.79±0.08	<0.01 mg/L
EB2	11.34±0.19	3.00±0.18	5.33±0.01	<0.01 mg/L
EB3	11.34±0.29	0.90±0.10	<0.01	<0.01 mg/L
SBB1	5.70±0.15	0.4±0.11	1.58±0.10	<0.01 mg/L
SBB2	5.67±0.16	0.46±0.02	0.38±0.12	<0.01 mg/L
SBB3	5.70±0.20	0.83±0.05	2.13±0.19	<0.01 mg/L
NEMA	No set limit	1.5	10	0.5
KEBS	250	1.5	10	0.5
WHO	250	1.5	50	1.5

Key: DB= Dandora Borehole; KB1, KB2= Kayole Borehole (1 and 2); PB1, PB2, PB3= Pangani Borehole (1,2, and 3); EB1, EB2 and EB3= Eastleigh borehole (1,2 and 3); SBB1, SBB2, SBB3 =South B Borehole (1,2 and 3); ±SD = standard deviation

Chloride levels in boreholes ranged from 5.67–28.4 mg/L. Sampling site KB2 was the highest (28.2 mg/L), while SBB2 and EB1 were the lowest. All the chloride values in boreholes at all the sites were within the guideline values of WHO and KEBS. NEMA had no guideline value. Excessive chloride concentrations corrode metals in the water's supply system. Natural sources of chloride includes sewage discharge, industrial effluents and urban runoff (Tepe & Aydin, 2017).

Figure 4.9 shows a histogram with chloride concentration values derived from Table 4.3. It compares the chloride ions in borehole waters from several locations in Nairobi County.

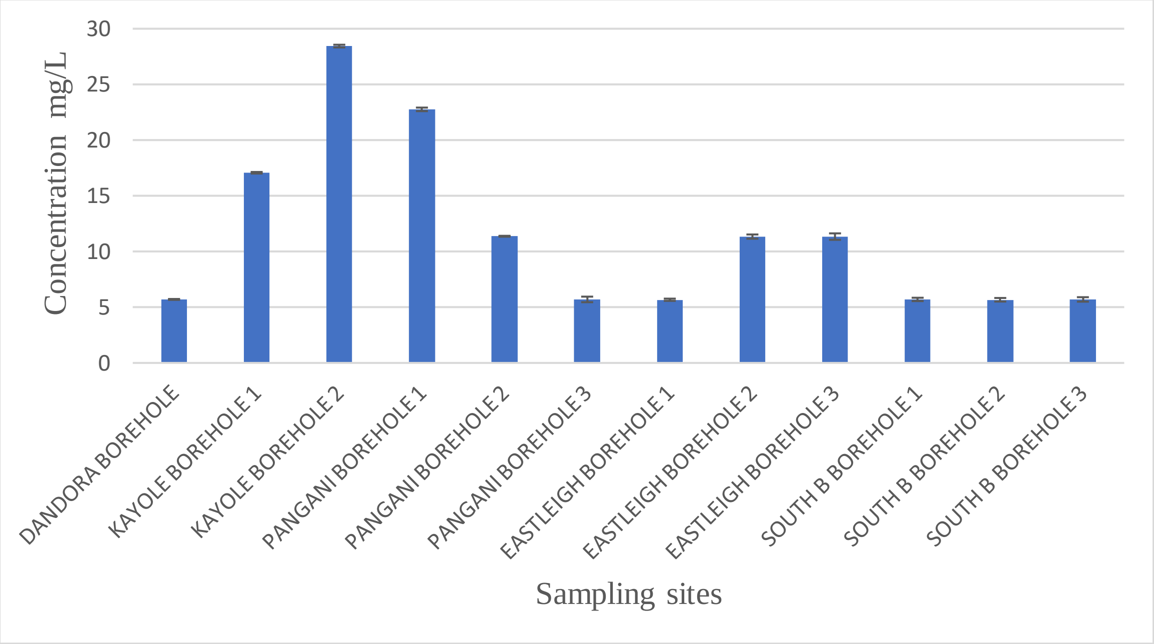

Fig 4.9: A histogram of values of chloride ion in boreholes of various Nairobi County locations

Fluoride levels in boreholes ranged from 0.40–4.00 mg/L. Sampling site PB2 had the highest value (4.00 mg/L), while SBB1 (0.40 mg/L) was the lowest. All the borehole fluoride values conformed to the guideline values except KB1 (3.00 mg/L), PB1 (2 mg/L), PB2 (4.00 mg/L) and EB2 (3 mg/L). From the results, it was evident that a lot of sampling sites had concentrations of fluoride higher than the allowed values by KEBS, NEMA and WHO (Adongo et al., 2022; Kut *et al.*, 2016).

Figure 4.10 shows a histogram with ion concentration values derived from Table 4.3. It compared the fluoride ion in borehole waters from several locations in Nairobi County

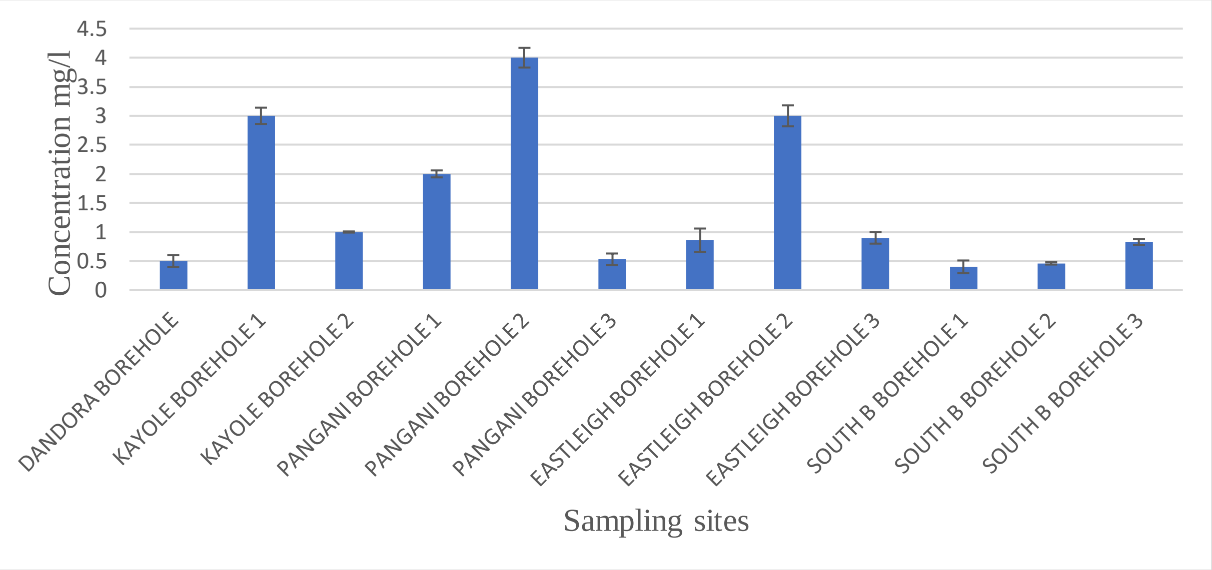

Fig 4.10: A histogram of values of fluoride ion in boreholes of various Nairobi County locations

Nitrate levels in boreholes ranged from < 0.01 to 25.09 mg/L. Sampling site PB1 (25.1 mg/L) was the highest, while EB3 (< 0.01 mg/L) was the lowest. All the borehole nitrate values conformed to the KEBS and NEMA guideline values except at site PB1 (25.1 mg/L) which was above. On the other hand, all the values of nitrate in all the sites conformed to WHO guideline value. High nitrate level could have been as a result of run off, wastewater, landfills, animal feedlots and septic tank systems (Alahi and Mukhopadhyay , 2018). Animal sewage discharge, industrial waste and agricultural usage of organic fertilizers are the primary contributors to nitrate pollution in water. Nitrate stimulates excessive algae and phytoplankton formation in aquatic environments, resulting in eutrophication (Alahi & Mukhopadhyay, 2018).

Figure 4.11 shows a histogram with nitrate ion concentration values derived from Table 4.3. It compared the nitrate ion in borehole waters from several locations in Nairobi County.

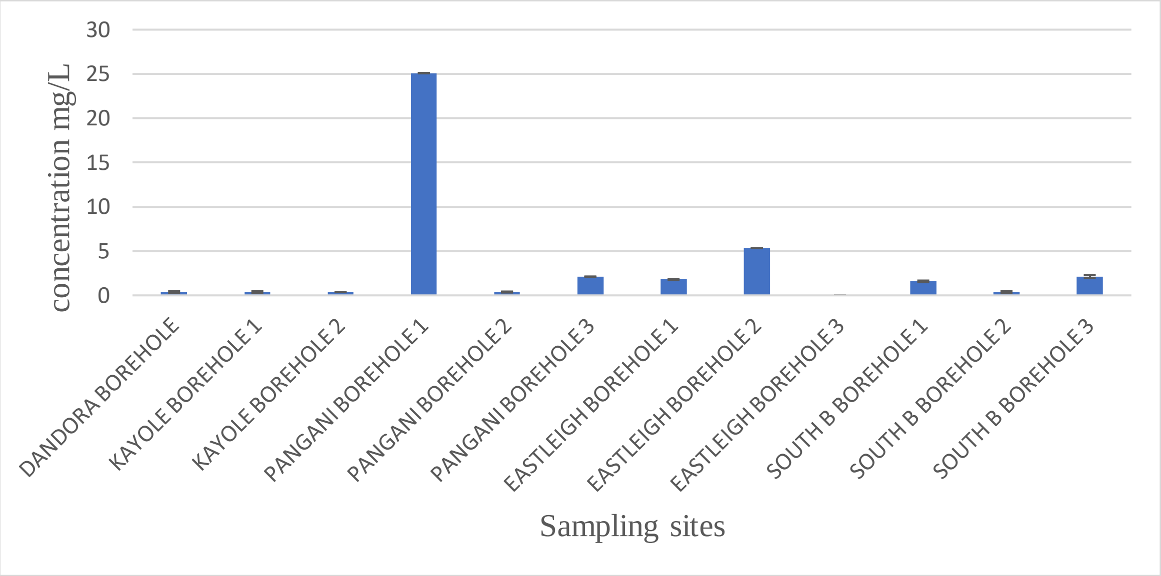

Fig 4.11: A histogram of values of nitrate ion in boreholes of various Nairobi County locations

The ammonia levels in boreholes of the sampling sites were within NEMA, KEBS and WHO guidelines. The ammonia was not detected (detection limit was < 0.01 mg/L) . The most common pollutant in drinking water is ammonia (both non-ionized NH_3 and ionized NH_4^+). Human activities in cities, metabolic processes, agricultural and industrial processes, as well as chloramine disinfection, all contribute to the presence of ammonia (Fu *et al.*, 2012). Ammonia toxicity in water has been extensively studied: its incomplete nitrification increases toxic nitrite content in water. Its presence in water increases the chlorine requirement during disinfection processes (Fu *et al.*, 2012).

Figure 4.12 shows a histogram with ammonia concentration values derived from Table 4.3. It compared the ammonia in borehole waters from several locations in Nairobi County.

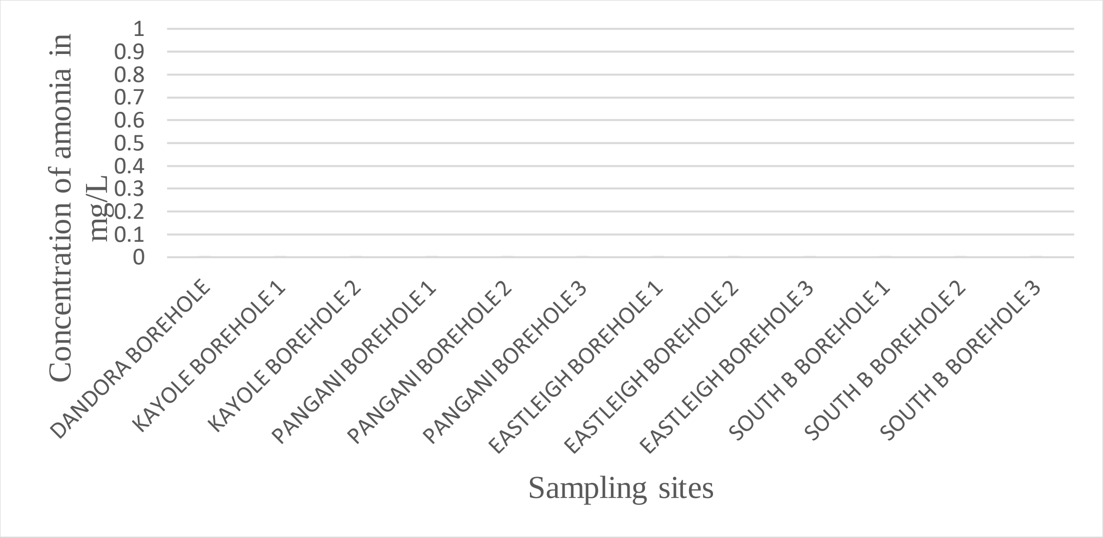

Fig 4.12: A histogram of values of ammonia in boreholes of various Nairobi County locations

4.4 Anion and ammonia values of physical-chemical parameters in water distribution tankers

Table 4.4 provides the results of the concentrations of anions and ammonia in water samples from distribution tankers.

Table 4.4: Concentration of chloride, fluoride, nitrate and ammonia in tankers water samples.

coded Sampling site	Concentration of anions and ammonia in tanker water samples (mg/L)			
	Chloride	Fluoride	Nitrate	Ammonia
DT	11.37±0.03	0.76±0.15	0.38±0.02	<0.01 mg/L
KT1	11.37±0.05	0.76±0.02	13.82±0.01	<0.01 mg/L
KT2	5.7±0.07	0.33±0.06	36.61±0.03	<0.01 mg/L
PT1	5.67±0.03	3.00±0.00	0.60±0.04	<0.01 mg/L
PT2	11.37±0.06	2.60±0.58	0.38±0.11	<0.01 mg/L
PT3	5.70±0.14	4.00±0.10	0.38±0.10	<0.01 mg/L
ET1	5.70±0.17	1.00±0.01	0.38±0.12	<0.01 mg/L
ET2	11.37±1.30	5.67±0.58	0.38±0.13	<0.01 mg/L
ET3	11.37±1.60	3.33±0.78	95.12±0.01	<0.01 mg/L
SCT1	39.75±0.07	3.30±0.68	18.42±0.02	<0.01 mg/L
SCT2	17.06±0.16	4.00±0.12	0.10±0.00	<0.01 mg/L
SCT3	11.37±1.22	3.30±0.20	0.01±0.00	<0.01 mg/L
C	0	0.56±0.04	0.39±0.01	<0.01 mg/L
NEMA	No set limit	1.5	10	0.5
KEBS	250	1.5	10	0.5
WHO	250	1.5	50	1.5

Key:DT= Dandora Tanker; KT1, KT2= Kayole Tanker (1 and 2); PT1, PT2, PT3= Pangani Tanker (1,2, and3); ET1, ET2 and ET3= Eastleigh Tanker (1,2 and 3) and SCT1,SCT2,SCT3=South C Tanker(1,2 and 3); C is a Control; ±SD= standard deviation

Chloride levels in tankers ranged from 5.7 to 39.7 mg/L. Sampling site SCT1 was the highest (39.7 mg/L), while PT1 (5.7 mg/L) was the lowest. All the chloride values in tankers at all the sites were within the guideline values of WHO and KEBS. There was no NEMA guideline value. Figure 4.13 depicts a histogram of ion concentrations generated from Table 4.4. It compared all of the chloride ion concentrations in distribution tankers in various locations in Nairobi County.

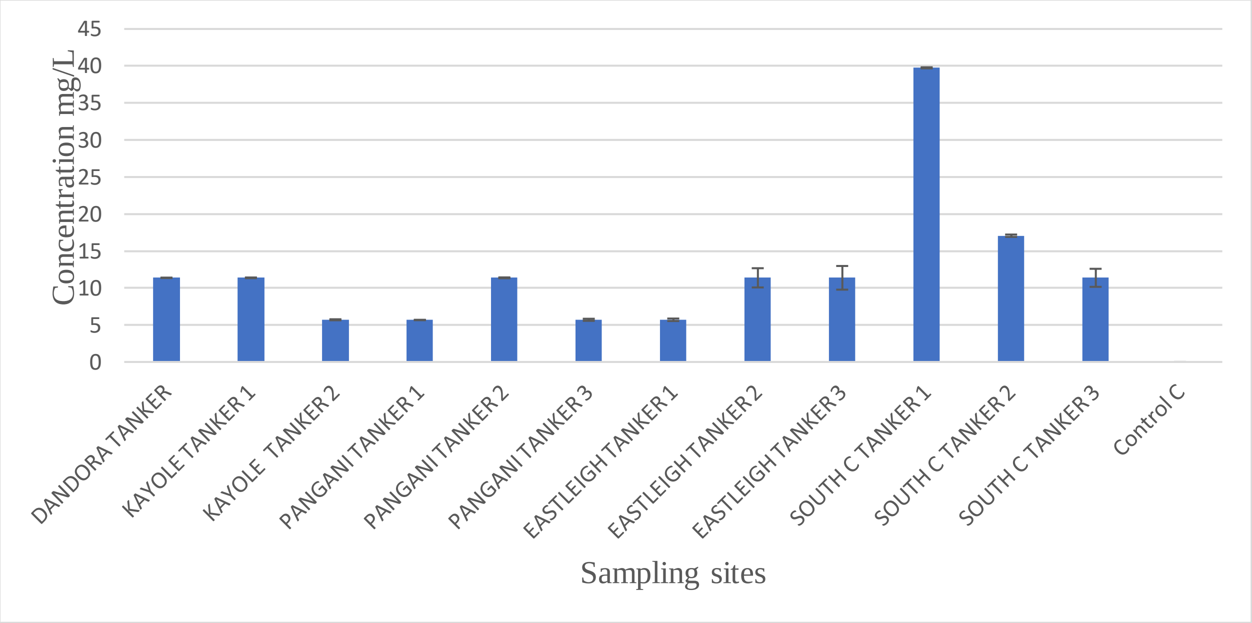

Fig 4.13: A histogram of chloride ion concentrations in tankers from several locations in Nairobi County

Fluoride levels in tankers ranged from 0.33–3.67 mg/L. Sampling site ET2 was the highest (5.67 mg/L), while KT2 (0.33 mg/L) was the lowest. All the tanker fluoride values conformed to the guideline values except PT1 (3.00 mg/L), PT2 (2.6 mg/L), PT3 (4.00 mg/L), ET2 (5.67 mg/L), ET3 (3.33 mg/L), SCT1 (3.3 mg/L), SCT2 (4.0 mg/L) and SCT3 (3.3 mg/L).

Figure 4.14 depicts a histogram of ion concentrations generated from Table 4.4. It compared all of the fluoride ion concentrations in distribution tankers in various locations in Nairobi County.

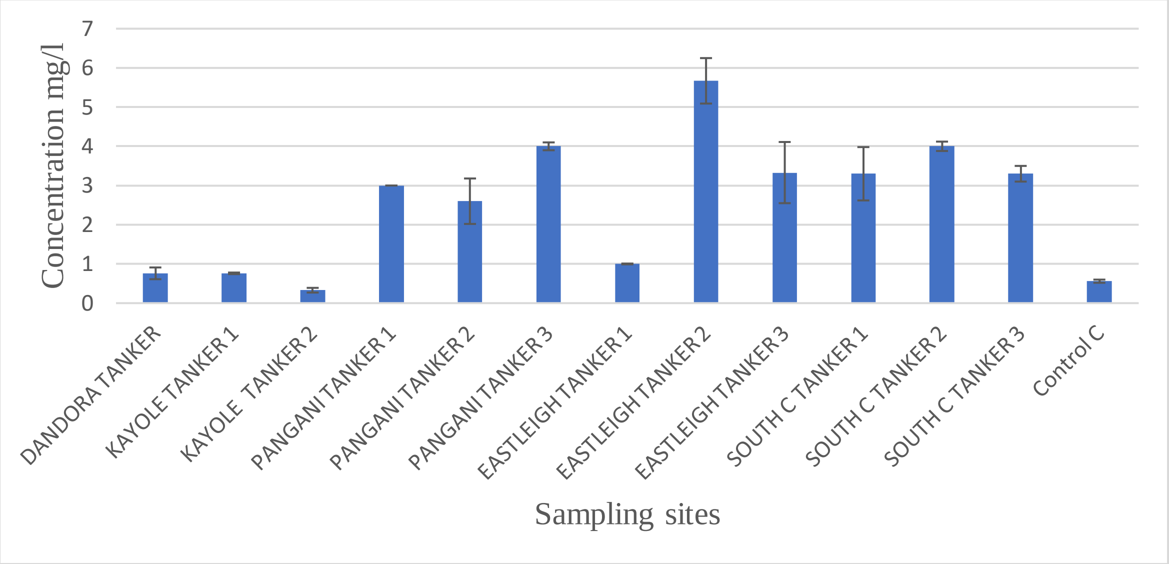

Fig 4.14: A histogram of fluoride ion concentrations in tankers from several locations in Nairobi County

Nitrate levels in tankers ranged from 0.01 to 95.1 mg/L. Sampling site ET3 (95.1 mg/L) was the highest, while SCT3 (0.01 mg/L) was the lowest. All the tanker samples for nitrate values conformed to the WHO guideline values except at site ET3. It also conformed to NEMA and KEBS guideline except at sites KT1, KT2, ET3 and SCT1.

Figure 4.15 depicts a histogram of ion concentrations generated from Table 4.4. It compared all of the nitrate ion concentrations in distribution tankers in various locations in Nairobi County.

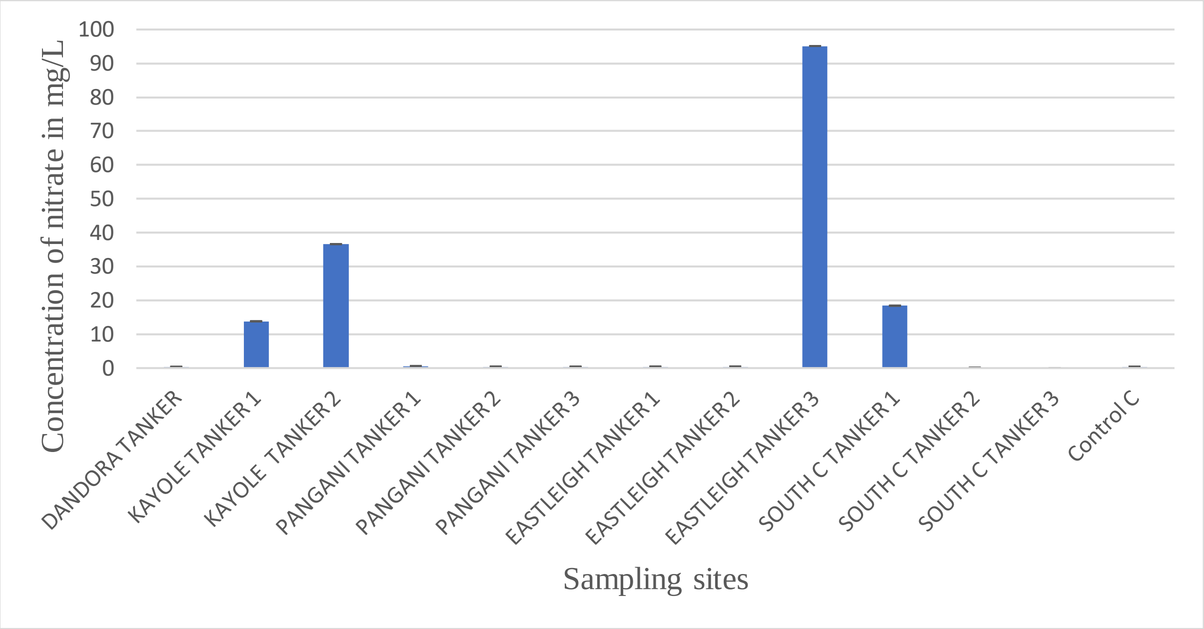

Fig 4.15: A histogram of nitrate ion concentrations in tankers from several locations in Nairobi County

Ammonia levels in tankers at the various sites conformed to NEMA and WHO guideline values. The ammonia was below the detection limit of 0.01 mg/L.

Figure 4.16 depicts a histogram of ion concentrations generated from Table 4.4. It compared all of the ammonia concentrations in distribution tankers in various locations in Nairobi County.

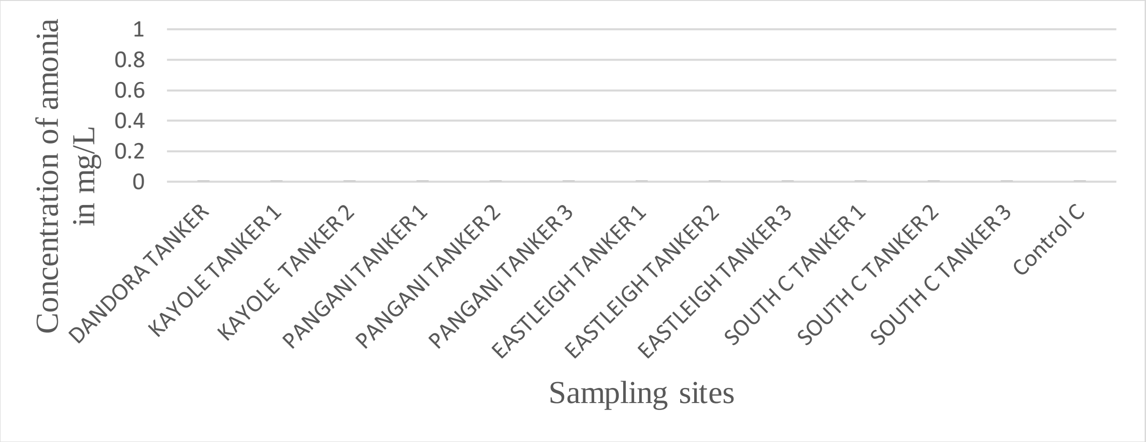

Fig 4.16: A histogram of ammonia concentrations in tankers from several locations in Nairobi County

4.5 Results and discussion of some selected heavy metal ions

Metallic elements are those that occur naturally in the environment. Their presence is unique in that, once they enter the environment, they are difficult to eradicate. Metals are a key class of hazardous substances found in a variety of occupational and environmental settings. The impact of these dangerous compounds on human health is currently a hot topic due to their widespread exposure. With the increasing usage of a wide spectrum of metals in business and in our daily lives, hazardous metal pollution has produced significant environmental challenges (Mahurpawar, 2015).

Table 4.5 shows the concentration of heavy metals in boreholes while Table 4.6 shows the concentration of heavy metals in tankers.

Table 4.5 Heavy metals concentration (mg/L) in boreholes

SAMPLING SITES	Heavy Metals Concentration in Boreholes (mg/L)			
	Zn	Cu	Pb	Cd
DB	0.73± 0.01	1.07 ± 0.02	0.56 ± 0.03	1.50 ± 0.02
KB1	0.65 ±0.10	1.07 ± 0.04	1.16± 0.02	1.50 ± 0.01
KB2	0.65 ± 0.12	1.12± 0.06	1.56 ± 0.01	1.48 ± 0.03
SBB1	0.65 ± 0.03	0.16 ± 0.02	0.50± 0.03	1.5 0± 0.10
SBB2	0.65 ± 0.01	1.09 ± 0.00	0.56 ± 0.04	1.50 ± 0.01
SBB3	0.65 ± 0.06	1.12 ± 0.01	0.63 ± 0.00	1.51 ± 0.00
PB1	5.21± 0.01	1.07 ± 0.03	2.25 ± 0.10	1.45 ± 0.11
PB2	8.13 ± 0.05	1.07 ± 0.03	2.41 ± 0.12	1.50 ± 0.12
PB3	8.74 ± 0.04	1.09± 0.04	2.75 ± 0.00	1.61± 0.02
EB1	0.95± 0.01	1.07 ± 0.02	1.00 ± 0.00	1.50 ±0.00
EB2	10.02 ± 0.03	1.07 ± 0.06	1.30 ± 0.02	1.56 ± 0.04
EB3	0.65 ± 0.04	1.08 ± 0.00	0.50 ± 0.00	1.55 ± 0.01
NEMA	1.5	0.05	0.05	0.01
KEBS	5	0.1	0.05	0.005
WHO	5	2	0.01	0.003

Key: Coded sampling site DB= Dandora Borehole; KB1, KB2= Kayole Borehole (1 and 2); PB1, PB2, PB3= Pangani Borehole (1,2, and3); EB1, EB2 and EB3= Eastleigh borehole (1,2 and 3) and SBB1,SBB2,SBB3=South B Borehole (1,2 and 3); ±SD = standard deviation.

Zinc levels in the borehole samples conformed to the guideline values except at sites PB1, PB2, PB3 and EB2. Copper, lead and cadmium all had values higher than the NEMA and KEBS guideline values. Cu level in borehole conformed to WHO guideline while lead and cadmium did not.

Figure 4.17 illustrates heavy metal concentrations that were generated from Table 4.5. It compared zinc ions in borehole waters from several areas in Nairobi County.

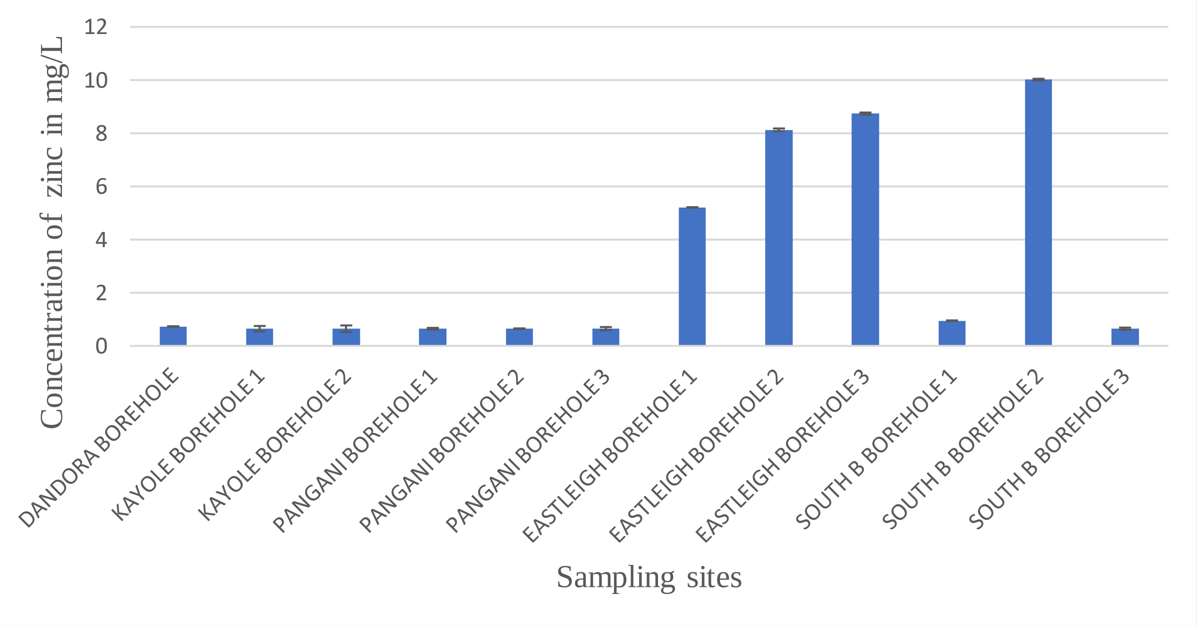

Fig. 4.17: A histogram showing the heavy metal zinc in boreholes from various Nairobi County sites

Figure 4.18 illustrates heavy metal concentrations that were generated from Table 4.5. It compared copper ions in borehole waters from several areas in Nairobi County.

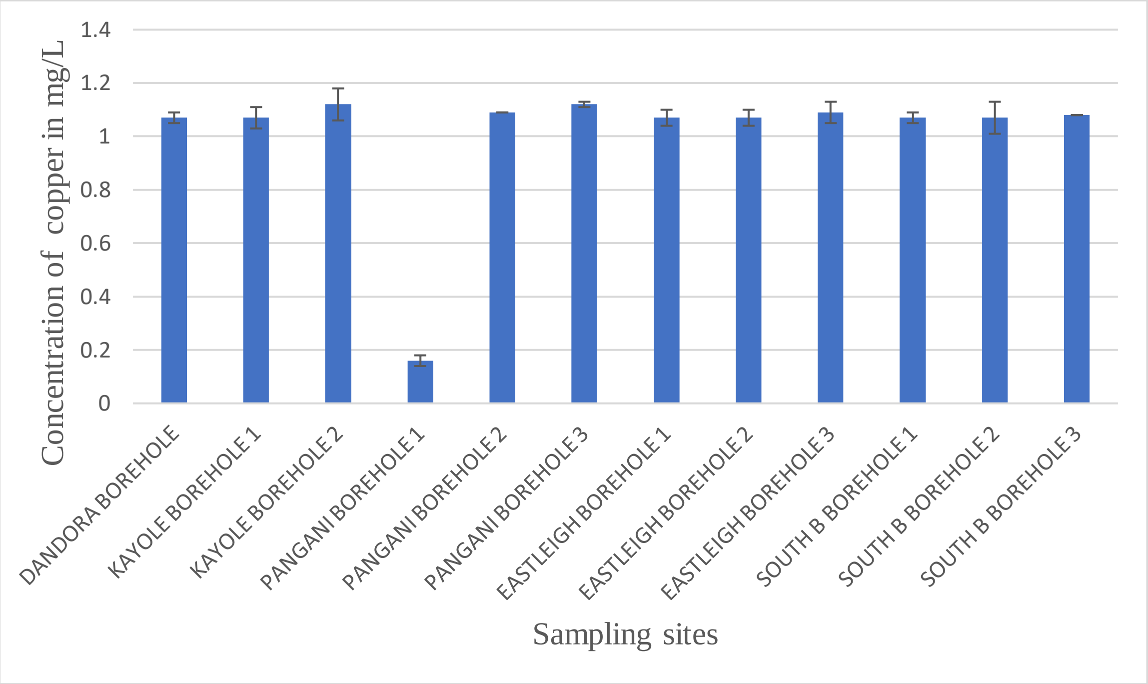

Fig. 4.18: A histogram showing the concentration of heavy metal copper in boreholes from various Nairobi County sites

Figure 4.19 illustrates heavy metal concentrations that were generated from Table 4.5. It compared lead ions in borehole waters from several areas in Nairobi County.

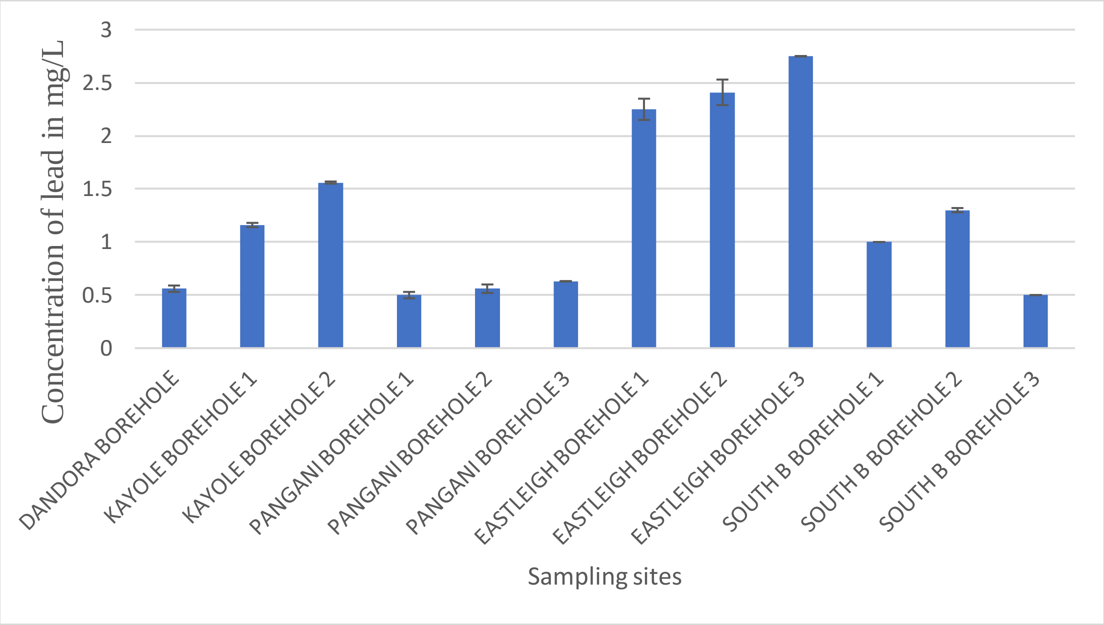

Fig. 4.19: A histogram showing the heavy metal lead in boreholes from various Nairobi County sites

Figure 4.20 illustrates heavy metal concentrations that were generated from Table 4.5. It compared cadmium ions in borehole waters from several areas in Nairobi County.

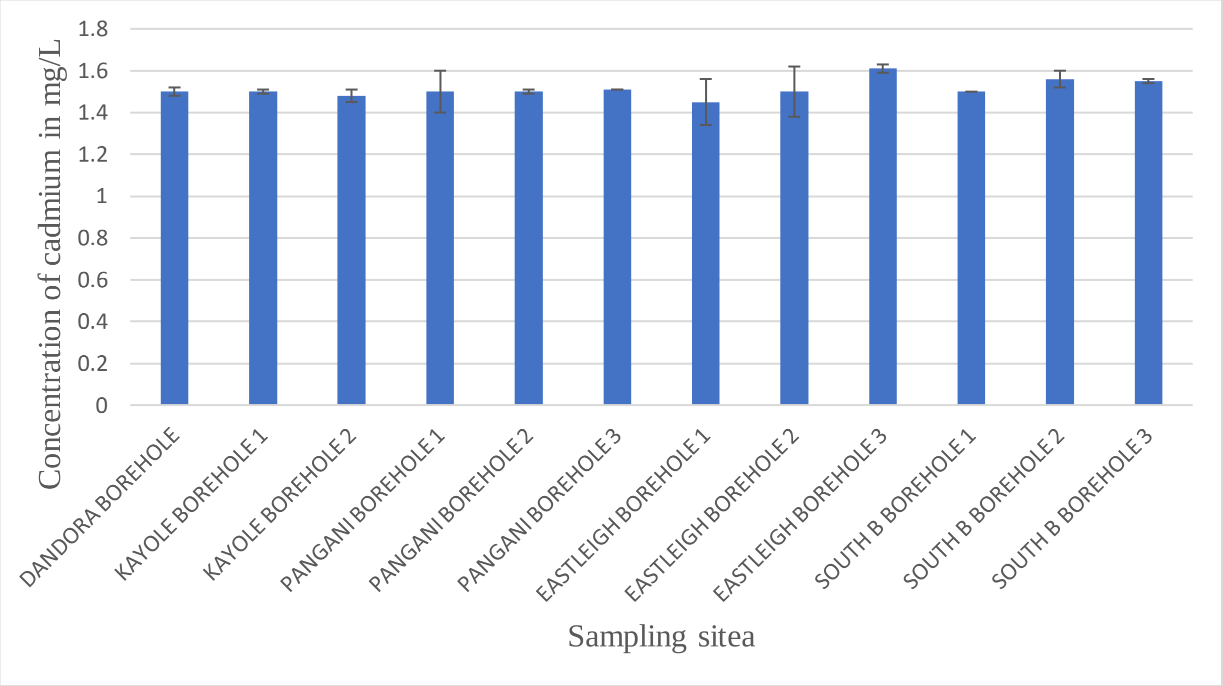

Fig. 4.20: A histogram showing the heavy metal cadmium in boreholes from various Nairobi County sites

Table 4.6 Heavy metals concentration (mg/L) in tankers

SAMPLING SITES	Heavy Metals Concentration in Tankers (mg/L)			
	Zn	Cu	Pb	Cd
DT	0.65± 0.02	1.07± 0.10	0.94± 0.01	1.49± 0.13
KT1	0.65± 0.01	1.18± 0.06	2.46± 0.13	1.48± 0.10
KT2	0.65± 0.04	1.22± 0.05	0.5± 0.14	1.55 ±0.10
SCT1	0.65± 0.01	1.08± 0.01	0.91± 0.02	1.46± 0.12
SCT2	0.65± 0.02	1.08± 0.03	2.15 ± 0.12	1.45± 0.03
SCT3	7.40± 0.13	1.07± 0.01	0.50± 0.02	1.45± 0.04
PT1	13.95± 1.30	1.13± 0.06	0.50± 0.03	1.61± 0.09
PT2	0.65± 0.03	1.09± 0.07	0.59 ±0.06	1.47± 0.04
PT3	0.65± 0.02	1.07± 0.06	0.56± 0.07	1.51± 0.01
ET1	4.14 ±0.02	1.13± 0.03	0.60 ±0.07	1.45± 0.12
ET2	11.14± 0.03	1.07± 0.12	4.22± 0.01	1.45± 0.09
ET3	0.67±0.01	1.07± 0.13	1.31 ±0.01	1.53± 0.08
C	1.29 ± 0.03	1.07 ± 0.03	1.31± 0.12	1.52± 0.07
NEMA	1.5	0.05	0.05	0.01
KEBS	5	0.1	0.05	0.005
WHO	5	2	0.01	0.003

Key: DT= Dandora Tanker; KT1, KT2= Kayole Tanker (1 and 2); PT1, PT2, PT3= Pangani Tanker (1,2 and 3); ET1, ET2 and ET3= Eastleigh Tanker (1,2 and 3); SCT1, SCT2, SCT3=South C Tanker(1,2 and 3); C is a Control ±SD = standard deviation

In Tankers samples, zinc levels Conformed to KEBS and WHO guideline values except at PT1, ET1and ET2 where the values were higher. All zinc values conformed to NEMA except at SCT3, PT1, ET1 and ET2.

Copper level in tankers samples were higher than NEMA and KEBS guideline values. Copper conformed to the WHO guideline. Lead and cadmium in tanker samples did not conform to NEMA, KEBS and WHO guideline values. They were all higher. The high levels of lead could have come from ores in the ground and also from plumbing pipes. Zinc and cadmium levels were also high. Zinc could have been introduced to the water from galvanized roofing materials and water pipes. Zinc can also be introduced by inorganic fertilizers.

Figure 4.21 illustrates a histogram of heavy metal concentrations generated from Table 4.6. It compared all of the heavy metal zinc ions in distribution tankers in various places around Nairobi County.

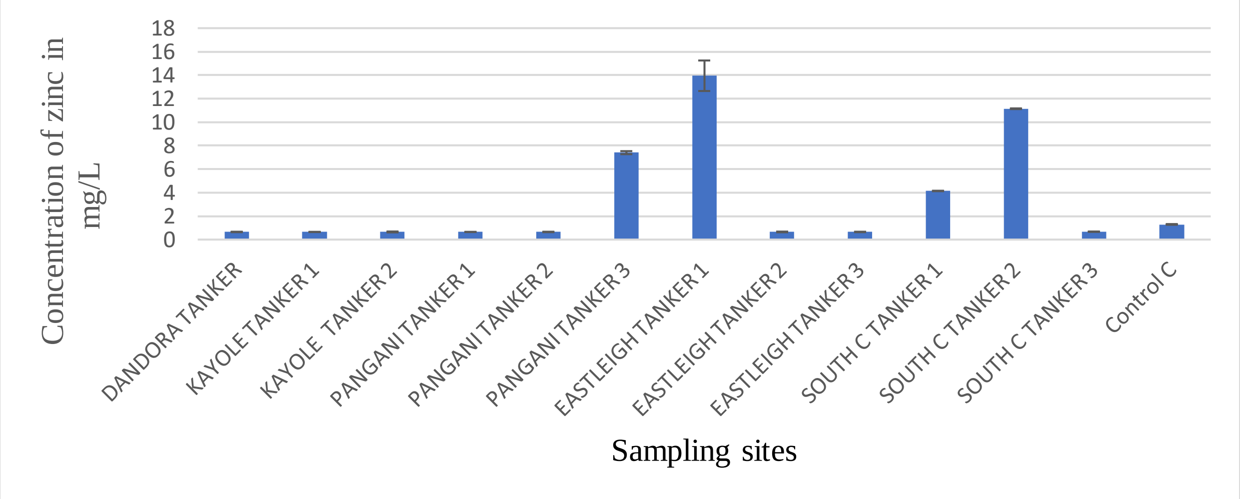

Fig. 4.21: A histogram of heavy metal zinc concentrations in tankers from various areas in Nairobi County

Figure 4.22 illustrates a histogram of heavy metal copper concentrations generated from Table 4.6. It compared all of the heavy metal zinc ions in distribution tankers in various places around Nairobi County.

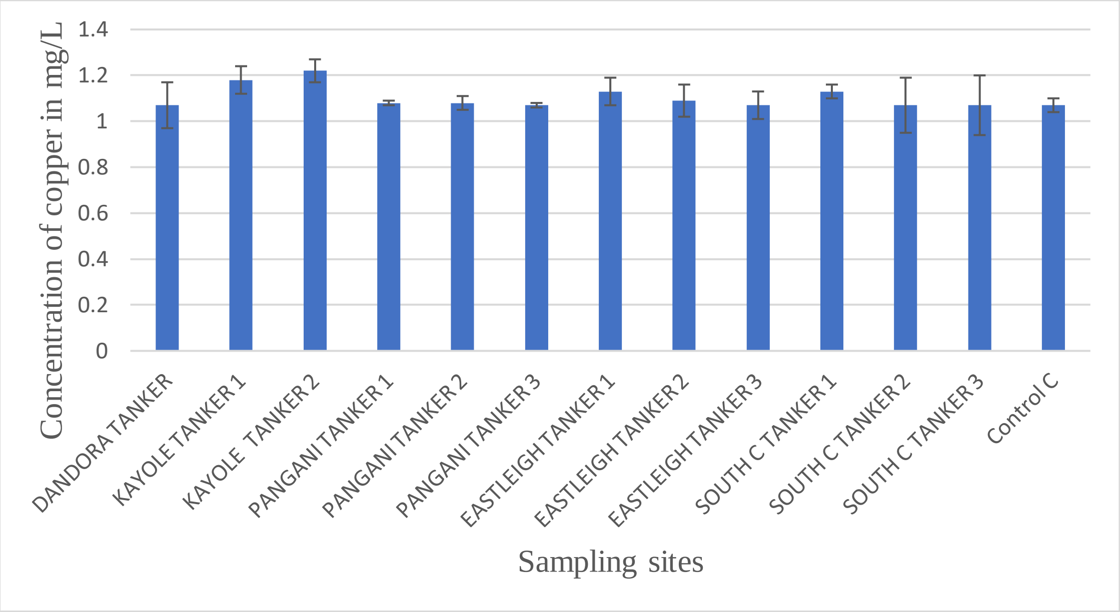

Fig. 4.22: A histogram of heavy metal copper concentrations in tankers from various areas in Nairobi County

Figure 4.23 illustrates a histogram of heavy metal lead concentrations generated from Table 4.6. It compared all of the heavy metal zinc ions in distribution tankers in various places around Nairobi County.

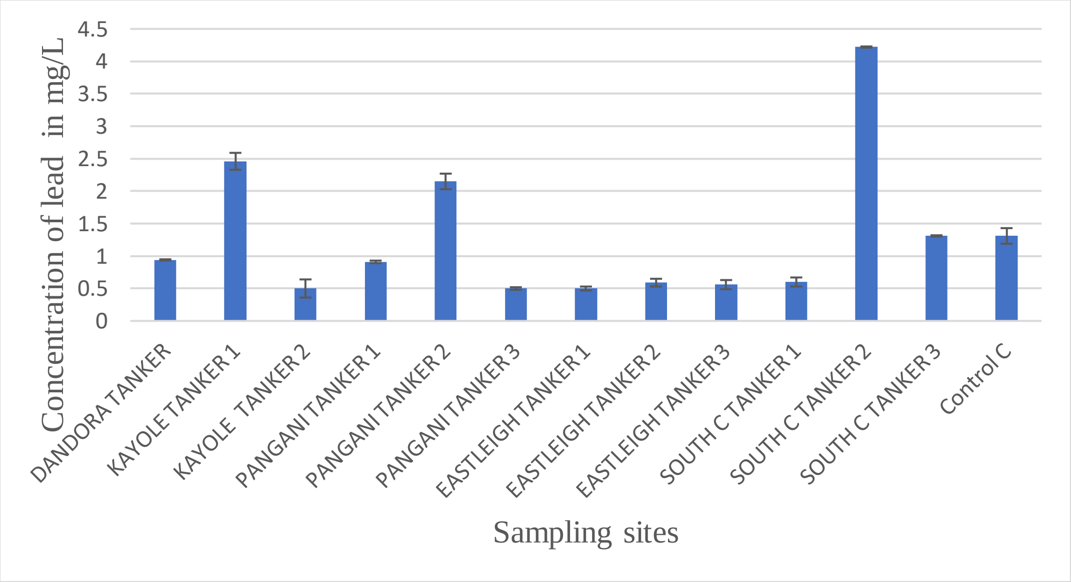

Fig. 4.23: A histogram of heavy metal lead concentrations in tankers from various areas in Nairobi County

Figure 4.24 illustrates a histogram of heavy metal cadmium concentrations generated from Table 4.6. It compared all of the heavy metal cadmium ions in distribution tankers in various places around Nairobi County.

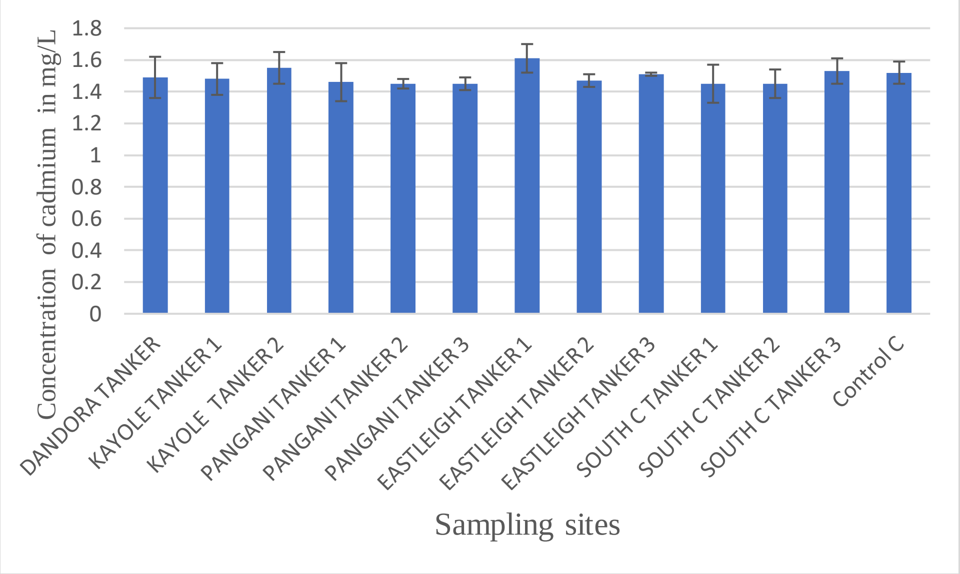

Fig. 4.24: A histogram of heavy metal cadmium concentrations in tankers from various areas in Nairobi County

4.6 Biological parameters

4.6.1: Biological parameters included Escherichia coli and Total count.

Tables 4.7 & 4.8 shows the results of all biological parameters in borehole sampling sites and Tankers sites.

Table 4.7: Results of *E. coli* and total coliform count in boreholes

Sampling sites in Boreholes	*E. coli*	Total count/100mL
DB	Nil	914
KB1	Nil	248
KB 2	Nil	659
PB1	Nil	64
PB 2	2	16
PB 3	Nil	11
EB 1	Nil	2
EB 2	Nil	8
EB 3	Nil	777
SB 1	Nil	8
SB 2	Nil	34
SB 3	Nil	23

Table 4.8: Results of *E. coli* and total coliform count in tankers

Sampling sites in tankers	*E. coli*	Total count 100mL
DT	Nil	78
KT 1	1	308
KT 2	Nil	10
PT 1	Nil	>2420
PT 2	1	4
PT 3	Nil	118
ET 1	Nil	3
ET 2	Nil	43
ET 3	Nil	1986
SCT1	1	>2420
SCT2	Nil	242
SCT3	Nil	55
C	Nil	104

From the data on the bacteriological examination of *E. coli* and total count, it's evident that most samples showed zero presence of *E. coli* as compared to Total Count which was higher in both the borehole and tankers samples. The maximum value recorded for total count was >2420 from two tankers sites like Pangani tanker one (PT1) and south C tanker one (SCT1).

CHEPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The pH, EC, TDS, and TSS values of boreholes conformed to guideline values. All tankers sampled for the same parameters also conformed to the requirements of NEMA and WHO.

In the study of chloride, fluoride, nitrate and ammonia in borehole samples, chloride was found to be within the guideline values. Fluoride was found to conform to the guideline values except at sites KB1, PB1, EB2 and PB2. Nitrate in borehole samples conformed to WHO and NEMA guideline values except for PB1, which was above the limit. Ammonia for borehole samples conformed to WHO and NEMA standards. In the case of tankers for the same parameters, chloride conformed to all the guideline values. Fluoride conformed except at sites PT1, PT2, PT3, ET2, ET3, SCT1, SCT2 and SCT3. In the case of nitrate, it conformed to the guideline values of the WHO except at ET3. In the case of NEMA and KEBS, it conformed except for KT1, KT2, ET3, and SCT1. Ammonia conformed to all the guideline values.

In heavy metal results, zinc levels in the borehole samples conformed to the guideline values except at sites PB1, PB2, PB3 and EB2. Copper, lead and cadmium all had values higher than the guideline values. In Tankers, zinc had all values conforming except at sites SCT3, PT1 and ET1. Copper, lead and cadmium all had values higher than the guideline values.

In the biological analysis of borehole samples, no *E. coli* was detected except at PB2. DB had the highest count at 914, followed by KB2 (659) and EB3 (777). In the case of tanker samples, no E. coli was detected except at KT1 (1) and PT2 (1). PT1 had the highest count at > 2420, followed by ET3 (1986).

5.2 RECOMMEDATIONS

The following recommendations were made:

1- Further research should be carried out on boreholes and tankers in other sub-counties not covered in this research.

2- Further research should be carried out on other heavy metals like chromium, manganese, iron and arsenic.

3- Further research should be carried out on other anions like sulphate and phosphate.

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APPENDICES

Appendix 1: Standardization of $AgNO_3$ with 0.1M NaCl

Titration No	1	2	3
Initial burette reading (mL)	0.00	0.00	0.00
Final burette reading (mL)	0.9	0.9	0.8
Volume of $AgNO_3$ used (mL)	0.9	0.9	0.8
Average Volume of $AgNO_3$ used	$\frac{0.9+0.9+0.8}{3}$ = 0.867±0.058		

The volume of 0.1M NaCl was 10 mL

$AgNO_3$ (aq) + NaCl (aq) = AgCl(s) + $NaNO_3$ (aq)

Scheme 4.3: Reaction of silver nitrate with sodium chloride

Moles of AgCl used = $\frac{mass}{relative\ molecular\ mass} = \frac{0.5843g}{58.44g/mol}$ = 0.01mole

Molarity = $\frac{moles \times 1000}{volume\ in\ ml} = \frac{0.01mole \times 1000}{100mL}$ = 0.1M

Moles of NaCl in 10mL = $\frac{o.1mole \times 10ml}{1000mL}$ = 0.001 mole

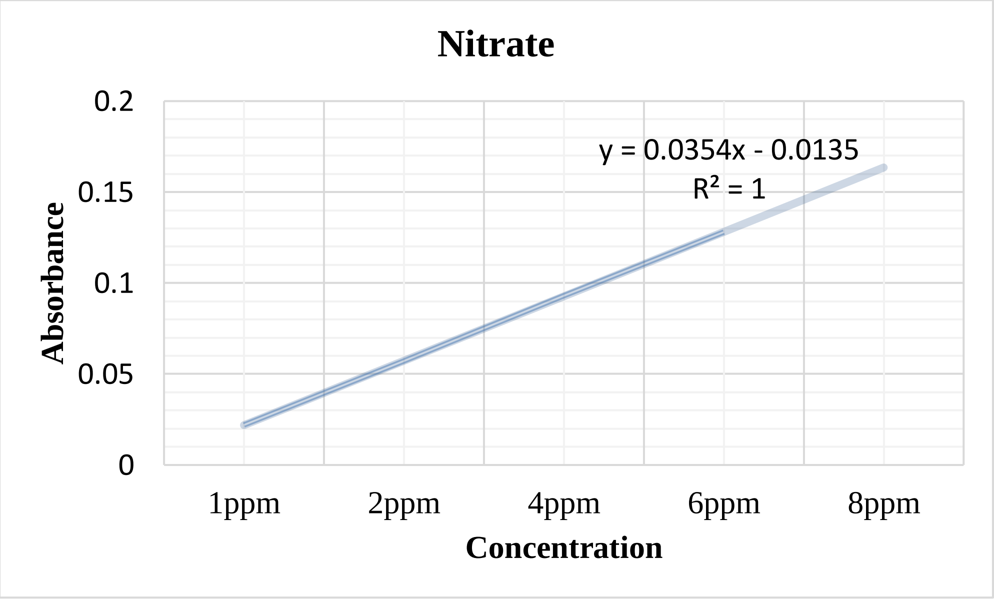
The Determination of chloride concentration used the following formula:

$$\frac{\text{molicular wieght} \times \text{molarity} \times 1000 \times \text{titration reading}}{\text{sample volume}}$$

Appendix 2a: Data of absorbance versus concentration of nitrate

Concentration ppm	*Absorbance*
0 ppm	0.00
1ppm	0.004
2ppm	0.022
4ppm	0.057
6ppm	0.093
8ppm	0.128

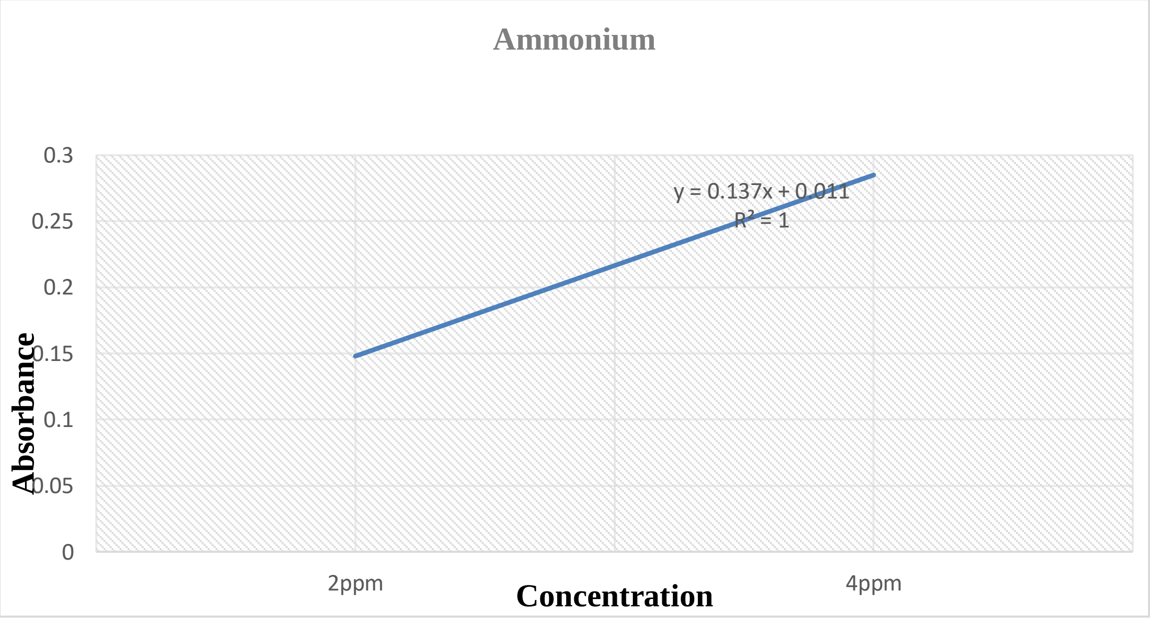
Appendix 2b: Calibration curve of nitrate



Appendix 3a: Data of absorbance versus concentration of ammonia

Concentration ppm	Absorbance
0 ppm	0.00
1ppm	0.0
2ppm	0.148
4ppm	0.285

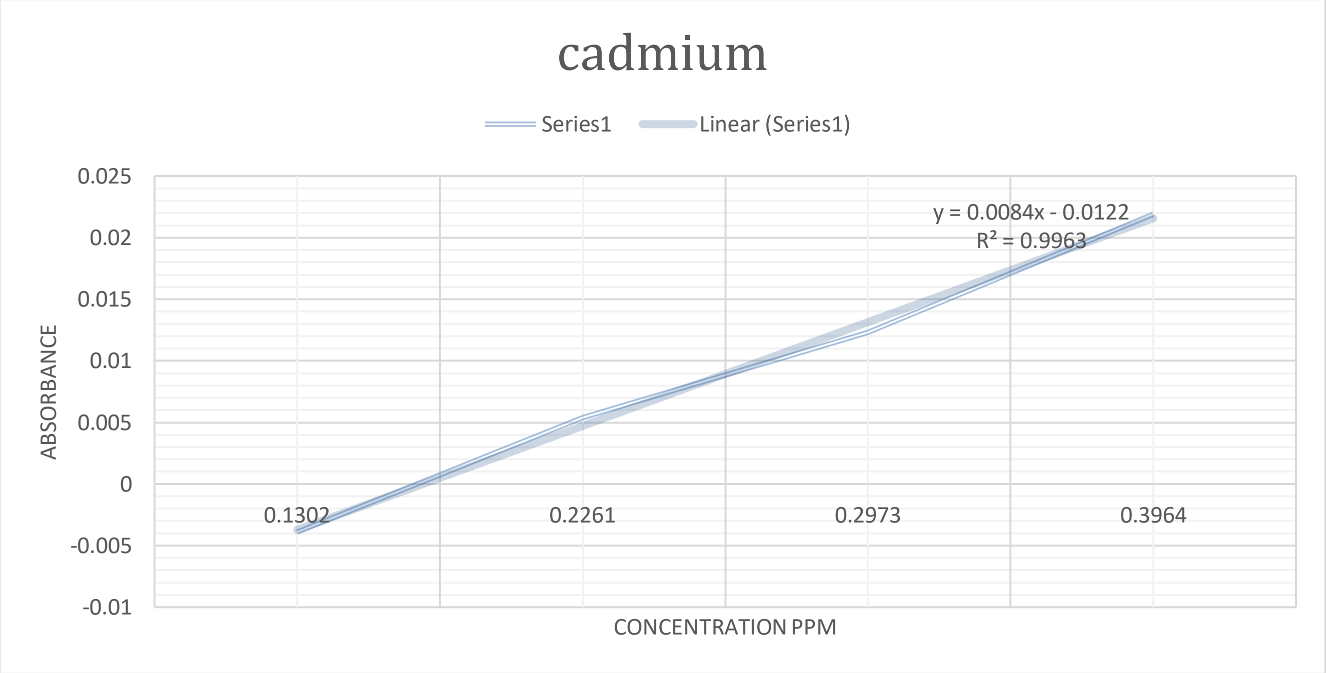
Appendix 3b: Ammonia calibration curve



Appendix 4a: Cadmium data of absorbance versus concentration

Concentration(ppm)	Absorbance
0.1302	-0.0039
0.2261	0.0054
0.2973	0.0123
0.3964	0.0219

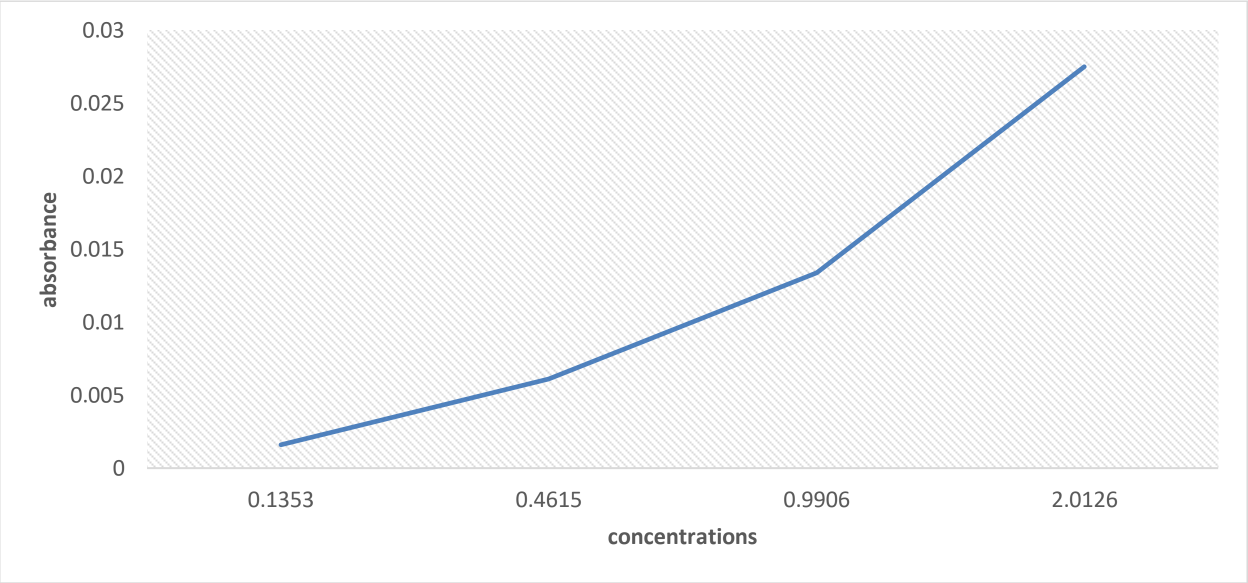
Appendix 4b: Calibration curve of cadmium



Appendix 5a: Copper data of absorbance versus concentration

Concentration(ppm)	Absorbance
0.1353	0.0016
0.4615	0.0061
0.9906	0.0134
2.0126	0.0275

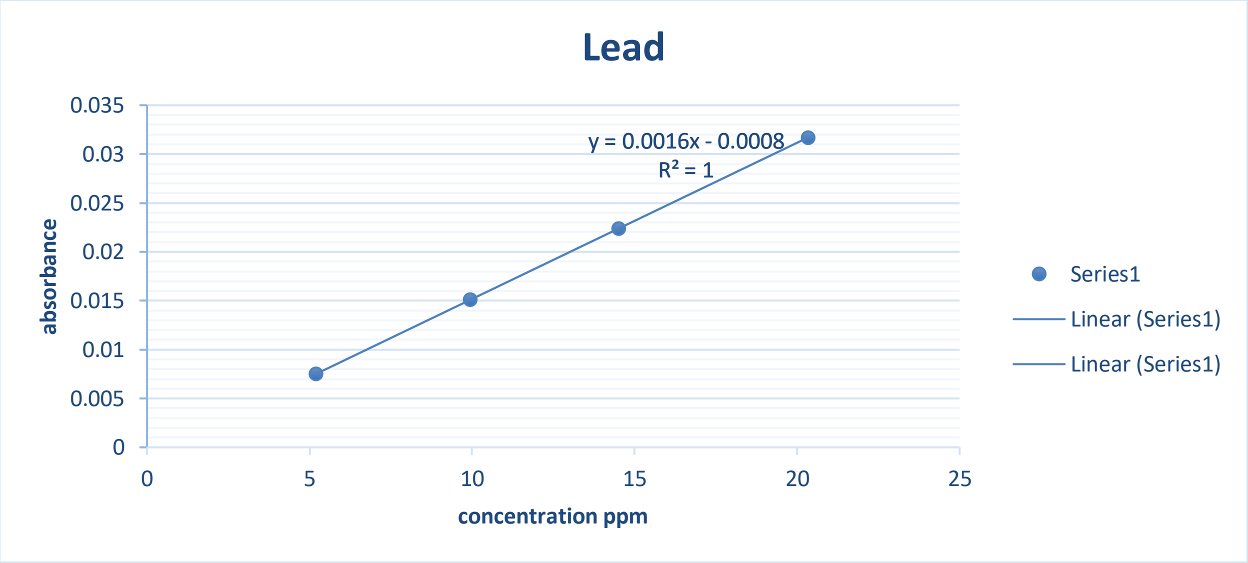
Appendix 5b: Calibration curve of copper



Appendix 6a: Lead data of absorbance versus concentration

Concentration(ppm)	Absorbance
5.1940	0.0075
9.9499	0.0151
14.5181	0.0224
20.3379	0.0317

Appendix 6b: Calibration curve of lead



Appendix 7a: Zinc data of absorbance versus concentration

Concentration ppm	Absorbance
0.0198	0.0011
0.1324	0.0070
0.2107	0.0111
0.2871	0.0151

Appendix 7b: Calibration curve of zinc