



UNIVERSITY OF NAIROBI

**ASSESSMENT OF WATER QUALITY FROM SELECTED BOREHOLES IN
NAIVASHA SUBCOUNTY, NAKURU COUNTY**

BY

**MOENGA DAVID NYAMWEYA
I56/80972/2015**

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Science in Analytical Chemistry of the
University of Nairobi.**

2020

DECLARATION

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


Signed.....

Date: 22-June-2020

This thesis has been submitted for examination with our approval as research supervisors:

Dr. John O. Onyatta

Signature



Date: 25th June 2020

Department of Chemistry

University of Nairobi

Prof. Amir O. Yusuf

Signature



Date: 25th June 2020

Department of Chemistry

University of Nairobi

Dr. Hezekiah K. Chepkwony

Signature



Date: 29th June 2020

Director NQCL

Ministry of Health



ABSTRACT

This study was undertaken to assess the quality of borehole water from Naivasha area in Nakuru County. High fluoride levels and the economic activities surrounding the area have raised a major concern over the quality of borehole water within the area. This study was conducted during the months of June 2017 to September 2018. Water samples were taken from 7 different boreholes namely: Matangi NNE (Karagita Area), Koinange Car Wash (Police Line Area), Ushirika Water Project (Kayole Area), Shamba House (Kabati Area), Keroche Borehole (Karate Area), Joywel School and a private borehole belonging to Geoffrey Kinyanjui. Each water sample was tested for pH and electrical conductivity using the pH/conductivity meter (Model: Jenway 3540), turbidity using the bench top turbidimeter (Model: HACH TU 5200), total suspended and dissolved solids (gravimetrically using dry filter papers and beakers), water color using the color analyzer (Model: LUTRON RGB-1002), fluoride using the EXTECH® fluoride meter, chloride using the MOHR's method with AgNO_3 standardized with M NaCl , chlorine using the EXTECH® chlorine meter, total hardness by complexometric titration with EDTA standardized with CaCO_3 , alkalinity - acid-base titration with H_2SO_4 standardized with Na_2CO_3 , manganese, cadmium, lead, copper, iron, chromium, sodium, potassium, zinc – using the AAS (Model: Shimadzu AA-6300), with respective standards and hollow cathode lamps, nitrates, sulfates were determined using the UV/Vis spectrophotometer (Model: Shimadzu UV-1800), and *E-coli* – using the multiple tube fermentation technique (MTF). A comparison was made with the East African Standard and the WHO drinking water guidelines. The results obtained were: pH (7.03-8.45); electrical conductivity (412-1218 $\mu\text{S}/\text{cm}$); turbidity (0.095-0.355 NTU); total suspended solids (1.93-48.00 mg/L); total dissolved solids (43-421 mg/L); water color (2-10 TCU); fluoride (1.20-5.00 mg/L); chloride (27.5-79.9 mg/L); chlorine (0.01-0.08 mg/L); sulfates (154.88-263.88 mg/L); nitrates (6.04-9.94 mg/L); sodium (8.74-17.81 mg/L); potassium (11.80-17.48 mg/L); alkalinity (168.62-511.35 mg/L); total hardness (28.6-85.78 mg/L as CaCO_3); manganese <0.01 mg/L; lead (0.0469-0.1962 mg/L); copper (0.1419-0.2139 mg/L); zinc (0.0236-0.0374 mg/L); iron (0.0210-0.1369 mg/L); chromium and cadmium were not detected and *E-coli* was found to be absent. The results were then compared with the East African Standard and the WHO guidelines for drinking water. The study showed that the total suspended solids, chlorine, fluoride and lead levels were higher than the WHO guideline values while the rest of the parameters met the guideline values. Based on the East African Standard and the WHO guideline for drinking water, none of the sampled borehole water was suitable for drinking purposes and therefore, there was need for some remediation before the water would be safe for drinking.

DEDICATION

This is dedicated to Prof. C.O. Ondari, my friend the late Richard ‘Jadha’ Sidindi and the Moenga’s family, my supervisors and everyone who in one way or another assisted me in making this a success.

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LIST OF ABBREVIATIONS, SYMBOLS AND ACRONYMS

AAS	-	Atomic absorption Spectrometer
AMD	-	Acid mine drainage
BH	-	Borehole
BGLB	-	Brilliant green lactose bile broth
CW	-	Car wash
EBT	-	Eriochrome black-T indicator
EAS	-	East African Standard
EC	-	Electrical conductivity
<i>E.Coli</i>	-	Escherichia Coli
EDTA	-	Ethylenediaminetetraacetic acid
EOLSS	-	Encyclopoedia of life support systems
EPA	-	Environmental Protection Agency
GK	-	Geoffrey Kinyanjui
HSE	-	House
ISE	-	Ion-selective Electrode
ISO	-	International Organization for Standardization
KEBS	-	Kenya Bureau of Standards
KSPCA	-	Kenya Society for the Protection and Care of Animals
LST	-	Lauryl sulfate tryptose broth
MTF	-	Multiple tube fermentation technique
ND	-	Not detected
NEMA	-	National Environment Management Authority

NGO	-	Non Governmental Organization
NMT	-	Not more than
NTU	-	Nephelometric turbidity units
PA	-	Phenolphthalein alkalinity
SCH	-	School
TA	-	Total alkalinity
TCU	-	True color units
TDS	-	Total dissolved solids
TH	-	Total hardness
TOC	-	Total organic carbon
TSS	-	Total suspended solids
UNESCO	-	United Nations Educational Scientific and Cultural Organization
UTI	-	Urinary tract infections
UV/Vis	-	Ultra Violet/ Visible Spectrophotometer
WHO	-	World Health Organization
WP	-	Water project
W/V	-	Weight to volume

CHAPTER ONE

INTRODUCTION

1.1 Background

Contamination of surface and groundwater has become an increased environmental concern in Kenya (Kenya National Water Development report, 2005). This is due to many different natural and anthropogenic activities that impact on the quality and the quantity of groundwater. This contamination is mainly due to rapid technological advances and population increase (Baba and Tayfur, 2011). Good quality water is an integral part of the environment, animals and human life (Shafqat *et al.*, 2012). Besides water covering an enormous percentage of the Earth's surface (about 70 %), it makes up to about 70 % of the human body mass (Shakhashiri, 2011). Its use for domestic consumption, agriculture and in industries is widespread. The sources of water in Kenya comprise of surface waters (wetlands, rivers, springs and lakes) and groundwater. Oceans and seas are the major sources of the world's precipitation, which constitutes about 97.5 %. Fresh water makes up the remaining 2.5 % of which 68.9 % is trapped in glaciers and ice caps, 30.8 % is underground water (boreholes and wells) and 0.3 % is the surface water (rivers and lakes) (UNESCO, 2003).

Increased human consumption, receding wetlands, pressure of the rising population, rainfall variability and climatic changes have put a strain on the availability of water. For the said reasons, Kenya has become vulnerable to most of the economic activities that are water dependent. Activities such as: tourism, trade, agriculture and manufacturing rely heavily on water (Ministry of Water and Irrigation Report, 2016). These activities also offer avenues

through which water is polluted. Continuous strain on the Earth's water supply has resulted in its scarcity which in turn has necessitated a search for new sources. Among these sources is groundwater which offers a great alternative source of water to the general public. Groundwater therefore is among the Nation's important natural resources (Kalanithi *et al.*, 2015; Hari *et al.*, 2016) It provides a significant input to the National public water supply mainly through Boreholes and Wells. Conditions of recharge, rock conditions and anthropogenic activities cause variations in quality of groundwater resources. Groundwater is considered fit for such uses as domestic, industrial use and for irrigation (Jadhav *et al.*, 2012; Ministry of Water and Irrigation Report, 2016).

A number of urban centres in Kenya rely greatly on groundwater for public and private water supply. These include: Nakuru, Naivasha, Wajir, Mandera and Lodwar (Mumma *et al.*, 2011). To the North West of Nairobi lies Naivasha, an urban centre at about 2084 m above the sea level. Naivasha derives its name from the Masaai community, 'Nai' Posha' to mean a place of 'Rough Water'. Just like other emerging urban centres, there is rapidly growing low-income settlements that have resulted from the floricultural practises within the locality (Norman and Parker, 2011). Following the 2009 census report (KNBS, 2009), the populace of Naivasha was reported to be 376,243 which has increased steadily (about 35% increase) and currently (2019) stands at approximately 507,928 persons. Water use in Naivasha is to a large extent dictated by the land use within the catchment area or the activities that require water within the area. A significant amount of the water is used for irrigation in flower farms and for domestic purposes. Besides the mentioned activities, urban centres have witnessed an increased rise in car washing stations, water recreational parks

and water vending kiosks that heavily rely on groundwater. The natural water catchment areas have been adversely affected by climatic changes and degradation of the catchment areas because of increased farming activities and river flows that are continually declining. The quality of the water has been adversely affected for various reasons among them being natural and other anthropogenic activities (De jong, 2011). The Naivasha Municipality's population is largely distributed around Lake Naivasha and the hills nearby. The low-income settlement areas include: Mirera, Karagita, Kamere and Kasarani. An NGO, Water and Sanitation for the Urban Poor (WSUP) has tried to improve on the availability of water in the area by construction of boreholes and supplying water to the locals through water kiosks (Norman and Parker, 2011).

Water quality is among the concerns of the regulator before borehole construction commences. This however is performed at the time of licensing but subsequent monitoring is often neglected (UNDP, 2011).

Considerable emphasis has been laid upon groundwater as an important source of clean water in many urban set ups and rural areas. In semi-arid areas, the general population relies entirely on groundwater. As much as groundwater contains a variety of essential minerals ranging from trace to high concentrations; it also contains contaminants such as fluoride which is found in the Kenyan rift (Gaciri and Davies, 1993). Apart from microbiological contamination, groundwater is also contaminated by heavy metals from natural and anthropogenic activities. These factors have greatly impacted on the quality of groundwater (NWSS,2016).

Since the local population in Naivasha have relied on boreholes as a crucial drinking water source and for other household purposes, this study was aimed at assessing the parameters that affect water quality in the area with the aim of establishing suitability for domestic use.

1.2 Statement of the problem

Borehole water quality in Naivasha is of concern because boreholes are considered a vital source of drinking water in the locality. However, there are some parameters that are a threat to the quality of water such as high fluoride levels above the WHO recommendation (1.5 mg/l) that have been reported in Naivasha area in rivers, soils, air and lake Naivasha (Rombo and Muoki, 2012).

1.3 Objectives of the study

1.3.1 General Objective

The general objective of this study was to assess some the water quality parameters in selected boreholes in Naivasha sub county, Nakuru County.

1.3.2 Specific Objectives

The specific objectives of this study were:

- i. To determine the physicochemical properties of selected borehole water in Naivasha sub county, Nakuru County.
- ii. To determine the levels of some selected anions and cations in borehole water.
- iii. To determine the levels of some selected heavy metals in the borehole water.
- iv. To determine the level of *E.coli* in the borehole water.

- v. To evaluate the water quality based on permissible levels of the water quality parameters.

1.4 Justification and significance of the study

Borehole water assessment is often conducted at the time of commissioning of the borehole but subsequent assessment is seldom conducted (UNDP, 2011). Therefore, there was need to assess the quality of these borehole waters by determining some water quality parameters since there were no records as to when any water quality assessment was conducted in the area. The assessment provided information on the nature of human activities within the area and their impact on groundwater quality. The Ministry of Water and Irrigation Report (2016) had raised concerns on human activities around the boreholes and the ground water quality. The results from this study would serve as an information source on the borehole water quality and its suitability for its use by the area residents. The study identified the human activities that are of concern to water quality and their impact on the suitability of the borehole water. Furthermore, the results are significant in forming the basis for further studies on borehole water quality in the area and in formulation of regulatory strategies for the management of underground water in Naivasha.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water quality

These are the physicochemical and biological attributes of water whose levels define its suitability for the intended use. The levels of these parameters differ widely and are set depending on the intended use (EPA, 2001). Water quality varies rapidly and sometimes fails depending on the prevailing environmental conditions. (WHO, 2006).

2.2 Physicochemical parameters of water

The quality of water may be described by its physical and chemical attributes. Researchers have applied physicochemical properties to assess the drinking water quality (Manjare *et al.*, 2010). In this study, physicochemical properties of borehole water from Naivasha were analyzed. The parameters included:

2.2.1 pH

This is the measure of the negative hydrogen ion logarithm. Water becomes more acidic when the pH decreases and more basic as it increases. pH changes in water may affect the concentrations of other components to more toxic forms. An increase in soluble mercury in water may be caused by a decrease in the pH. An increase on the other hand, enhances conversion of the ammonium ion to toxic ammonia. The pH of water is also affected by dissolved gases. The pH of a substance is measured using a pH meter (ILMB,BC 1998). The acceptable values of pH for drinking water according to the East African Standard and the WHO guideline for drinking water is given as 6.5 – 8.5 (WHO, 2011).

2.2.2 Turbidity

Turbidity and color of water are parameters that impact on the appearance of water. Turbidity in water is effected by suspended or dissolved particles which cause light scattering and gives the water a murky or cloudy appearance. It occurs when there is reduced transparency as a result of the presence of particulate matter or suspended sediments such as: fine organic matter, plankton or microscopic organisms and clay or silt. The sediments can carry pathogens, pollutants and nutrients. In the aquatic life, they are responsible for clogging of fish gills (ILMB,BC 1998). Turbidity causes light scattering or absorption causing water to appear murky or cloudy (Minesota Pollution Control Agency, 2008). It is determined by use of a Nephelometric laser turbidimeter and reported in Nephelometric Turbidity Units (NTU). The maximum allowable value for turbidity is given as 1 NTU for the East African Standard and the WHO guideline for drinking water (WHO, 2011).

2.2.3 Electrical conductivity

It is the attribute that makes water able to conduct an electric charge. This occurs because of the existence of free charges in water. It is used to estimate the total ionic concentration in water. Conductivity is reported in microsiemens per centimeter ($\mu\text{S}/\text{cm}$) or millisiemens per centimeter (Compendium for Watershed Monitoring and Assessment, 2010), by use of a conductivity meter. The maximum acceptable limit of conductivity for drinking water according to the East African Standard and the WHO guidelines for drinking water is given as 2500 $\mu\text{S}/\text{cm}$ (WHO, 2011).

2.2.4 Water color

Water color is brought about by colored organic matter usually humic and fulvic acids and inorganic ions that are present in water due to soil humus. Industrial effluents also play a crucial role in giving water color and so does corrosion products, as well as natural impurities. Water color is measured in true color units (TCU) using a color analyzer. The maximum acceptable limit of color for drinking water according to the East African Standard and the WHO guidelines for drinking water is given as 15 TCU (WHO, 2011).

2.2.5 Total Suspended Solids (TSS)

TSS is matter that is not dissolved completely in water. The solids can be filtered and hence remain on a filter when water is filtered through (ISO 3025 part 16). The suspended material gives water a poor aesthetic value and provide sites for adsorption of biological as well as chemical agents (ISO 3025 part 16). The amount of suspended solids is determined gravimetrically. The East African Standard and the WHO guideline for drinking water however state that there should not be any suspended solids in drinking water (WHO, 2011).

2.2.6 Total dissolved solids (TDS)

This is matter that is dissolved completely in water. The solids can be filtered and are always left behind as a residue in a vessel whenever water is evaporated and further dried at a specified temperature (ISO 3025 part 16). High values of TDS in water makes it unsuitable for domestic use (ILMB,BC 1998). The dissolved solids lead to scaling in boilers, corrosion and degradation of metallic products (ISO 3025 part 16). The amount of dissolved solids is determined gravimetrically. The East African Standard and the WHO guidelines for drinking water give the maximum value of dissolved solids as NMT 1500 mg/L (WHO, 2011).

2.3 Inorganic constituents

Ionic constituents that may affect water quality include: fluoride (F^-), chloride (Cl^-), nitrates (NO_3^-), ammonium (NH_4^+), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and sulfates (SO_4^{2-}) among others (Ndungu *et al.*, 2015).

2.3.1 Fluoride

Fluoride occurs in nature as fluorspar (CaF_2), cryolite (Na_3AlF_6) and fluoroapatite ($Ca_5(PO_4)_3F$) (Mutonga, 2014). Most of the Kenyan water fluoride is as a result of volcanic activity arising from the weathering of rocks and rift valley formation (Gaciri and Davies, 1993).

Exposure to concentrations of fluoride amounts of more than 1.5 mg/L results in skeletal fluorosis which may result in bone deformation (Figure 1.1). It also causes discoloration of teeth or dental fluorosis. This condition affects the dental enamel leading to brown, yellow and sometimes opaque white colour which appears as horizontal bands on the teeth. (Figure 1.2) (Ochieng and Kyende, 2013).



Figure 1.1: Deformation of bones caused by skeletal fluorosis.

(Source: <http://www1.lehigh.edu/news/patented-nanotechnology-clean-drinking-water>)



Figure 1.2: Manifestation of Dental fluorosis exhibited on this child's teeth.

(Source: <http://www.de-fluoride.net/fluorosis.html>)

2.3.2 Water hardness

This results from the presence of calcium and magnesium ions. Calcium ions result from the dissolution of carbonate rocks by the carbonic acid in water or from gypsum that is common in sedimentary rocks. Ca^{2+} ions are the majority of all cations in low-mineralized water. Magnesium ion is more abundant in water compared to calcium. The increase in concentration of Mg^{2+} ion in water is enhanced due to its weaker biological activity (Nikanorov and Brazhnikova, 2009). These two ions when present in water cause hardness and scale-forming properties. Hardness is determined titrimetrically using standard EDTA. The maximum allowable amount is given as 300 mg/L as CaCO_3 (WHO, 2011).

2.3.3 Sulfates

Most of the surface and ground water contain SO_4^{2-} ions that originates from various sedimentary rocks or from oxidation of sulfide and hydrogen sulfide. The presence of SO_4^{2-} ions in water is however limited by the formation of CaSO_4 that is slightly soluble in water

(Nikanorov and Brazhnikova, 2009). High levels of sulfates have an over laxative effect and give water a bitter test when combined with other ions (Driscoll *et al.*, 2002). The mineral content of water has a great contribution of sulfates as barite, epsomite and gypsum (ISO 3025 Part 24). Acid Mine Drainage (AMD) makes a generous contribution of sulfates to ground water is through oxidation of pyrite (ISO 3025 Part 24). The East African Standard and the WHO guidelines for drinking water have however not indicated the maximum allowable values for sulfates.

2.3.4 Manganese

The element manganese occurs naturally in the Earth's crust constituting about 0.1%. Its occurrence is not in the pure form. It occurs at low levels in water and food resulting from many human activities including production of matches, fireworks, dry-cell batteries and fertilizers (EPA, 2003). At trace levels, manganese is a vital element to human life. It is mostly found in bones, adrenal and pituitary glands and other body tissues with a major role of digestive enzymes activation, production of energy, and metabolism of iron and anemia prevention. In high amounts, manganese causes a syndrome known as manganism that further leads to Parkinson disease, anorexia, muscle pain and slowed speech (WHO, 2011).

2.3.5 Iron

Iron is found in soil material partly in an oxidized solid state or in a dissolved form. Its presence in aquifers is dependent on the oxygen state of the aquifer, its structure and the aquifer characteristics (Hatva. 1989). Iron is an essential mineral being a major component of hemoglobin which transports oxygen throughout the body tissues. It occurs naturally in foods and also as a dietary supplement. Owing to its ability to create free radicals, iron has

to be kept within balance in the body and this is because it may lead to damage to the body tissues due to iron overload or anemia in case of deficiencies (Abbaspour *et al.*, 2014). The most allowable amount of iron in water for drinking is given as 0.3 mg/L (WHO, 2011)

2.3.6 Chloride

Chloride occurs naturally in water. It occurs as halite or sodium chloride, potassium chloride and calcium chloride in the Earth's crust (Kelly *et al.*, 2012). The high solubility of these chloride salts is responsible for the high migratory ability of the Cl^- ion. High concentrations of the Cl^- ion in water causes corrosion of metallic pipes (Driscoll *et al.*, 2002). Chloride gives a salty taste when combined with sodium to make sodium chloride (NaCl). High levels of chloride are not thought to be harmful however, high levels of sodium are known to cause hypertension, heart and kidney failure (WHO, 2003). The maximum allowable level for chloride in water for drinking is given as 250 mg/L (WHO, 2011).

2.4 Heavy metals

Heavy metals are metallic elements whose density and atomic weight that is more than 5 times that of water (Tchounwou *et al.*, 2012). They occur naturally in varying amounts depending on the location. Significant amounts of heavy metals finds their way into groundwater through various avenues. Some of them come from industrial production and emissions, leaching during transportation and other human activities like farming through application of fertilizers and deliberate disposal of the heavy metals in landfills. These metals consequently find their way into the human body through drinking of polluted water, inhalation of their dust or consumption of vegetables that have taken up the metals through

their roots (Nazir *et al.*,2015). The properties of some of the selected heavy metals are described below:

2.4.1 Cadmium

The Earth's crust contains about 0.1 mg/kg of cadmium accumulated largely on sedimentary rocks. It has found widespread use in industry in production of batteries, pigments and alloys. Humans are exposed to cadmium through: direct inhalation and ingestion of foods that may contain trace amounts like fish from polluted waters. Cadmium finds its way around the body through the blood circulatory system and as a consequence causes gastrointestinal corrosion, pulmonary irritation, renal failure and possibly death. Lung damage is another effect of cadmium to the body and this occurs as a result of inhalation of high levels of cadmium (Tchounwou *et al.*, 2012). The most allowable amount of cadmium in water for drinking is given as 0.03 mg/L (WHO, 2011)

2.4.2 Chromium

Most of the sedimentary rocks contain chromium and chromium compounds. These compounds may then leach into groundwater. Chromium has gained great reputation for its use as metal protective coating, magnetic tapes, metal alloys and as pigments for rubber, cement, paints, floor tiles and other materials. Chromium (III) is a known essential nutrient while, chromium (VI) compounds are harmful to the body. Inhalation of high levels of chromium is reported to cause ulcers in the nose lining, breathing complications like asthma, chronic coughs and wheezing. Contact with the skin also causes skin ulcers whereas long term exposures are a major contributing factor to liver damage and neurotic damage (Centre for Hazardous Substance Research, 2009). The utmost allowable level of chromium in water for drinking is given as 0.05 mg/L (WHO, 2011)

2.4.3 Lead

Lead is toxic. However, it has been used for decades as an additive to petroleum products, productions of batteries, ammunition and shielding devices for X-rays. Other uses include production of paints and solder wires. Exposure to lead is through: drinking of water contaminated with lead in old water pipes in older homes, use of lead containing cosmetics and lead based paints among others (Jaishankar *et al.* 2014). Long term exposure to lead has been reported to cause nervous system impairment, weakness in joints, blood pressure increase and anemia. Accumulated amounts of lead results in brain and kidney damage that would lead to death. It can also cause miscarriages in expectant women. In men, it is known to cause low sperm count due to damage to the reproductive organs (Centre for Hazardous Substance Research, 2009). The maximum permissible amount of lead in water for drinking is given as 0.01 mg/L (WHO, 2011)

2.4.4 Zinc

Anthropogenic accumulation is the leading cause of the unnatural increase of zinc in the environment. Industrial activities like mining, processing of steel and combustion of waste have made a significant contribution to the increase of zinc amounts in the environment. Drinking of zinc polluted water is also a known avenue through which zinc enters the human body. This occurs normally by drinking water stored for a long time in zinc containing metallic tanks. Zinc deficiencies may cause birth deformities and for such reasons, it is essential in trace quantities to the human development. However, high amounts of zinc are a health concern as it causes stomach cramps, nausea and vomiting (Wuana and Okieimen, 2011). The utmost allowable level of zinc in water for drinking is given as 5 mg/L (WHO, 2011)

2.4.5 Copper

Ground water contains copper, however its presence is primarily as complexes. Its amounts are mainly affected by such factors as, hardness, pH and the availability of copper around the aquifers (WHO, 2011). Nutritionally, copper is an essential element in the formation of connective tissues and the proper function of the nervous and immune system, muscle functions and production of red blood cells. It is also essential in prevention of bone defects. In high doses copper can be toxic leading to nausea, kidney failure and sometimes death. The maximum allowable value for copper is given as 2 mg/L (WHO, 2011)

2.5 Biological water quality parameters

2.5.1 *Escherichia coli (E.coli)*

This is a bacterial type that makes up the total coliform group of bacteria. It is likely to be found in the intestines of mammals, humans included. It is normally harmless in the intestines however in other parts of the body, it causes such disease as urinary tract infections (UTIs), meningitis and bacteracemia among others (WHO, 2006). *Escherichia coli* presents itself in large amounts in human and animal faeces and thus can cause faecal water pollution if the wastes find their way into any water body (Servais *et al.*, 2002). The level of *E.coli* can therefore be used as a biological quality indicator for drinking water and is determined in terms of colony forming units in 100 mL of the sample (CFU/100mL) (New Hampshire Water Well Board, 2010)

2.6 Instrumental methods of analysis

2.6.1 Fluoride Ion-selective electrode

Fluoride is often analyzed by use of an Ion-Selective electrode (Bratovcic and Odobasic, 2011). This electrode measures the potential difference between the analyte and the ion-selective electrode. Current is conducted through the interface due the presence of the analyte in solution and this depends on how the analyte interacts with the membrane surface (Bratovcic and Odobasic 2011.). This determination follows the Nernst equation (Equation 2.1) which can be represented in a straight line according to equation 2.2:

$$E = E^0 + (2.303/nF) \log a \quad (2.1)$$

$$y = mx + c \quad (2.2)$$

where: $y = E$ = Total potential (mV) or the electrode response

n = number of moles of the electrons

$x = \text{Log } a$ = measured ion activity logarithm

$c = E^0$ or the y intercept

F = Faraday's constant 96485 C/mole.

However, to conveniently apply the above equation, complexes should be avoided since the electrode is only sensitive to free ions. A plot of the measured electrode potential (mV) against the log of concentration gives a straight line with a negative slope (Bratovcic and Odobasic, 2011). A calibration of the electrode has to be performed prior to the analysis with solutions whose concentrations are known. Standard solutions are prepared to provide at least 5 -6 point calibration to cover the range within which the concentration of the unknown is expected to lie. In some cases the standard addition method may be applied in case the analyte concentration is significantly low (Rajković *et al.*, 2007).

2.6.2 Atomic absorption spectrometry (AAS)

This technique is used in elemental analysis in a sample. An atom in a low energy level absorbs light energy of wavelengths that are characteristic to the element when light passes through atoms that are vaporized. The amount of light absorbed is reliant on the vaporized atoms concentration in the sample. Therefore, the measured absorbance is can be used to quantify the amount of the element in the sample. The hollow cathode lamp (HCL) emits a light signal which is specific to the element that is being analyzed. The beam is illuminated through the flame where the aspirated sample is atomized. The flame is produced by a fuel gas (acetylene) and a support gas (air). A deuterium lamp produces a reference beam which is not illuminated through the sample. The reference beam and the sample beams are directed to the chopper mirror where they are modulated and then directed to the monochromator where dispersion occurs and light of a specific wavelength is isolated which then goes to the detector (Beaty and Kerber, 1993). The detector then computes the light intensity and amplifies the given signal. The given readout represents a ratio of the sample beam relative to the reference beam. The Beer – Lambert’s law (Equation 2.3) gives a description of how the measured absorbance relates to the analyte concentration. The absorbed energy is in direct proportionality to the analyte concentration (WHO, 2006)

$$A = \epsilon lc \quad (2.3)$$

Where: A = Absorbance

ϵ = absorptivity constant

l = cell path length (cm)

c = concentration of the analyte

A schematic diagram of AAS is shown in Figure 2.1

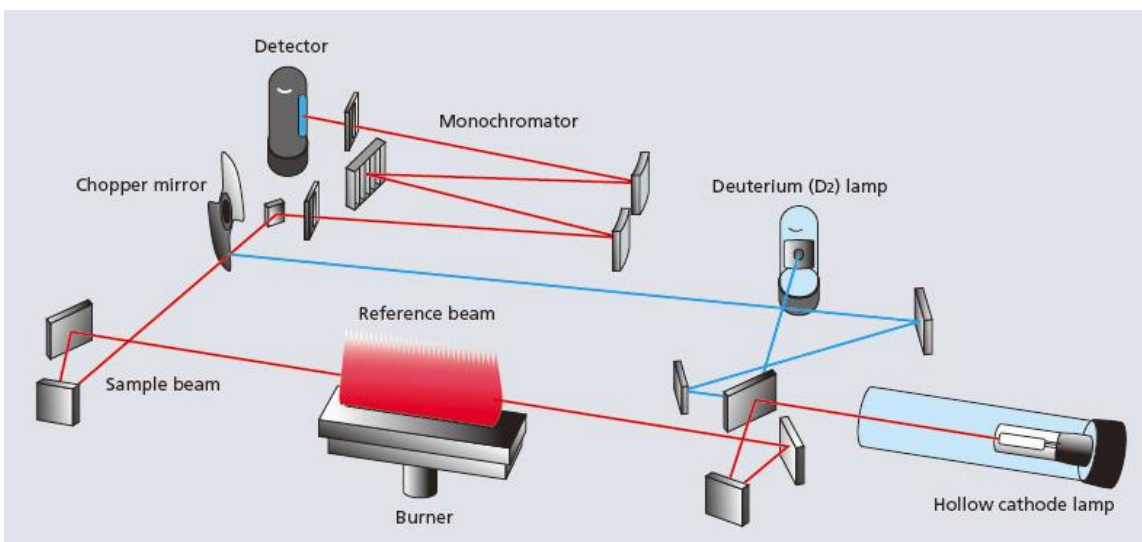


Figure 2.1 : Schematic diagram of an AAS.

(<https://www.shimadzu.com/an/elemental/aa/aa6200-3.html>)

2.6.3 UV/Vis spectrometry

This is a colorimetric analytical technique that has a basis on the Beer-Lambert's law (Equation 2.3). The proportion of the absorbed electromagnetic radiation by a sample is measured at a specific wavelength. UV or Visible light is illuminated through a sample in a cell and the transmitted intensity is measured. A visible or ultra violet beam from the source is reflected by a mirror and then directed to the monochromator where it is split into its components by a prism. The monochromatic beam is divided into two beams of similar intensity by the half mirror. The beam of the sample goes through a cuvette holding the sample in a suitable diluent while the reference beam goes through another cuvette with the diluent. The beams then go to the detector where their intensities are determined (Sanda *et al.*, 2012).

The analyte concentration in a given sample determine the intensity of the absorbed radiation. A calibration curve is then obtained by use of known concentrations which is

subsequently used to quantify the sample analyte concentration. Compounds that have a chromophore absorb UV light of wavelength between 190–380 nm relative to their concentration. UV/Vis therefore can be used to identify and quantify organic substances, because of the presence of a chromophore in organic compounds (WHO, 2006).

A schematic diagram of a UV/Vis spectrometer is shown in Figure 2.2

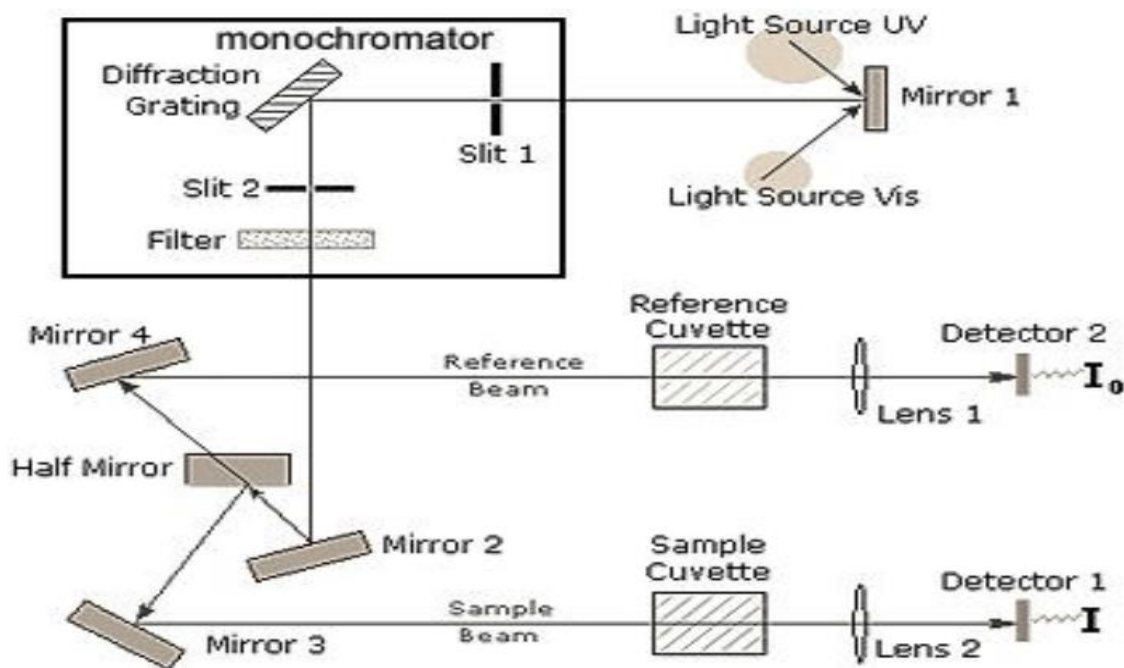


Figure 2.2: Schematic diagram of a double beam UV/Vis spectrometer.

(Source: https://www.researchgate.net/figure/A-dual-beam-UV-vis-spectrophotometer-8_fig20_314081363).

2.6.4 Laser Turbidimeter

Foreign particles suspended in water cause scattering of incident light and a subsequent change of direction. Particles like clay, silt, algae and other organic matter particles cause directional changes to the illuminated light. The resolution of determined turbidity is in direct proportionality to the angle of incident light and the position of the detector. The 90°

angle is the most sensitive (Omar and MatJafri, 2009). The higher the turbidity, the greater the scattering of light. Turbidimeters measure scattering of a portion of light through a 90° angle to that of the incident. (Omar and MatJafri, 2009).

A schematic diagram of a nephelometric turbidimeter is shown in Figure 2.3

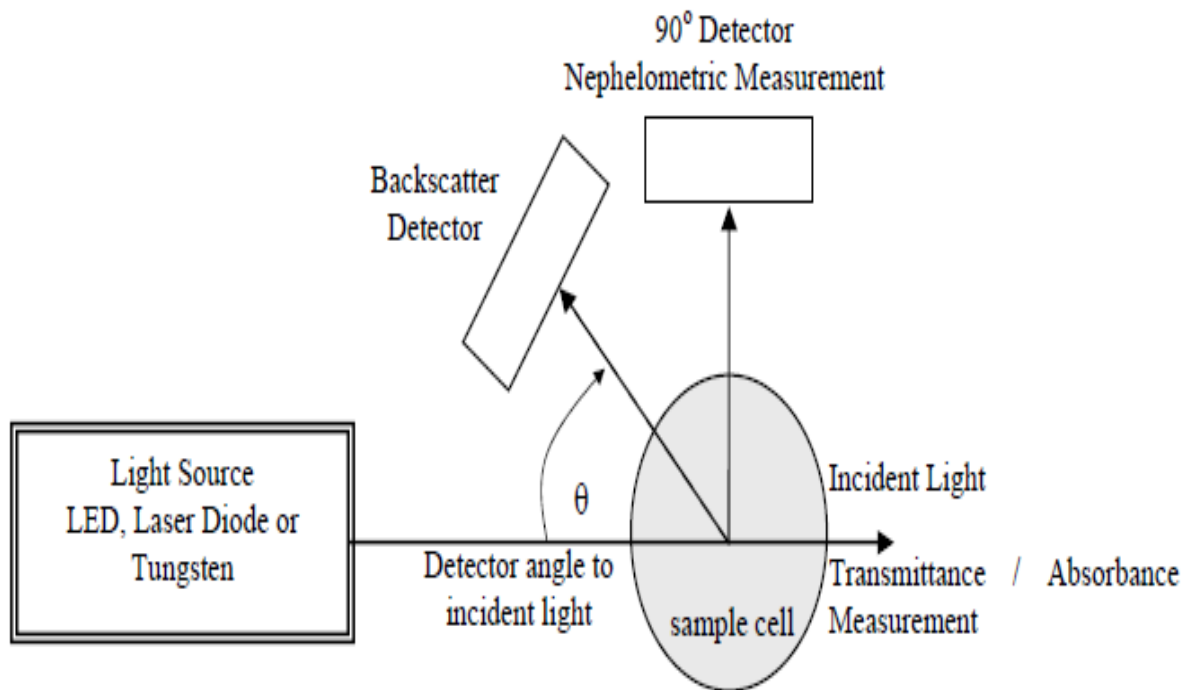


Figure 2.3: Schematic diagram of a Nephelometric turbidimeter

(Source: Omar and MatJafri, 2009)

2.7 Other methods of analysis

2.7.1 *Escherichia coli* (*E.coli*)

This is determined by use of the multiple tube fermentation technique (MTF). Serial dilutions of the water samples are made and then the samples are analyzed. Each of the samples are used to inoculate tubes of culture medium. In the presumptive/ isolation test, a series of tubes containing lauryl tryptose (lactose) culture medium are inoculated with

appropriate sample dilutions incubated at a defined temperature for a stated amount of time. Turbidity in the culture medium, presence of gas and/or pH change indicate presence of coliforms. Brilliant green lactose bile broth (BGLB) is used as the culture media in the confirmation test for total coliforms and *E. coli* medium for faecal coliforms (UNEP/WHO, 1996).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The research was carried out within Naivasha Sub County, Nakuru County. Naivasha is a commercial town located to the North Western side of Nairobi (about 90 km from Nairobi) and forms part of the county of Nakuru. It is at 2086 m above the level of the sea and $0^{\circ} 43' 0''$ S and $36^{\circ} 26' 0''$ E (latitude and longitude respectively). The soil in the area is generally volcanic and alkaline in nature. It is quite permeable and contains high amounts of sodium, fluoroapatite, flourspar, zeolite, and ammonia among other minerals (Becht *et al.*, 2005). The map of Naivasha Sub County is given in Figure 3.1.

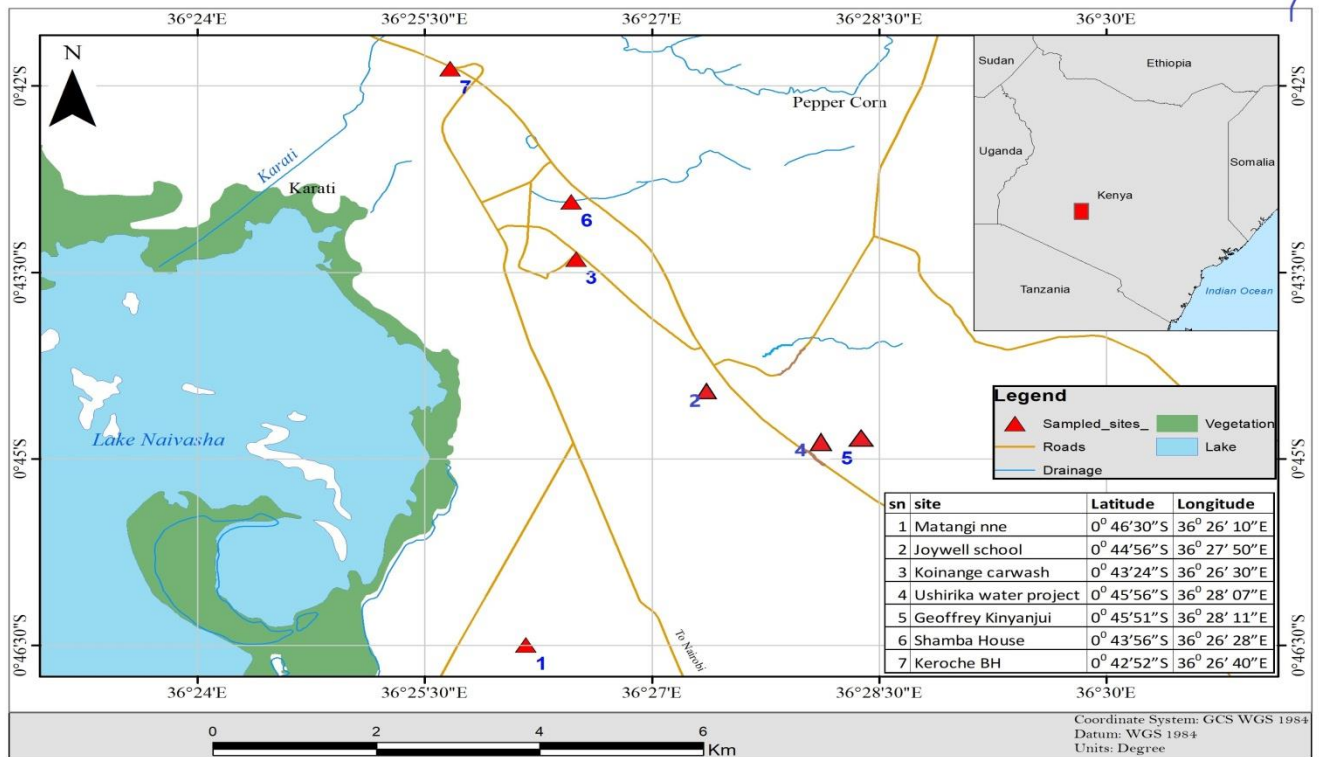


Figure 3.1: Map of Naivasha Sub Count, Nakuru County showing the boreholes numbered

1-7.

3.2 The sampling locations

Water was sampled from Seven (7) boreholes in different locations in Naivasha Sub County. The sampling locations were selected based on their proximity to horticultural farms (to check whether they impacting on the water quality), proximity to auto repair garages and other small scale industries, ownership of the boreholes and population that the boreholes served in a day. All the seven (7) sampled boreholes were sealed.

Matangi Nne Borehole (1) is located at $0^{\circ} 46' 29.84''$ S, $36^{\circ} 26' 9.97''$ E in the Karagita Area. The borehole was drilled and constructed in 2002 with a depth of about 180 feet. It is located next to the Wildfire Flower Farm. Four overhead water tanks were hoisted next to the borehole hence the name “Matangi Nne”. The borehole serves most of the Karagita area and is used for drinking, cooking, small scale farming and other domestic activities. Surrounding the borehole are various activities among them: floricultural farming, hospitality (Hoteliers) and small scale farming. There is also an elaborate piping network whereby the borehole supplies treated and untreated water to the nearby estates, Kiwa House and the Kenya society for the protection and care of animals (KSPCA) Naivasha. Water quality tests had been conducted in the past.

Joywel Academy Borehole (2) is located at $0^{\circ} 44' 56.28''$ S, $36^{\circ} 27' 51.50''$ E. It was constructed by the Joywel Primary School. It has a depth of about 165 feet. Water from this borehole is used for domestic purposes, drinking, cooking and cleaning. Activities surrounding the borehole include car washing and carpet cleaning, building and construction. The water sampling process at the Joywel School borehole is shown in Figure 3.2.



Figure 3.2: Sampling at the Joywel Primary School borehole

Koinange Car Wash borehole (3) is located at $0^{\circ} 43' 23.65''$ S, $36^{\circ} 26' 29.80''$ E in Police line Area of Naivasha town. The area is predominantly surrounded by motor vehicle garages, car wash and carpet cleaning services and a trading center. This borehole was constructed in July 2013, with a depth of > 150 feet and serves over 160 people per day. There is a water tower present at the borehole site. Domestic use, carpet cleaning and car washing are the main uses of water from Koinange Car Wash borehole. At the time of sampling no previous tests had been conducted on the said borehole.

The Ushirika Water Project borehole (4) is located at $0^{\circ} 44' 55.49''$ S, $36^{\circ} 28' 6.53''$ E in Kayole Area about 200 meters off the Naivasha-Nakuru highway. This borehole was constructed in June 2012 after the previous one was blocked. It is 226 feet in depth. It serves over 160 people who use the water mostly for domestic purposes, farming, drinking and

cooking, car washing and animal raring. Water bowsers also fetch water from this borehole. Quality tests had been conducted in 2015. The borehole did not have a water tower present. The Ushirika Water Project borehole in Kayole Area is shown in Figure 3.3.



Figure 3.3: Ushirika Water Project borehole in Kayole Area.

The Geoffrey Kinyanjui borehole (5) is located at $0^{\circ} 44' 50.67''$ S, $36^{\circ} 28' 11.11''$ E within the Kayole area. The owner of this borehole had constructed the borehole in 2014 solely for cattle raring and processing of milk and milk products. The borehole is about 230 feet deep with a water tower. The borehole serves the owner's domestic use, farming, cattle raring and milk processing and about 100 to 150 other people in a day. Main activities surrounding the

area were: farming, cattle rearing and building and construction. Quality tests for the said borehole are conducted biannually. The Geoffrey Kinyanjui borehole is shown in Figure 3.4.



Figure 3.4: Geoffrey Kinyanjui borehole

Shamba House borehole (6) is located at $0^{\circ} 42' 56.31''$ S, $36^{\circ} 26' 27.91''$ E within the Kabati Area. This Borehole was constructed in the year 2000. It had a depth of > 200 feet and is well covered. However, there was no water tower present. The borehole serves about 300 people in a day. The main activities surrounding the borehole included: trading and building and construction. The people around the area use the water mostly for domestic purposes, cooking, drinking and for other animals. Quality tests had been conducted in the past.

However, no documentation about the same was available. Water sampling at Shamba House borehole, Kabati Area is shown in Figure 3.5.



Figure 3.5: Sampling at the Kabati Area – Shamba House.

Keroche borehole (7) is located at $0^{\circ} 41' 51.69''$ S, $36^{\circ} 25' 39.99''$ E in Karati Area. It is owned by the Keroche Breweries. It is about 350 meters from the main road and about 15 kilometers from the Keroche Industries. The borehole was constructed purposely for use in the brewing activities. It thus serves the Keroche Industries and the people around Karati area that is surrounded by small scale farms. It has a water tower. Keroche Industries routinely conduct quality tests and treatment for further use within the industry. The Keroche borehole in the Karati Area is shown in Figure 3.6.



Figure 3.6: Keroche Industries Borehole in Karati area

3.3 Sample collection

The samples were taken into previously cleaned and dried plastic containers. Water from the borehole was used to rinse the plastic containers at least twice. The samples were then taken into the containers and stoppered to avoid contamination. The containers were then labeled with such information as: The date of sampling, amount sampled, name of the personnel conducting the sampling, name of the borehole and the location where the borehole was located. For total metal analysis, the samples were taken into different containers and about 2 mL of conc. nitric acid was then added. Other information was filled in the sample collection form which included: the name of the borehole, a reference number given to the sample, amount of sample collected, the date of drilling and construction, presence or absence of a water tower, the population the borehole served per day, economic activities

surrounding the area, major uses of the borehole water and the mode of water collection from the area and whether quality tests had been conducted in the past. The form also had the type of tests conducted at the point of sampling namely: The samples temperature, pH and the electrical conductivity. The samples were transported to the laboratory. Some samples were kept in clean sterile 100 mL bottles for biological testing in a refrigerator at a temperature of between 2-8 °C.

3.4 Experimental procedure

3.4.1 pH

To determine the samples pH, the Jenway 3540 pH and conductivity meter was used. It was first calibrated before use at room temperature using pre-prepared buffers of pH 2.0, 4.0 and 7.0. After calibration, each of the samples was poured into a previously cleaned and dried 100 mL beakers. The samples pH were then determined dipping the pH probe into the samples while stirring using a magnetic stirrer. Three determinations were made for each sample then the average values were taken as the samples pH.

3.4.2 Electrical conductivity

The Jenway 3540 pH and conductivity meter was used to ascertain the samples Electrical conductivity. The probe was calibrated by use of a 12.88 $\mu\text{S}/\text{cm}$ KCl solution at 25 ° C. Each of the samples were placed into 100 mL beakers and their Electrical conductivity determined by placing the conductivity probe into each of the samples. Three determinations were made for each sample and the averages recorded.

3.4.3 Turbidity

The HACH TU5200 bench top turbidimeter was used to ascertain the turbidity of the samples. A 2 point standard calibration (std 1: 20 NTU, std 2: 600NTU) was done on the instrument and thereafter a standard verification (10 NTU) before the samples analysis. The sample cell was then rinsed using deionised water. Each of the samples were taken into the sample cell and then placed into the sample holding compartment for subsequent determination. The displayed value was then recorded.

3.4.4 Water color

The water color determination was performed using the LUTRON RGB-1002 color analyzer. The machine was calibrated using the provided white color calibration card in the no light mode. The samples were placed in clear 100 mL beakers. The measurement probe was then held firmly against the beaker and the displayed value recorded.

3.4.5 Total suspended solids (TSS)

Filter papers were labeled for the respective samples and placed on evaporating dishes. They were then dried for 2 hours in a vacuum oven at 105 ° C. The filter papers were then weighed after cooling them for 45 minutes in a desiccator and their respective initial weights recorded (W_1). 300 mL of the respective samples was then passed through the respective filter papers which were again placed on the evaporating dishes and dried for 2 hours in the oven at 105 C and then cooled for 45 minutes in a desiccator. They were then weighed and their final weights recorded (W_2). The formula below was used to ascertain the sample's total suspended solids

Formula: Total suspended solids (TDS mg/L) = $(W_2 - W_1) \times 1000 / \text{Vol.}$

Where: W_1 = Initial filter paper weight (mg)

W_2 = Final filter paper weight (mg)

Vol. = Volume of the sample (mL)

The TSS in the samples were given in mg/L.

3.4.6 Total dissolved solids (TDS)

250 mL beakers that had been previously dried for 2 hours in the oven at 105 ° C and cooled in the desiccator for 30 minutes were weighed and their weights documented (W_1). 200 mL of each of the filtered samples were taken into the respective beakers and then evaporated to dryness on a heating mantle. The empty beakers plus the residues were then cooled for 45 minutes in a desiccator. They were subsequently weighed and their final weights recorded (W_2).

Formula: Total dissolved solids (TDS mg/L) = $(W_2 - W_1) \times 1000 / \text{Vol.}$

Where: W_1 = Initial weight of the beaker (mg)

W_2 = Final weight of the beaker (mg)

Vol. = Sample volume (mL)

The TDS in the samples were given in mg/L.

3.4.7 Alkalinity

3.4.7.1 Standard sodium carbonate (0.01M Na_2CO_3)

About 5.0 g of sodium carbonate (98.5%) was taken into a drying dish and oven dried for 2 hours at 100 °C. The dish was left to cool in the desiccator for 30 minutes. 0.86866 g of the dried Na_2CO_3 was then weighed and diluted with distilled water to 1000 mL. This solution had a concentration of 0.01M Na_2CO_3 and was used to standardize the sulfuric acid.

3.4.7.2 Mixed indicator

10.02 mg of methyl red and 50.05 mg of bromocresol green indicators were weighed in a weighing boat then transferred to a 50 mL volumetric flask and dissolved to volume using 95% aqueous ethanol.

3.4.7.3 Phenolphthalein Indicator (1 % w/v)

200.04 mg of phenolphthalein indicator was weighed in a weighing boat and dissolved in a 20 mL volumetric flask and topped up to the mark using 95% aqueous ethanol.

3.4.7.4 Standardization of sulfuric acid (0.01M) with standard Na₂CO₃

To prepare 0.01M H₂SO₄, 30 mL of 0.35M H₂SO₄ was taken into a 1000 mL volumetric flask and slowly making to volume using deionized water. It was then standardized using sodium carbonate Na₂CO₃ standard. 20 mL of the standard Na₂CO₃ was taken into a previously cleaned 250 mL conical flasks using a clean pipette, 2 drops of phenolphthalein indicator were then added making the solution pink. This solution was then titrated against H₂SO₄ till the pink color cleared. The volume of the H₂SO₄ used was then recorded. To the same solution, 2 drops of the mixed indicator were also added, making the solution blue and the titration proceeded till the solution became red. The H₂SO₄ volume was recorded. The combined volumes of the H₂SO₄ for the two titrations were then used to determine the actual concentration of the sulfuric acid.

3.4.7.5 Alkalinity determination in the samples

20 mL of the borehole water sample was measured then taken into a 100 mL conical flask with a further addition of 2 drops of phenolphthalein indicator which turned the sample pink. The sample was then titrated with the standardized sulfuric acid till the pink color

vanished. The average volume of the sulfuric acid (V_1) was recorded which was then used to calculate the phenolphthalein alkalinity. Furthermore, 2 drops of the mixed indicator were added to the same sample in flask, turning the solution blue. The titration then proceeded with the sulfuric acid until the solution turned red. The combined volume of sulfuric acid (V_2) was then used to determine the sample's total alkalinity.

3.4.8 Total Hardness determination

3.4.8.1 Standard calcium carbonate (0.01M CaCO_3)

5.0 g of CaCO_3 (98.5%) was taken into a drying dish and dried for 2 hours at 100 °C. It was then cooled for 30 minutes. 0.9997 g of the anhydrous CaCO_3 was then weighed in a weighing boat and carefully transferred to a 250 mL conical flask. A small amount of a mixture of water and hydrochloric acid (1:1) was added while swirling the flask. 200 mL of water was then added then 2 drops of methyl red solution followed by a dropwise addition of ammonium hydroxide solution until an intermediate orange solution formed. The solution was then topped up to 1000 mL using deionized water. This solution had a concentration of 0.01M CaCO_3 .

3.4.8.2 Ammonia-Ammonium chloride Buffer preparation

50 mL of deionised water was taken into a 500 mL beaker. 1.17902 g of Ethylene di-amine tetra acetic acid disodium salt (EDTA) (99.0%) was weighed and transferred into the same beaker and dissolved thoroughly. 16.89993 g of anhydrous ammonium chloride and 780.01 mg of magnesium sulfate were also weighed and added to the contents of the beaker. Using a measuring cylinder, 143 mL of ammonium hydroxide solution was added to the same beaker. This solution was then carefully transferred into a 250 mL volumetric flask while

rinsing it thoroughly and topped up to volume. The ammonia-ammonium chloride buffer was used to keep the water pH between 9 and 10.

3.4.8.3 Eriochrome Black-T indicator

0.12485 g of eriochrome black-T indicator was taken into a 25 mL volumetric flask and then diluted to volume using deionized water. This was used to indicate the titration end point.

3.4.8.4 Standardization of EDTA (0.01M) with standard CaCO₃

The EDTA was standardized by titrating it against standard calcium carbonate. 3.7231 g of EDTA was weighed and put in a 1 liter volumetric flask and then made to the mark with deionized water. This solution had a concentration of 0.01M EDTA. To standardize the EDTA solution, 20 mL of the standard CaCO₃ was measured into 4 clean 250 mL conical flasks followed by 2 mL of the buffer. Subsequently, 2 drops of the eriochrome black-T indicator was also added turning the solution to wine red. This solution was then titrated using the standardized EDTA until the solution became steel blue in color. The EDTA volume was recorded. The average volumes of the four determinations was subsequently used to calculate the true molarity of the EDTA solution.

3.4.8.5 Total hardness determination in the samples

20 mL of the borehole water sample was measured into a 100 mL conical flask, 2mL of the ammonia buffer solution was then added to it. This was done to keep the analysis pH between 9 and 10. This was followed by an addition of six drops of the eriochrome black - T indicator and the color changed to wine red. The sample was then titrated with the standardized EDTA until the solution color turned to blue indicating the complexing of all the Mg²⁺ and the Ca²⁺ ions in the sample and hence the end point. The standard EDTA

volume (V) used was recorded which was then used to calculate the total hardness in the samples.

3.5 Determination of anions in the water samples

3.5.1 Chloride

The following reagents were prepared for the chloride ion determination:

3.5.1.1 Standard sodium chloride (0.1M)

2.92192 g of previously dried sodium chloride (99.0%) was accurately weighed in a washed down completely with distilled water into a 500 mL volumetric flask and made to the mark using deionized water.

3.5.1.2 Potassium chromate Indicator

2.5 g of anhydrous potassium chromate (99.8%) was accurately weighed into a 100 mL beaker that had a small amount of water. A few drops of a solution of silver nitrate were added to the formation of a slight red precipitate was formed. This solution was further let to stand for about 12 hours and then topped up to 100 mL volumetric flask with distilled water.

3.5.1.3 Standardization of silver nitrate using standard 0.1M NaCl

16.98875 g of silver nitrate (99.9%) was accurately weighed and carefully transferred by completely washing it with distilled water into a 1000 mL flask and then made to volume using deionized water. This solution was standardized using standard sodium chloride. 20 mL of the standard 0.1M NaCl was measured into a clean 100 mL volumetric flask. 2 mL of potassium chromate indicator was then added to the flask causing the solution to turn to yellow. The solution was subsequently titrated with the standard silver nitrate until it turned

to wine red. Four readings were taken and the average volume of the silver nitrate solution was used to determine its concentration.

3.5.1.4 Determination of chloride ion in the samples

20 mL of the borehole water sample was measured into a clean 100 mL conical flask. 1 mL of the potassium chromate indicator was then added to the flask with the sample, the color turned to yellow. This sample solution was then titrated with the standard silver nitrate until the color turned to brick red. The silver nitrate volume used was recorded. Four determinations were conducted for each sample and the average recorded. A blank titration was conducted by pipetting 20 mL of distilled water into a clean 100 mL conical flask with a further addition of 1 mL of the potassium chromate indicator. Immediately, the solution was then titrated using the standardized silver nitrate until the color changed to brick red. The volume for the four determinations were then recorded.

3.5.2 Sulfates

The following reagents were prepared for the determination of sulfates:

3.5.2.1 Conditioning reagent

25 mL of glycerol was measured and carefully poured into a previously cleaned and dried beaker. To the same beaker, 15 mL of conc. hydrochloric acid was added. This was then followed by 50 mL of 95% isopropyl alcohol and the solution was properly mixed. 37.5 g of sodium chloride was accurately weighed and dissolved in about 100 mL of distilled water. The mixtures were then transferred into a 250 mL volumetric flask and topped up to the mark using distilled water.

3.5.2.2 Stock sulfate standard solution

1.479 g of anhydrous sodium sulfate was carefully weighed in a weighing boat and transferred into a 1000 mL volumetric flask dissolved and made up to the mark using deionized water. 1 mL was corresponded to 1.0 mg SO_4^{2-} .

3.5.2.3 Blank preparation, standards and testing of the samples

Six 50 mL volumetric flasks were taken for standards. 2.5 mL of the standard sulfate solution was taken into the first volumetric flask (50 mg/L), 5 mL to the second (100 mg/L), 10 mL to the third (200 mg/L), 20 mL to the fourth (400 mg/L), 30 mL to the fifth (600 mg/L) and 40 mL to the sixth (800 mg/L) respectively and labeled appropriately. Seven 50 mL volumetric flasks were also taken for the respective samples and 20 mL of the samples added into each of them. 5 mL of the conditioning reagent was added to all the volumetric flasks and topped up to volume using deionized water. A few crystals of barium chloride was then added to each of the volumetric flasks. One 50 mL volumetric flask was taken and filled with deionized water and subsequently used as the blank. The sulfate determination was done using the UV/VIS Spectrophotometer at a 420 nm.

3.5.3 Nitrates

The following reagents were prepared for the determination of nitrates:

3.5.3.1 Salicylic acid (5%)

2.49996 g of salicylic acid was weighed in a weighing boat. It was taken into a 50 mL volumetric flask. 10 mL conc. sulfuric acid was added to dissolve then made to volume with conc. sulfuric acid.

3.5.3.2 Sodium hydroxide (4M)

40.0268 g of sodium hydroxide was weighed in a weighing boat. It was transferred into a 500 mL volumetric flask. 200 mL of deionised water was added and placed in an ultra-sonic bath. The solution was then cooled in the fume chamber for 30 minutes and made to volume using distilled water.

3.5.3.3 Nitrate standards preparation

1.6473 g of anhydrous potassium nitrate (99.0%) was accurately weighed in a weighing boat and taken into a 1000 mL volumetric flask. 200 mL of deionized water was then added to the flask. It was treated by ultra-sonic waves until it dissolved and then topped to the mark with deionized water. The stock solution contained 1000 mg/L nitrates. A 100 mg/L solution was then made from the original solution using: $C_1V_1 = C_2V_2$. Subsequent dilutions to 2.0 mg/L, 4.0 mg/L, 6.0 mg/L, 12.0 mg/L, 16.0 mg/L and 20.0 mg/L were prepared from the 100 mg/L solution

3.5.3.4 Preparation of the samples for analysis

Eight clean 100 mL volumetric flasks were taken for each of the samples. 25 mL of the samples were carefully measured into the respective volumetric flasks using a clean pipette. 25 mL of deionized water was taken into one of the flasks which was used as the blank. 5 mL of 5% salicylic acid was subsequently added to each of the flasks. The volumetric flasks were then vortexed for two minutes and left to stand in a fume hood for 30 minutes. 50 mL of 4M sodium hydroxide was also added to each of the flasks, vortexed and left to stand for one hour. The standards and samples absorbance was then determined by use of the Shimadzu UV/Vis spectrometer at a 410 nm.

3.6 Elemental determination of the borehole water samples

3.6.1 Determination of sodium

This was determined using the emission mode on the Shimadzu AA6300 Atomic absorption spectrophotometer. Preparation of standard sodium (1000 mg/L) was done by accurately weighing 2.54455 g of sodium chloride (99.0%) in a weighing boat and completely washing it into a 1000 mL volumetric flask and making up to the mark using deionized water. The stock solution contained 1000 mg/L sodium. A 100 mg/L solution was made from the original solution using: $C_1V_1 = C_2V_2$. Subsequent dilutions to 2.0 mg/L, 4.0 mg/L, 6.0 mg/L, 8.0 mg/L and 10.0 mg/L were then prepared from the 100 mg/L solution. These standards were used to obtain a calibration curve on the AAS.

3.6.2 Determination of potassium

This was determined using the emission mode on the Shimadzu AA6300 Atomic absorption spectrophotometer. Preparation of standard potassium (1000 mg/L) was done by accurately

weighing 1.9087 g of potassium chloride (99.2%) in a weighing boat and diluting to volume to 1000 mL in a volumetric flask using distilled water. This contained 1000 mg/L of potassium. A solution of 100 mg/L was then made from the stock solution by use of the formula $C_1V_1 = C_2V_2$. Subsequent dilutions to 2.0 mg/L, 3.0 mg/L, 4.0 mg/L, 5.0 mg/L, 6.0 mg/L, 8.0 mg/L and 10.0 mg/L were made from the 100 mg/L solution. These calibration standards were used to obtain a calibration curve on the AAS.

3.6.3 Determination of manganese

Standard manganese (1000 mg/L) was prepared by accurately weighing 3.60604 g of manganese chloride (98.9%) in a weighing boat and washing it into a 1000 mL volumetric flask and a subsequent addition of 50 mL of conc. hydrochloric acid to dissolve the powder and then made up to volume with deionized water. Using the formula: $C_1V_1 = C_2V_2$, a solution of 10 mg/L was made from the 1000 mg/L. 10 mL of the standard manganese standard solution (1000 mg/L) was pipetted into a 1000 mL volumetric flask and made up to the mark using deionized water. Subsequent dilutions to 0.2 mg/L, 0.3 mg/L 0.4 mg/L, 0.6 mg/L, 0.8 mg/L, 1.2 mg/L, and 2.0 mg/L were prepared from the 10 mg/L solution. The calibration standards were used to obtain a calibration curve on the AAS.

3.6.4 Determination of cadmium

Cadmium hollow cathode lamp was used for this analysis. Preparation of standard cadmium (1000 mg/L) was done by weighing 1.63244 g of cadmium chloride (99.6%) in a weighing boat and washed it into a 1000 mL volumetric flask and then made to the mark using deionized water to make a 1000 mg/L of cadmium. Using the formula: $C_1V_1 = C_2V_2$, a solution of 10 mg/L was made from the 1000 mg/L solution. 10 mL of the cadmium

standard (1000 mg/L) was pipetted into a 1000 mL volumetric flask and topped up to the mark using deionized water. Subsequent dilutions to 0.2 mg/L, 0.3 mg/L, 0.4 mg/L, 0.6 mg/L, 0.8 mg/L and 1.2 mg/L were prepared from the 10 mg/L solution. These calibration standards were used to obtain a calibration curve on the AAS.

3.6.5 Determination of lead

A lead hollow cathode lamp was used for this analysis. Preparation of standard lead (1000 mg/L) was done by weighing 1.61502 g of lead nitrate (99.0%) in a weighing boat and taken into a 1000 mL volumetric flask and then dissolved using deionized water to make 1000 mg/L of lead solution. Using the formula: $C_1V_1 = C_2V_2$, a stock standard solution of 10 mg/L was made from the 1000 mg/L lead standard. 10mL of the 1000 mg/L lead standard was pipetted into a 1000 mL volumetric flask and topped up to the mark with deionized water. Subsequent dilutions to 0.2 mg/L, 0.3 mg/L, 0.4 mg/L, 0.6 mg/L, 0.8 mg/L, 1.2 mg/L, 2.0 mg/L and 2.5 mg/L were prepared from the 10 mg/L standard. These standards were used to obtain a calibration curve on the AAS.

3.6.6 Determination of copper

A copper hollow cathode lamp was used for this analysis. Preparation of standard copper (1000 mg/L) was done by weighing 3.92915 g of copper (II) sulfate pentahydrate (98.7%) in a weighing boat and diluted to volume in a 1000 mL volumetric flask using deionized water. This standard contained 1000 mg/L of copper. A 100 mg/L standard was then made from the stock standard by use of $C_1V_1 = C_2V_2$. Subsequent dilutions of 0.2 mg/L, 0.4 mg/L, 0.6 mg/L, 0.8 mg/L, 2.0 mg/L and 2.5 mg/L were prepared from the 10 mg/L solution. These standards were used to obtain a calibration curve on the AAS.

3.6.7 Determination of iron

An Iron hollow cathode lamp was used for this analysis. Preparation of standard iron (1000 mg/L) was done by weighing 4.85668 g of ferric chloride hexahydrate (99.3%) and diluting it to make 1000 mL using deionized water to make 1000 mg/L of iron standard. Then using the formula: $C_1V_1 = C_2V_2$, a stock standard of 10 mg/L was made from the 1000 mg/L Iron standard. This was prepared by taking 5 mL of the 1000 mg/L stock solution into a 500 mL volumetric flask and making up to the mark with deionized water. Subsequent dilutions to 0.4 mg/L, 0.6 mg/L 0.8 mg/L, 1.0 mg/L, 1.4 mg/L, 1.8 mg/L, and 2.0 mg/L were prepared from the 10 mg/L standard. These standards were used to obtain a calibration curve on the AAS.

3.6.8 Determination of chromium

Chromium hollow cathode lamp was used for this analysis. Preparation of standard chromium (1000 mg/L) was done by weighing 2.83175 g of potassium dichromate (99.9%) in a weighing boat and diluted to volume to make 1000 mL using distilled water to make 1000 mg/L of chromium standard. Using the formula: $C_1V_1 = C_2V_2$, a solution of 10 mg/L was made from the 1000 mg/L. 5 mL of the standard chromium stock solution (1000 mg/L) was pipetted into a 500 mL volumetric flask and topped up to the mark using distilled water. Subsequent dilutions to 0.2 mg/L, 0.3 mg/L 0.5 mg/L, 0.8 mg/L, 1.0 mg/L, 1.6 mg/L and 2.0 mg/L were made from the 10 mg/L standard. These calibration standards were used to obtain a calibration curve on the AAS.

3.6.9 Determination of zinc

The zinc hollow cathode lamp was used for this analysis. Preparation of standard zinc (1000 mg/L) was done by weighing 1.0002 g of (99.6% pure) zinc granules in a weighing boat and transferred into a 1000 mL volumetric flask. 30 mL of 5 M HCl was added to dissolve the granules and then made to volume using deionized water. Using the formula: $C_1V_1 = C_2V_2$, a stock standard of 10 mg/L was made from the 1000 mg/L. 5 mL of the standard zinc standard solution (1000 mg/L) was pipetted into a 500 mL volumetric flask and made up to the mark using deionized water. Subsequent dilutions to 0.2 mg/L, 0.3 mg/L, 0.4 mg/L, 0.6 mg/L, 0.8 mg/L, 1.2 mg/L, 2.0 mg/L and 2.5 mg/L were made from the 10 mg/L solution. These standards were used to obtain a calibration curve on the AAS.

Table 3.1 shows the elements analyzed and the respective AAS set up for their analysis.

Table 3.1 AAS conditions for analysis

Element	Wavelength (nm)	Slit width (mm)	Lamp mode	Flame type
Sodium	589.0	0.2	Emission	Air - Acetylene
Potassium	766.5	0.7	Emission	Air - Acetylene
Manganese	279.5	0.2	Absorption	Air - Acetylene
Cadmium	228.8	0.7	Absorption	Air - Acetylene
Lead	283.3	0.7	Absorption	Air - Acetylene
Copper	324.8	0.7	Absorption	Air - Acetylene
Iron	248.3	0.2	Absorption	Air - Acetylene
Chromium	357.9	0.7	Absorption	Air - Acetylene
Zinc	213.9	1.0	Absorption	Air - Acetylene

3.6.10 Determination of *Escherichia coli* (*E.coli*)

Escherichia coli was determined by use of the multiple tube fermentation technique (MTF). This was done in the Biological Analysis Unit in the National Quality Control Laboratory. The media was sterilized in the autoclave and the analysis performed in the Bioban Biosafety cabinet.

3.6.10.1 Preparation of lauryl sulfate tryptose broth (LST)

20 g of tryptose and 5 g of lactose were dissolved in 500 mL distilled water in a previously cleaned and dried 1000 mL conical flask. 2.75 g of dibasic potassium orthophosphate, 2.75 g of monobasic potassium orthophosphate, 5 g of sodium chloride and 0.1 g sodium dodecyl sulfate were also added to the flask. This solution was then topped up to 1000 mL with distilled water. The final pH of this solution was 6.8. 10 mL portions of the solution was dispensed into 20 × 150 mm tubes containing inverted 10 × 75 mm fermentation tubes and autoclaved for 15 minutes at 121°C.

3.6.10.2 Preparation of brilliant green lactose bile broth

10 g of peptone and 10 g of lactose were dissolved in 500 mL distilled water in a previously cleaned and dried 1000 mL conical flask. 20 g of anhydrous oxgall previously dissolved in 200 mL deionized water was added. 275 mL deionized water was added to make 975 mL and 13.3 mL of 0.1% aqueous brilliant green was added and the solution was then topped up to 1000 mL with water. The final pH of the solution was found to be 7.2. The media was then dispensed into fermentation tubes, while ensuring that fluid level covered inverted vials and then autoclaved for 15 minutes at 121°C.

3.6.10.3 Microbiological analysis of the water samples

3.6.10.3.1 Presumptive test

100 mL of samples were taken into 100 mL previously sterilized bottles. 5 tubes with 10 mL of the lauryl sulfate tryptose (LST) medium were inoculated with 10 mL of undiluted samples. The tubes were set in an incubator at 35°C. After 24 hours elapsed, the tubes were taken out of the incubator and examined for growth and gas formation what would have been evidenced if the medium had been displaced in the fermentation tubes or the medium effervesced as the tubes were gently agitated. The tubes were then put back into the incubator for another 24 h and re- examined.

3.6.10.3.2 Confirmed test

This test was carried out on the tubes from the presumptive test earlier. Each of the presumptive tube was lightly shaken then by use of a sterile loop of 3.0 mm, two full loops of the LST broth from the presumptive tubes were transferred fully into the brilliant green lactose bile broth (BGLB broth) tubes. These tubes were put a 35°C incubator for 48 hours and then checked for production of gas.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 pH

The determined pH for water samples from the seven boreholes and the control sample are shown in Table 4.1.

Table 4.1 pH of the Borehole water samples

Sample	pH	EAS/WHO guideline value
Bottled water (control sample)	7.06 ± 0.00058	6.5 – 8.5
Matangi Nne	8.40 ± 0.00058	
Ushirika Water Project	8.04 ± 0.00351	
Koinange CW	8.04 ± 0.0020	
Geoffrey Kinyanjui	8.45 ± 0.0062	
Shamba House	8.24 ± 0.0013	
Keroche borehole	7.03 ± 0.0031	
Joywel School	8.32 ± 0.0096	

The pH values for the sampled boreholes were found to be in the range of pH 7.03 - 8.45. The ascertained pH for the water samples were all within the East African Standard and the WHO guideline value of 6.5 to 8.5 and therefore based on pH values the water was safe for drinking purposes. Keroche borehole had the least pH value among the sampled points with

a pH of 7.03 while the borehole belonging to Geoffrey Kinyanjui had the highest pH value of 8.45. This was an indication that there might have been slightly more anions in the water than there were cations and therefore low acidity. The summary of the pH values of the water samples is shown in Figure 4.1. The summary shows how the pH of the water samples and the control sample compared to the East African Standard and the WHO guideline for drinking water.

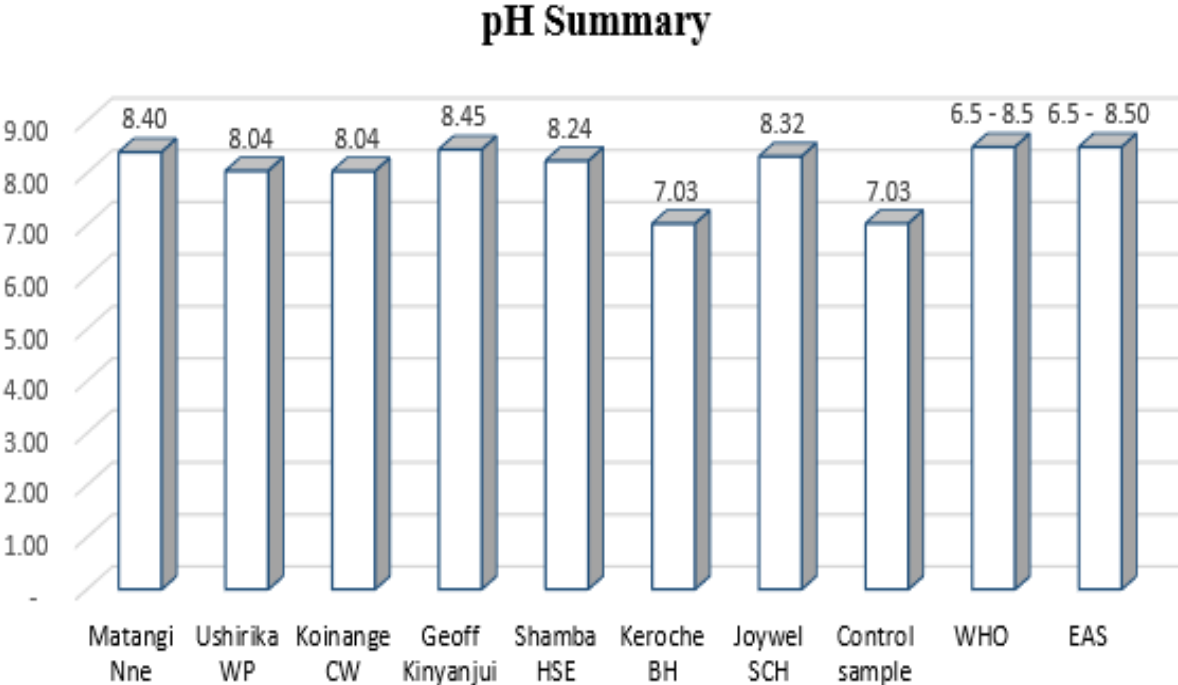


Figure 4.1: Summary of the pH of the Borehole water samples

4.2 Electrical conductivity

The values of the electrical conductivity of the water samples determined in the laboratory are given in Table 4.2.

Table 4.2 Electrical conductivity of the borehole water samples

Sample	Electrical conductivity ($\mu\text{S}/\text{cm}$)	EAS/WHO Guideline value ($\mu\text{S}/\text{cm}$)
Bottled water (control sample)	0.05 ± 0.0057	2500
Matangi Nne	1218 ± 1.528	
Ushirika Water Project	677 ± 1.000	
Koinange Car Wash	887 ± 1.000	
Geoffrey Kinyanjui	667 ± 0.577	
Shamba House	755 ± 1.000	
Keroche borehole	412 ± 1.732	
Joywel School	648 ± 1.000	

The electrical conductivity of the sampled boreholes was found to be between 412 to 1218 $\mu\text{S}/\text{cm}$ which were within the East African Standard and the WHO guideline value for drinking water of not exceeding 2500 $\mu\text{S}/\text{cm}$. Based on the guidelines, having recorded the electrical conductivities were safe for drinking. The lowest electrical conductivity recorded was for the Keroche borehole with 412 $\mu\text{S}/\text{cm}$ while the highest recorded value was Matangi Nne borehole with 1218 $\mu\text{S}/\text{cm}$. The summary of the recorded electrical conductivities of the sampled boreholes is shown in Figure 4.2. The summary shows how the electrical conductivities of the water samples and the control sample compared to the East African Standard and the WHO guideline for drinking water.

EC Summary

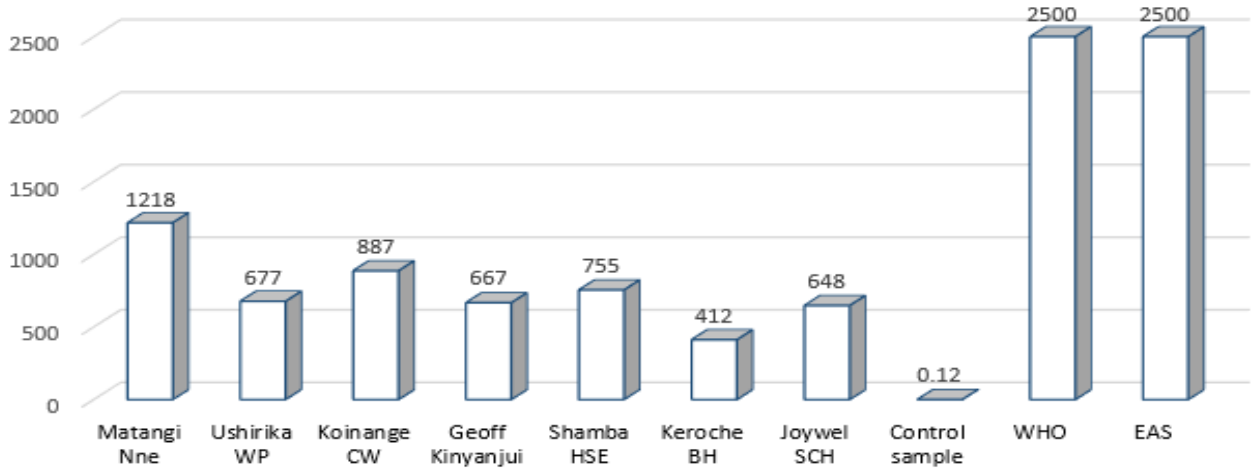


Figure 4.2: Summary of the electrical conductivity of the borehole water samples

4.3 Turbidity

The turbidity measurements for water samples in the seven boreholes are given in Table 4.3.

Table 4.3 Turbidity of the borehole water samples

Sample Point	Turbidity (NTU)	EAS/WHO Guideline Value (NTU)
Bottled water (control sample)	0.157 ± 0.152	1
Matangi nne	0.135 ± 0.001	
Ushirika Water Project	0.099 ± 0.001	
Koinange Car Wash	0.116 ± 0.000	
Geoffrey Kinyanjui	0.095 ± 0.001	
Shamba House	0.108 ± 0.001	
Keroche borehole	0.210 ± 0.002	
Joywel School	0.355 ± 0.002	

The Turbidity of the water samples was found to be in the ranges of 0.095 to 0.355 NTU. The least recorded turbidity for the sampled boreholes was the private borehole belonging to Geoffrey Kinyanjui with a value of 0.095 NTU while the most turbid of the sampled points was the Joywel Primary School with 0.355 NTU. This indicated that the water did not contain so much suspended matter that would make it cloudy or turbid and therefore aesthetically acceptable for drinking. However, all the sampled boreholes were within the specified amount in the East African Standard and the WHO guideline value for turbidity which did not exceed 1 NTU. Figure 4.3 shows the summary of the turbidity of the water samples and the control sample and how they compared to the East African Standard and the WHO guideline for drinking water.

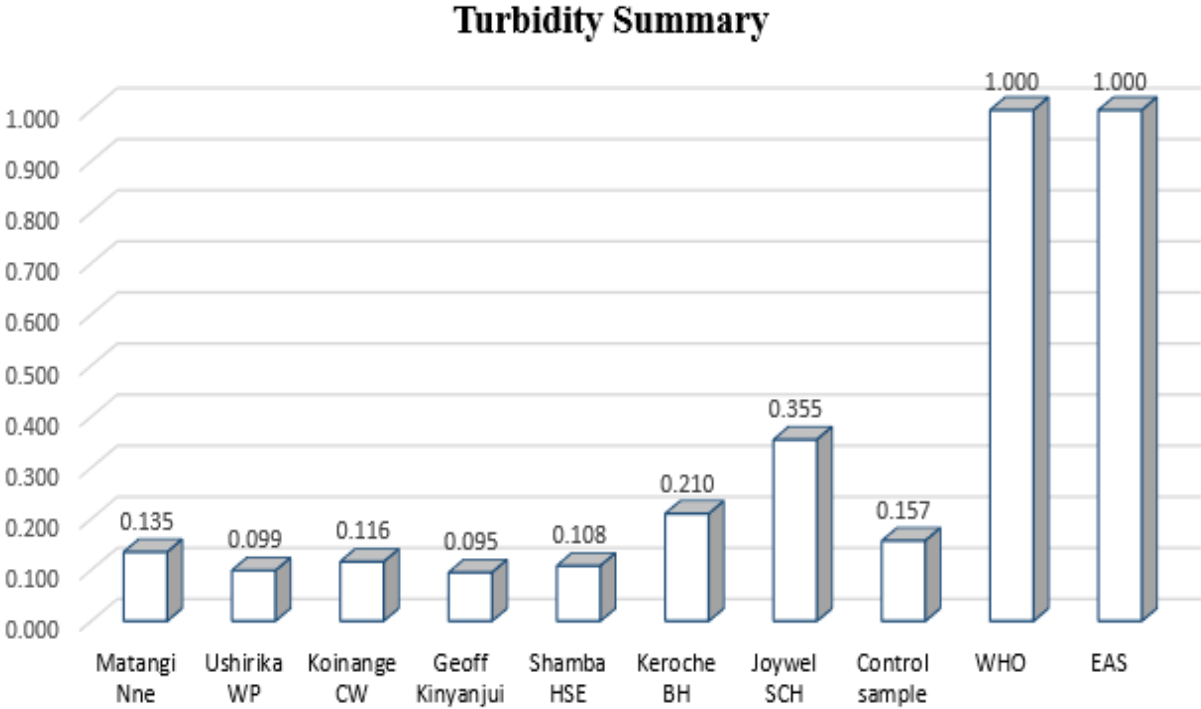


Figure 4.3: Summary of the Turbidity of the borehole water samples

4.4 Water color

The water color of the water samples was found to be between 2 to 10 TCU (Table 4.4). The least recorded water color for the sampled boreholes was the Joywel School borehole with a value of 2 TCU while the most colored of the sampled points was the Matangi Nne borehole with 10 TCU.

Table 4.4 Water color of the borehole water samples

Sample Point	Color (TCU)	WHO Guideline Value (TCU)
Bottled water (control sample)	5.0 ± 0.00	15
Matangi nne	10.0 ± 1.00	
Ushirika WP	5.0 ± 0.00	
Koinange CW	4.0 ± 0.00	
Geoffrey kinyanjui	6.0 ± 1.00	
Shamba HSE	4.0 ± 0.00	
Keroche BH	9.0 ± 1.00	
Joywel SCH	2.0 ± 0.00	

The study showed that the water color from all the boreholes were within the East African Standard and the WHO guideline value for water color since the values did not exceed 15 TCU. The low values for the color may have been as a result of absence of pigmentation or algae that would aesthetically not be appealing for drinking purposes. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes. The summary in Figure 4.4 shows how the color of the water samples and the control sample compared to the East African Standard and the WHO guideline for drinking water.

Water color Summary

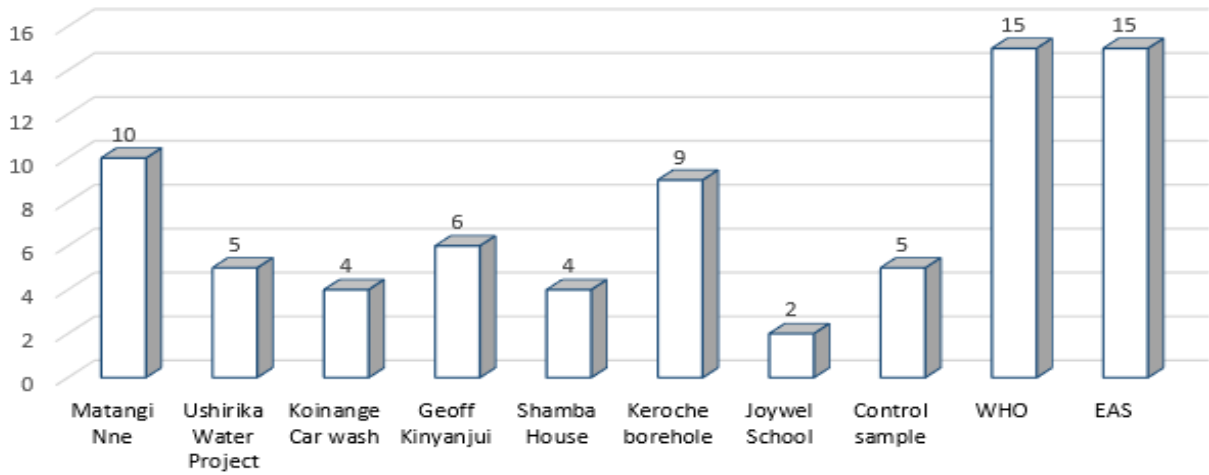


Figure 4.4: Summary of the water color of the borehole water samples

4.5 Total suspended solids

The TSS values for the water sample from the boreholes were calculated using equation 4.1:

$$\text{TSS (mg/L)} = \frac{(W_2 - W_1) \text{ mg} \times 1000 \text{ mL}}{V (300 \text{ mL})} \quad (4.1)$$

where: W_1 = weight of filter paper (mg)

W_2 = weight of filter paper + Sample filtrate (mg)

$W_2 - W_1$ = amount of filtrate (mg)

V = volume of sample (mL)

Table 4.5 shows the TSS values of the sampled boreholes.

The calculated values for the TSS are given in Table 4.5. The lowest recorded value of Total suspended solids was that of the Shamba HSE borehole which was 1.93 mg/L while the highest value was for Keroche BH with 48.0 mg/L

Table 4.5 Total suspended solids values of the sampled boreholes

Sampling point (borehole)	Weight of filter paper W₁ (mg)	Weight of filter paper + sample filtrate W₂ (mg)	Amount of filtrate (W₂ - W₁) (mg)	TSS Value mg/L	EAS/WHO guideline value (mg/L)
Matangi Nne	920.89	921.85	0.96	3.33	ND
Joywel School	912.17	912.77	0.60	2.00	
Koinange CW	896.84	903.83	6.99	23.30	
Ushirika WP	906.03	909.76	3.73	12.43	
Geof. Kinyanjui	898.20	908.69	10.49	34.97	
Shamba House	926.21	926.79	0.58	1.93	
Keroche BH	893.34	907.74	14.4	48.00	

The study showed that there was suspended matter present in the water samples. This may have resulted from little particles of dirt that may have been present in the boreholes. The East African Standard and the WHO guideline have however state that no suspended matter should be present in drinking water hence none of the sampled boreholes met that said criteria and therefore it would be necessary to filter the borehole water before consumption. Based on this parameter, water from all the sampled boreholes was not safe for drinking purposes. Figure 4.5 shows the summary of the TSS values of the water samples and the control sample and how they compared to the East African Standard and the WHO guideline for drinking water.

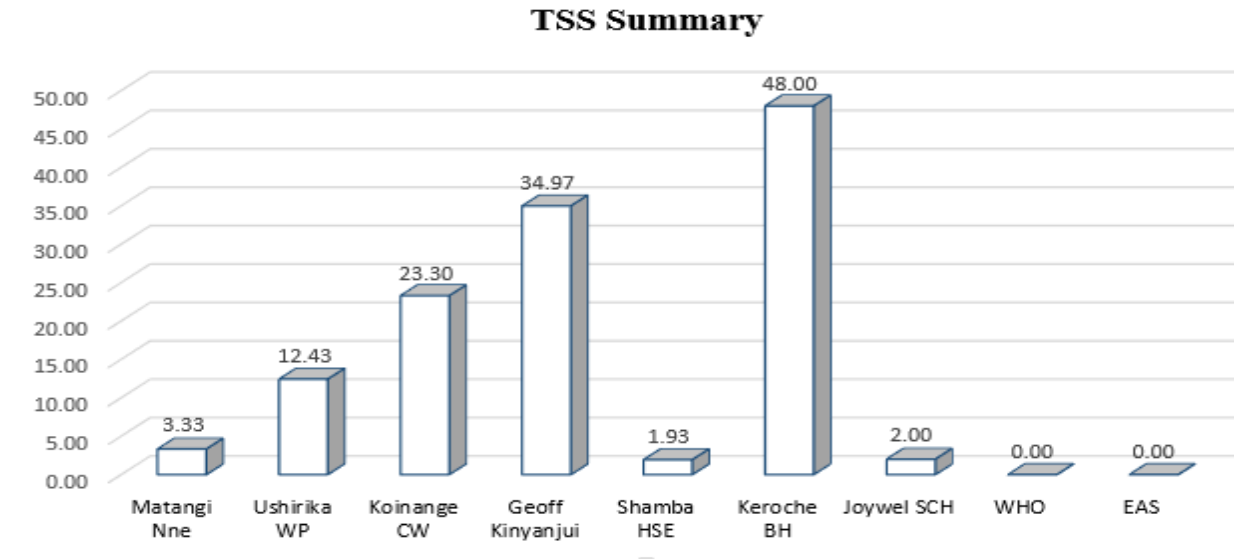


Figure 4.5: Summary of the TSS values for the sampled boreholes

4.6 Total dissolved solids

Total dissolved solids for the water samples from the boreholes were calculated using equation 4.2:

$$\text{TDS (mg/L)} = \frac{(W_2 - W_1) \text{ mg} \times 1000 \text{ mL}}{V (200 \text{ mL})} \quad (4.2)$$

Where: W_1 = weight of empty beaker (mg)

W_2 = weight of beaker + sample residue (mg)

$W_2 - W_1$ = amount of residue (mg)

V = volume of sample (mL)

The calculated values for the TDS in the sampled boreholes is given in Table 4.6

Table 4.6 Total dissolved solids of the sampled boreholes.

Sampling point (borehole)	Weight of beaker W_1 (mg)	Weight of beaker + sample residue W_2 (mg)	Amount of residue ($W_2 - W_1$) (mg)	TDS Value mg/L	EAS/WHO guideline value (mg/L)
Matangi Nne	99995.00	100079.20	84.20	421.00	NMT 1500
Joywel School	101250.00	101302.20	52.20	261.00	
Koinange CW	98760.00	98768.60	8.60	43.00	
Ushirika WP	100250.00	100299.20	49.20	246.00	
Geof. Kinyanjui	100660.00	100702.20	42.20	211.00	
Shamba House	99860.00	99918.20	58.20	291.00	
Keroche BH	100610.00	100645.80	35.80	179.00	

From the sampled boreholes, the least value of the TDS was recorded for Koinange Car Wash borehole which had 43 mg/L. Matangi Nne borehole had the highest value of TDS with 421 mg/L, this may have been due to its close proximity to the Wildfire flower farm and possibly many contaminants from the use of chemical based herbicides and pesticides in the farm finding their way into the borehole. However, the East African Standard and the WHO guideline value for the TDS is 1500 mg/L whereby all the sampled boreholes met this criteria. Therefore, based on this parameter, water from all the sampled boreholes was safe for drinking purposes. Figure 4.6 shows how the TDS for the water samples and the control sample compared to the East African Standard and the WHO guideline for drinking water.

TDS Summary

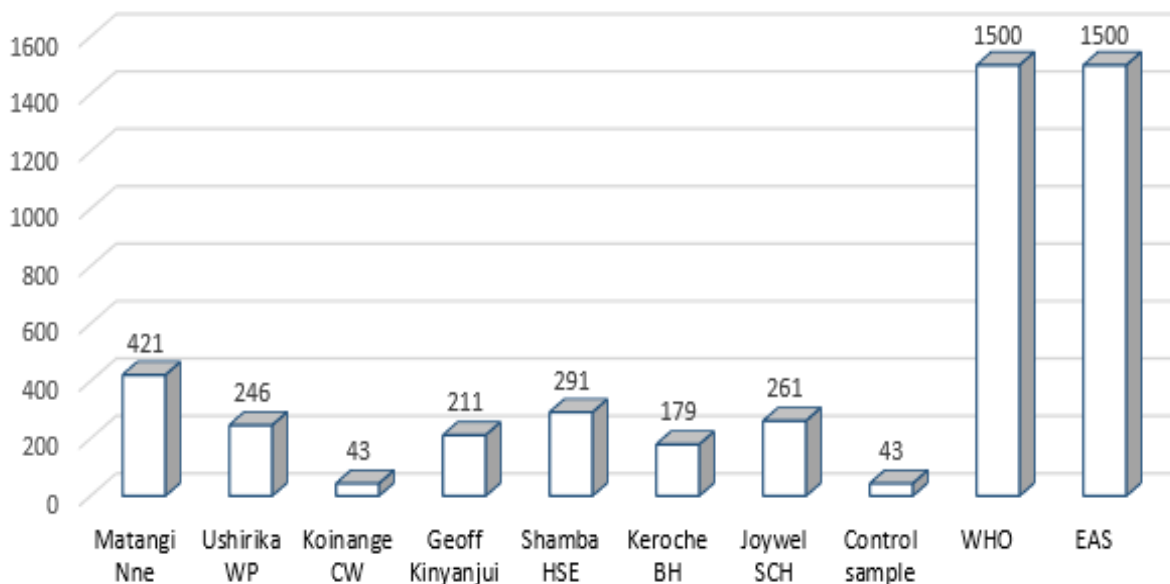


Figure 4.6: Summary of the TDS values for the sampled boreholes

4.7 Total hardness

The hardness for the samples was calculated as outlined in the following sections:

4.7.1 0.01M calcium carbonate standard

The calcium standard solution was prepared as follows:

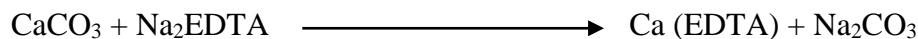
Amount of CaCO_3 weighed = 0.99997 g

No. of moles of CaCO_3 = $\frac{0.99997 \text{ g}}{100.0869 \text{ g/mole}}$ = 0.009991 moles of Ca^{2+}

Concentration of CaCO_3 = $\frac{0.009991 \text{ moles of CaCO}_3 \times 1000}{1000 \text{ mL}}$ = 0.0099991M

4.7.2 EDTA Standardization with 0.01M calcium carbonate standard

The stoichiometric reaction between calcium carbonate and EDTA is as follows:



The reaction ratio between standard CaCO_3 and 0.01M EDTA from the stoichiometric reaction above is 1:1. 0.01M EDTA was titrated against 20 mL standard CaCO_3 . The results for standardization of EDTA with standard calcium carbonate are given in Table 4.7.

Table 4.7: EDTA Standardization with 0.0099991M calcium standard

Titration No.	Vol. of CaCO_3 (mL)	Burette Reading (mL)		Volume of EDTA (mL)
		Final	Initial	
1	20	19.7	0.0	19.7
2	20	39.7	19.7	19.8
3	20	19.8	0.0	19.9
4	20	39.8	20.0	19.8
Av. volume of EDTA (mL) = $\frac{19.7 + 19.8 + 19.9 + 19.8}{4} = 19.8 \text{ mL} \pm 0.0816$				

$$\text{No. of moles of CaCO}_3 = \frac{\text{Molarity} \times \text{Volume taken}}{1000 \text{ mL}} = \frac{0.0099991 \text{ M} \times 20 \text{ mL}}{1000 \text{ mL}}$$

$$= 1.9982 \times 10^{-4} \text{ moles of EDTA}$$

$$\text{Actual Molarity of EDTA} = \frac{1.9982 \times 10^{-4} \text{ moles} \times 1000 \text{ mL}}{19.8 \text{ mL}} = \underline{\underline{0.01009\text{M}}}$$

The formula (4.3) was used to quantify the water hardness in mg/L as CaCO_3

$$\left(\frac{\text{mg}}{\text{L}}\right) = M \text{ of EDTA} \times \frac{\text{Av.vol of EDTA}}{1000 \text{ mL}} \times M. \text{Mass of CaCO}_3 \times \frac{1000 \text{ mL}}{\text{Vol of Sample}} \quad (4.3)$$

$$\text{Volume of sample used} = 20 \text{ mL}$$

$$\text{Molar mass of CaCO}_3 = 100.09 \text{ g/mole}$$

$$\text{Molarity of EDTA} = 0.01009\text{M}$$

The calculated hardness for the water samples are shown in Table 4.8.

The calculations for the hardness of individual water samples are shown in Appendices AI to AVIII.

Table 4.8: Hardness values for the water samples.

Sampling point (Borehole)	Hardness as CaCO ₃ (mg/L)	EAS/WHO guideline value
Matangi Nne	47.13	300 mg/L
Ushirika Water Project	43.76	
Koinange Car Wash	43.76	
Geoffrey Kinyanjui	31.97	
Shamba House	31.97	
Keroche Borehole	85.84	
Joywel School	28.62	
Bottled water (control)	2.52	

From the sampled boreholes (Table 4.8), the TDS for the boreholes was found to be 28.62 mg/L for the lowest value which was recorded for Joywel School borehole. The highest recorded value was 47.13 mg/L for Matangi Nne borehole. This may have resulted from its close proximity to a flower farm that may be using calcium and magnesium based farm chemicals which over time may have leached into the aquifers. However, based on the East African and the WHO guideline value, all the sampled boreholes were within the acceptable value that is set as 300 mg/L. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes. Figure 4.7 shows the summary of the calculated water hardness for the water samples and the control sample and how they compared with the East African Standard and the WHO guideline for drinking water.

Total hardness Summary

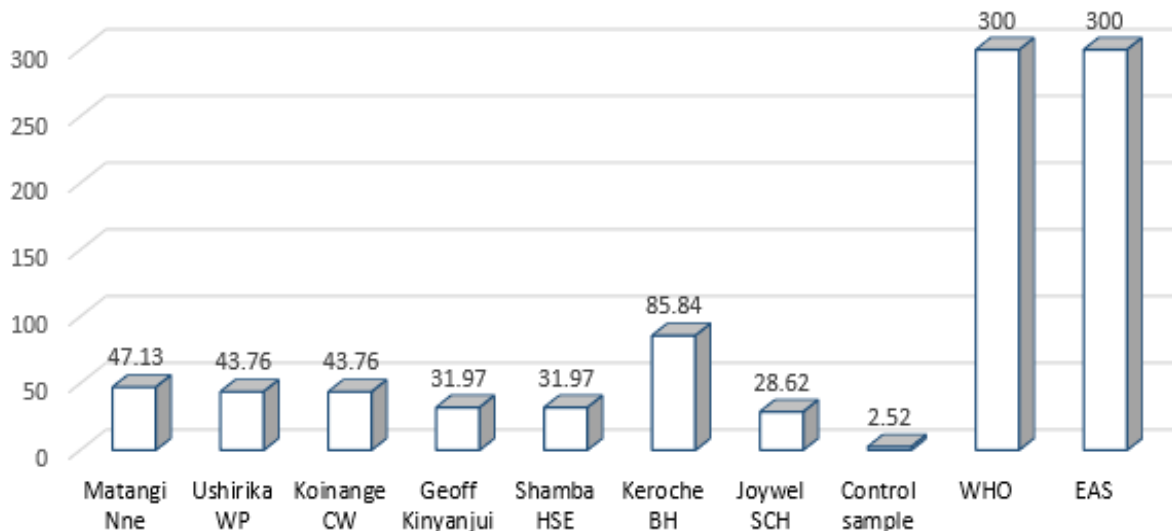


Figure 4.7: Summary of the Total hardness values for the sampled boreholes.

4.8 Alkalinity

The alkalinity of water was calculated as outlined in the following sections.

4.8.1 0.01M Sodium carbonate standard

The concentration of sodium carbonate standard was determined as follows:

$$\text{No. of moles of Na}_2\text{CO}_3 = \frac{0.86866 \text{ g}}{105.99 \text{ g/mole}} = 0.0081957 \text{ moles}$$

$$\text{Concentration of Na}_2\text{CO}_3 = \frac{0.0081957 \text{ moles} \times 1000}{1000 \text{ mL}} = \underline{\underline{0.0081957\text{M}}}$$

4.8.2 H₂SO₄ Standardization with 0.0081957M Na₂CO₃ standard

Table 4.9 shows the standardization of 0.01M H₂SO₄ using standard 0.0081957M Na₂CO₃.

Four determinations were made from which the actual concentration of H₂SO₄ was calculated.

Table 4.9: H₂SO₄ Standardization with 0.0081957M Na₂CO₃ standard

Titration No.	Vol. of Na ₂ CO ₃ (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	16.2	0.0	16.2
2	20	31.9	16.2	15.7
3	20	15.6	0.0	15.6
4	20	31.3	15.6	15.7
Average volume of H ₂ SO ₄ (mL) = $\frac{16.2 + 15.7 + 15.6 + 15.7}{4} = 15.8 \text{ mL} \pm 0.271$				

$$\text{No. of moles of Na}_2\text{CO}_3 \text{ in 20 mL} = \frac{\text{Molarity} \times \text{Volume taken}}{1000 \text{ mL}} = \frac{0.0081957\text{M} \times 20 \text{ mL}}{1000 \text{ mL}}$$

$$= 1.63914 \times 10^{-4} \text{ moles of Na}_2\text{CO}_3$$

$$\text{Actual Conc. of H}_2\text{SO}_4 = \frac{1.63914 \times 10^{-4} \text{ moles} \times 1000 \text{ mL}}{15.8 \text{ mL}}$$

$$\text{Determined H}_2\text{SO}_4 \text{ concentration} = \underline{\underline{0.0103743\text{M}}}$$

The formula (4.4) was used to calculate the Phenolphthalein/Total (P/T) alkalinity of the water samples:

$$\left(\frac{\text{mg}}{\text{L}}\right) = M \text{ of H}_2\text{SO}_4 \times \frac{\text{Av.vol of H}_2\text{SO}_4}{1000 \text{ mL}} \times M. \text{Mass of Na}_2\text{CO}_3 \times \frac{1000 \text{ mL}}{\text{Vol of Sample}} \quad (4.4)$$

$$\text{Molar mass of Na}_2\text{CO}_3 = 105.987$$

$$\text{Volume of borehole water taken} = 20 \text{ mL}$$

$$\text{Concentration of H}_2\text{SO}_4 = 0.0103743\text{M}$$

The determined phenolphthalein alkalinity and the total alkalinity for the borehole water samples are shown in Table 4.10. The individual calculations are shown in Appendices BI to BVIII.

Table 4.10: Phenolphthalein and total alkalinity values for the water samples.

Sampled Borehole	Phenolphthalein Alkalinity (mg/L)	Total Alkalinity (mg/L)	EAS/WHO guideline value
Matangi Nne	36.65	511.29	Not Indicated
Ushirika Water Project	18.32	355.48	
Koinange Car Wash	34.82	359.17	
Geoffrey Kinyanjui	18.32	315.20	
Shamba House	29.32	320.68	
Keroche Borehole	14.66	168.60	
Joywel School	43.98	329.99	
Bottled water (control)	0.00	2.75	

From the sampled boreholes (Table 4.10), the lowest phenolphthalein alkalinity value was found to be 14.66 mg/L for Keroche borehole while the highest was 43.98 mg/L for Joywel School borehole. The lowest total alkalinity value was found to be 168.60 mg/L for Keroche borehole while the highest was 511.29 mg/L for Matangi Nne borehole. Keroche borehole was in a secluded area a little further from the business district and surrounded by small scale farmers. This may have been the reason for its low values for alkalinity owing to little anthropogenic activities surrounding it. Matangi Nne on the other hand, was so close to a large flower farm that may be using carbonates or hydrogen carbonate based fertilizers and thus contributing to the high alkalinity value. The East African Standard and the WHO guidelines for drinking water however have not stated the maximum allowable value for phenolphthalein and total alkalinity. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes. Figure 4.8 shows the summary of the determined phenolphthalein and the total alkalinity of the water samples and the control and how they compared with each other.

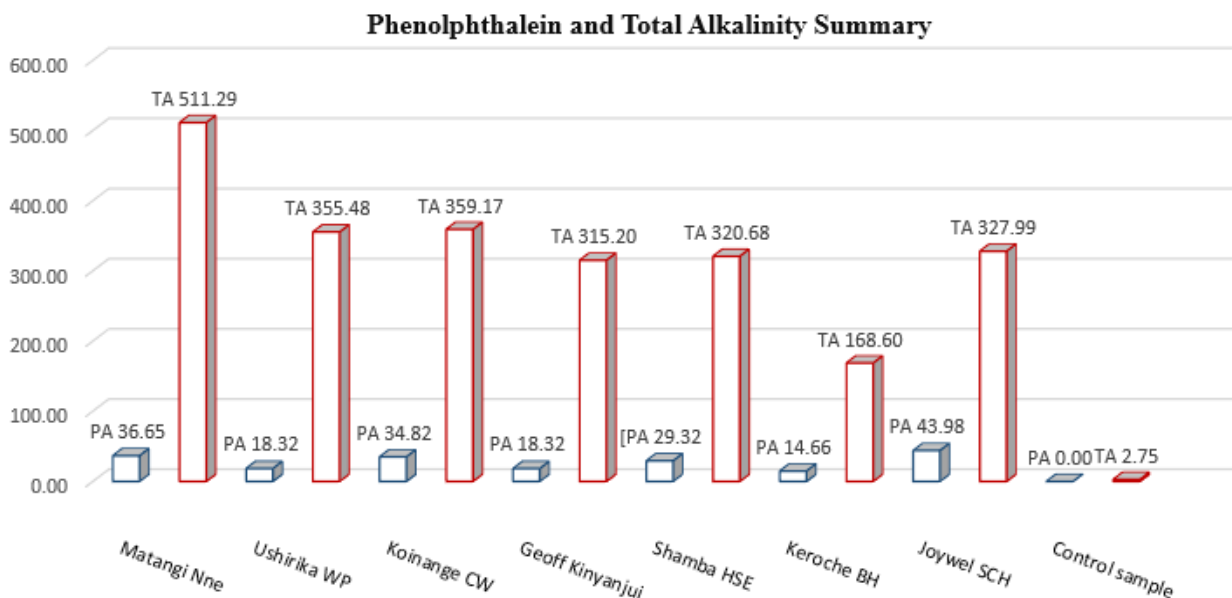


Figure 4.8: Summary of the Phenolphthalein and Total Alkalinity values for the sampled boreholes

4.9 Concentration of anions in the water samples.

4.10 Concentration of chloride in the water samples

The determination of Chloride ion was done using Mohr's method

4.10.1 0.1M Sodium chloride standard

The concentration of the sodium chloride standard was determined as follows:

Weight of the NaCl taken = 2.92192 g

Topped up to 500 mL using deionized water.

$$\text{No. of moles of NaCl} = \frac{2.92192 \text{ g}}{58.44 \text{ g/mole}} = 0.04999 \text{ moles}$$

$$\text{Concentration of NaCl} = \frac{0.4999 \text{ moles} \times 1000}{500 \text{ mL}} = \underline{\underline{0.0999\text{M}}}$$

4.10.2 Silver nitrate standardization with 0.0999M NaCl standard

Titration values for the standardization of silver nitrate with standard sodium are shown in Table 4.11. Four determinations were made from which the actual concentration of the silver nitrate was calculated.

Table 4.11: Silver nitrate standardization with 0.0999M NaCl standard

Titration No.	Vol. of NaCl (mL)	Burette Reading (mL)		Volume of AgNO ₃ (mL)
		Final	Initial	
1	15	15.1	0.0	15.1 ± 0.10 mL
2	20	35.3	15.1	20.2 ± 0.10 mL
3	25	24.9	0.0	24.9 ± 0.10 mL
4	30	30.1	0.0	30.1 ± 0.10 mL

$$\text{No. of moles of NaCl in 15 mL} = \frac{\text{Molarity} \times \text{Volume taken}}{1000 \text{ mL}} = \frac{0.09999\text{M} \times 15 \text{ mL}}{1000 \text{ mL}}$$

$$= 1.4999 \times 10^{-3} \text{ moles of AgNO}_3$$

$$\text{Conc. of AgNO}_3 = \frac{1.4999 \times 10^{-3} \text{ moles} \times 1000 \text{ mL}}{15.1 \text{ mL}} = 0.09933\text{M}$$

$$\text{No. of moles of NaCl in 20 mL} = \frac{\text{Molarity} \times \text{Volume taken}}{1000 \text{ mL}} = \frac{0.09999\text{M} \times 20 \text{ mL}}{1000 \text{ mL}}$$

$$= 1.9998 \times 10^{-3} \text{ moles of AgNO}_3$$

$$\text{Conc. of AgNO}_3 = \frac{1.9998 \times 10^{-3} \text{ moles} \times 1000 \text{ mL}}{20.2 \text{ mL}} = 0.0990\text{M}$$

$$\text{No. of moles of NaCl in 25 mL} = \frac{\text{Molarity} \times \text{Volume taken}}{1000 \text{ mL}} = \frac{0.09999\text{M} \times 25 \text{ mL}}{1000 \text{ mL}}$$

$$= 2.4999 \times 10^{-3} \text{ moles of AgNO}_3$$

$$\text{Conc. of AgNO}_3 = \frac{2.4999 \times 10^{-3} \text{ moles} \times 1000 \text{ mL}}{24.9 \text{ mL}} = 0.10040\text{M}$$

$$\text{No. of moles of NaCl in 30 mL} = \frac{\text{Molarity} \times \text{Volume taken}}{1000 \text{ mL}} = \frac{0.09999\text{M} \times 30 \text{ mL}}{1000 \text{ mL}}$$

$$= 2.999 \times 10^{-3} \text{ moles of AgNO}_3$$

$$\text{Conc. of AgNO}_3 = \frac{2.999 \times 10^{-3} \text{ moles} \times 1000 \text{ mL}}{30.1 \text{ mL}} = 0.09963\text{M}$$

$$\text{Actual Conc. of AgNO}_3 = \frac{0.09933 + 0.0990 + 0.1004 + 0.09963}{4} = \underline{\underline{0.09959\text{M}}}$$

4.10.3 Determination of the blank

Titration values for the determination of the blank are shown in Table 4.12.

Table 4.12: Determination of the blank (Distilled water)

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of AgNO ₃ (mL)
		Final	Initial	
1	50	0.10	0.00	0.10
2	50	0.35	0.25	0.10
3	50	0.50	0.35	0.15
Average vol. of std. AgNO ₃ (mL) = $\frac{0.10 + 0.10 + 0.15}{3} = 0.12 \text{ mL} \pm 0.03$				

Volume of the blank determination = 0.12 mL

The following formula (4.5) was used to quantify the amount of chlorides in the borehole samples:

$$\text{Cl}^- (\text{mg/L}) = \frac{(V_2 - V_1) \times \text{Eq. of AgNO}_3 \times \text{M of AgNO}_3 \times 1000\text{mL}}{\text{Sample Vol.}} \quad (4.5)$$

Where: Average Vol. of AgNO₃ (V₂)

Average Vol. of the Blank (V₁) = 0.12 mL (Blank correction)

Average Vol. of AgNO₃ used = (V₂ - V₁)

Equivalence of Chloride = 35.45

Sample volume = 50 mL

The calculated values for chlorides for the borehole water samples are given in Table 4.13.

The individual calculations are shown in Appendices CI to CVII.

Table 4.13: Chloride values for the water samples

Sampling point (Borehole)	Chloride as Cl^- (mg/L)	EAS/WHO guideline value
Matangi Nne	79.78	250 mg/L
Ushirika Water Project	26.65	
Koinange Car Wash	52.80	
Geoffrey Kinyanjui	36.24	
Shamba House	53.98	
Keroche Borehole	30.36	
Joywel School	29.18	

From the sampled boreholes, the lowest determined value for the chlorides was found to be 25.65 mg/L for Ushirika Water Project borehole in Kayole Area, that may have resulted from the naturally occurring chloride salts in the natural rocks while the highest value was 79.78 mg/L for Matangi Nne borehole that may have resulted from chloride based chemicals that may be used in the flower farm close by. The relatively higher amounts of chlorides in the Shamba House and Koinange Carwash borehole may have resulted from improper disposal of chloride batteries from motor vehicle repair shops close by. However, all the sampled boreholes met the East African Standard and the WHO guideline value for the chloride set at NMT 250 mg/L therefore, this parameter was within acceptable limits. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes. Figure 4.9 shows the summary of calculated chlorides content of the water samples and the control sample and how they compared with the East African Standard and the WHO guideline for drinking water.

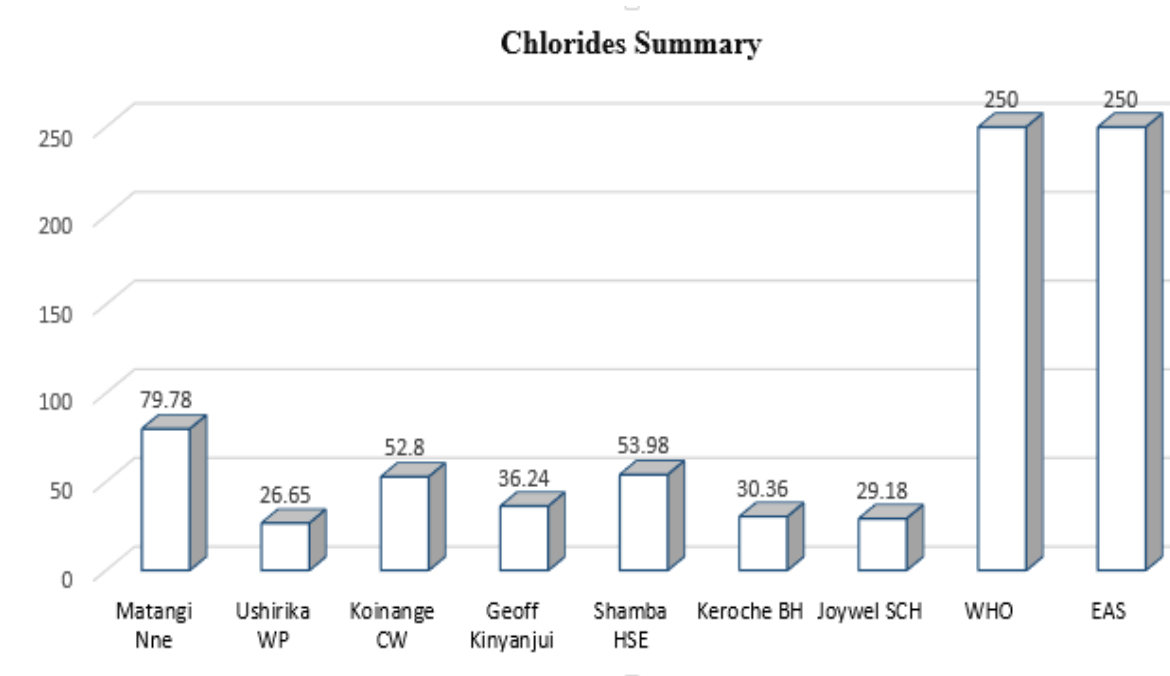


Figure 4.9: Summary of the chlorides content for the sampled boreholes

4.11 Chlorine

Chlorine determination was done using the Extech® digital chlorine meter.

4.11.1 Chlorine determination in the samples

The chlorine levels in the water samples from the seven boreholes are shown in Table 4.14.

Table 4.14: Amount of chlorine in the borehole samples

Sampling point (Borehole)	Sample Volume (mL)	Amount of chlorine (mg/L)	EAS/WHO guideline value
Distilled water	20	0.00 ± 0.00	5 mg/L
Matangi Nne	20	0.01± 0.0058	
Ushirika Water Project	20	0.01 ± 0.00	
Koinange Car Wash	20	0.01 ± 0.058	
Geoffrey Kinyanjui	20	0.08 ± 0.01	
Shamba House	20	0.01± 0.00	
Keroche Borehole	20	0.01 ± 0.00	
Joywel School	20	0.06 ± 0.015	
Bottled water (control)	20	0.01 ± 0.00	

From the sampled boreholes (Table 4.14), the amount of free chlorine was found to be 0.01 mg/L for all sampled boreholes except Geoffrey Kinyanjui and Joywel School boreholes whose values were 0.08 mg/L and 0.06 mg/L of chlorine respectively. The presence of free chlorine in the area may have been caused by use of chlorine based bleaches in the surrounding industries or from the sodium hypochloride (JIK) that is often used as a household bleaching agent that may have leached into the underground water. The East African Standard and the WHO guidelines value is given as 5 mg/L whereby all the sampled boreholes complied with this criteria. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes.

4.12 Fluoride

The fluoride ion determination was done using the Extech digital fluoride meter.

4.12.1 Fluoride determination in the samples

The amounts of fluoride in the water samples from the seven boreholes are shown in Table 4.15.

Table 4.15: Amount of fluoride in the water samples

Sampling point (Borehole)	Sample Volume (mL)	Amount of Fluoride (mg/L)	EAS/WHO guideline value
Distilled water	20	0.00 ± 0.00	1.5 mg/L
Matangi Nne	20	4.63 ± 0.058	
Ushirika Water Project	20	2.43 ± 0.152	
Koinange Car Wash	20	5.00 ± 0.100	
Geoffrey Kinyanjui	20	4.82 ± 0.020	
Shamba House	20	4.60 ± 0.000	
Keroche Borehole	20	1.20 ± 0.100	
Joywel School	20	3.50 ± 0.100	
Bottled water (control)	20	0.13 ± 0.058	

From the sampled boreholes (Table 4.15), the least amount of fluoride was found to be 1.20 mg/L for Keroche borehole and the highest obtained value was 5.0 mg/L for Koinange Car Wash borehole. The East African Standard and the WHO guideline set value for fluoride is 1.5 mg/L. None of the sampled boreholes complied with this criteria except Keroche borehole. Therefore, based on this parameter, Keroche borehole was the only one whose water was safe for drinking purposes. The high levels of fluoride in the area may be attributed to the naturally occurring minerals such as fluorspar, fluoroapatite and cryolite that disintegrate overtime releasing fluoride into the groundwater. Anthropogenic activities such as mining and salinity build up due to large scale irrigation also impact on the fluoride amounts in groundwater. Keroche borehole may have had a lower value perhaps due to some remediation measure put in place by the company.

4.13 Concentration of sulfates in the samples

The determination of the sulfate content in the samples was done using the Shimadzu UV-1800 UV/VIS Spectrometer at 420 nm. A calibration curve was obtained using the four standards which was then used to determine the sulfates content in the samples using distilled water as the blank. The sulfates standards concentration vs their respective absorbances are shown in Table 4.16.

Table 4.16: Absorbance vs conc. of sulfate standards

Std Conc (mg/L)	Absorbance
0.0	0.0168
50	0.0415
100	0.0762
200	0.1398
400	0.2896
600	0.4577
800	0.6086

The calibration curve drawn from the concentration of the sulfate standards and the absorbance values obtained (Table 4.16) is shown in Figure 4.10.

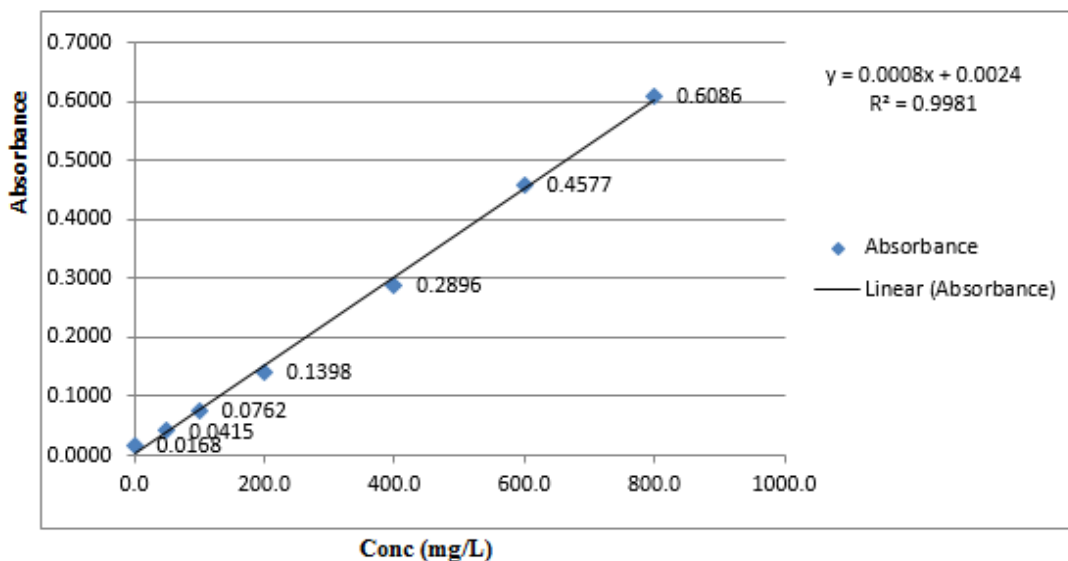


Figure 4.10: Calibration curve for sulfates standards

The calculated amounts of sulfates in the boreholes samples are shown in Table 4.17.

Table 4.17: Actual amount of sulfates in the samples

Sampling point (Borehole)	Absorbance (y- Axis)	$x = \frac{y - 0.0024}{0.008}$	Actual Conc. (mg/L) = X * 20 mL	Limit of Detection LOD	EAS/WHO guideline value
Matangi Nne	0.1080	13.194	263.88	0.0028	500 mg/L
Koinange Car Wash	0.0856	10.400	208.00		
Ushirika Water Project	0.0962	11.719	234.38		
Shamba House	0.1020	12.456	249.13		
Joywel School	0.0918	11.181	223.63		
Geoffrey Kinyanjui	0.0943	11.488	229.75		
Keroche Borehole	0.0644	7.744	154.88		
Bottled water (control)	0.0061	0.463	9.25		

From the analysis (Table 4.17), the borehole with the least amount of sulfates was Keroche borehole with 154.88 mg/L while the highest amount was obtained from Matangi Nne borehole which had 263.88 mg/L of sulfates. The values for the amounts of sulfates obtained may have been as a result of natural occurrence e.g. gypsum or geological processes for instance oxidation of pyrites. The other sources would be anthropogenic such as use of ammonium sulfate fertilizers, pesticides (for the case of Matangi Nne borehole) and decomposition of urban waste for the rest of the boreholes. The East African Standard as well as the WHO guideline value of 500 mg/L was however met by all the sampled points and therefore, water from all the sampled boreholes was safe for drinking purposes based on this parameter.

4.14 Concentration of nitrates in the samples

The nitrate ion determination was determined by the UV/Vis spectrometer. The nitrates calibration standards against their obtained absorbances are shown in Table 4.18.

Table 4.18: Absorbance vs conc. of nitrates standards

Std Conc (mg/L)	Absorbance
0.0	0.0005
2.0	0.1240
4.0	0.2380
6.0	0.3600
12.0	0.7330
16.0	0.9568
20.0	1.1897

The calibration curve drawn from the concentration of the nitrates standards and the absorbance values obtained (Table 4.18) is shown in Figure 4.11.

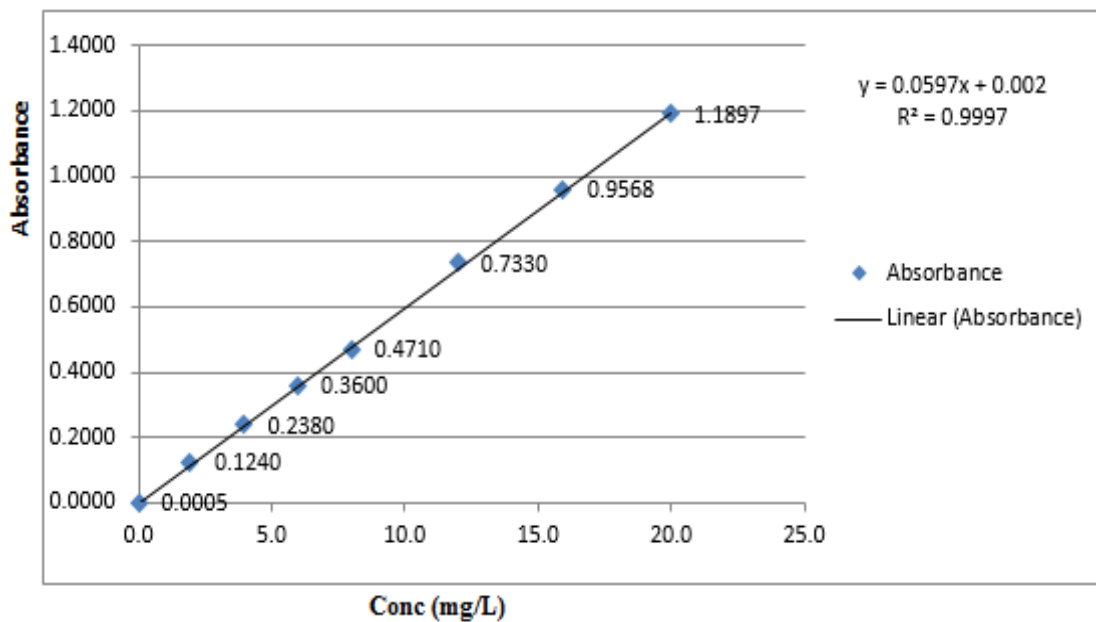


Figure 4.11: Calibration curve for nitrate standards

The calculated amounts of nitrates in the boreholes samples are shown in Table 4.19.

Table 4.19: Actual amount of nitrates in the samples

Sampling point (Borehole)	Absorbance (y- Axis)	$x = \frac{y - 0.002}{0.0597}$	Actual Conc. (mg/L) = X * 25	Limit of Detection LOD	EAS/WHO guideline value
Matangi Nne	0.0166	0.2448	6.12	0.0161	50 mg/L
Koinange Car Wash	0.0255	0.3936	9.84		
Ushirika Water Project	0.0256	0.3960	9.90		
Shamba House	0.0164	0.2416	6.04		
Joywel School	0.0257	0.3976	9.94		
Geoffrey Kinyanjui	0.0221	0.3364	8.41		
Keroche borehole	0.0228	0.3476	8.69		
Bottled water (control)	0.0149	0.2164	5.41		

From the analysis (Table 4.19), the borehole with the least amount of nitrates was Shamba House borehole with 6.04 mg/L while the largest amount was obtained from Joywel School borehole which had 9.94 mg/L of nitrates. The values obtained in the study may have resulted from use of nitrogen fertilizers within the area, improper septic systems and spreading of manure whereby small amounts are leached through surface runoffs into the ground. However, these values were much lower than the East African Standard and the WHO guideline value set at 50 mg/L. Water from all the sampled boreholes was safe for drinking purposes Based on this parameter.

4.15 Concentration of cations in the water samples

4.16 Concentration of sodium in the samples

The sodium content for the samples was ascertained using the AAS in the emission mode at a wavelength of 588.76 nm. The emission values obtained from the respective sodium calibration standards are shown in Table 4.20.

Table 4.20: Emission vs conc. of sodium calibration standards

Std Conc (mg/L)	Emission
2.00	0.2897
4.00	0.5144
6.00	0.7005
8.00	0.9015
10.00	1.1256

The calibration curve drawn from the concentration of the sodium standards and the emission values obtained (Table 4.20) is shown in Figure 4.12.

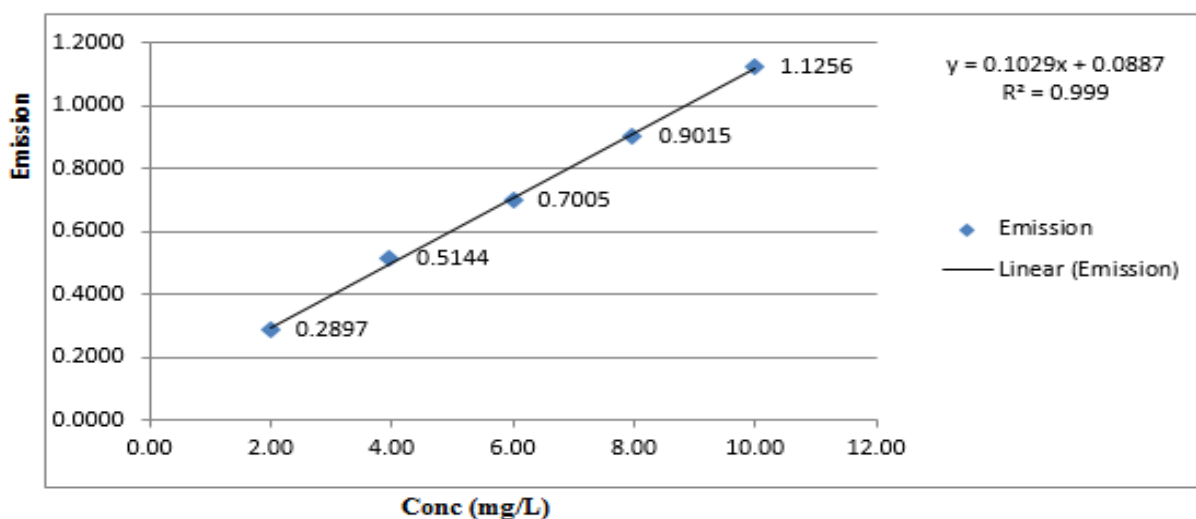


Figure 4.12: Calibration curve for sodium standards

The calculated amounts of sodium in the boreholes samples are shown in Table 4.21.

Table 4.21: Actual amount of sodium in the samples

Sampling point (Borehole)	Emission (y- Axis)	Actual Conc. (mg/L) $x = \frac{y - 0.0887}{0.1029}$	Limit of Detection LOD	EAS/WHO guideline value
Matangi Nne	1.5891	14.58	0.1404	200 mg/L
Koinange Car Wash	1.8001	16.63		
Ushirika Water Project	1.9213	17.81		
Shamba House	1.3274	12.04		
Joywel School	1.7798	16.43		
Geoffrey Kinyanjui	1.2356	11.15		
Keroche borehole	0.9885	8.74		
Bottled water (control)	0.4413	3.43		

From the analysis (Table 4.21), the borehole with the least amount of sodium was Keroche borehole with 8.74 mg/L while the highest amount was obtained from the Ushirika Water Project borehole which had 17.81 mg/L of sodium. The amounts of sodium obtained may have been as a result of natural occurrence of sodium compounds that erode overtime depositing it into groundwater or anthropogenic where road salt is infiltrated into the ground and also from leaching landfills. The East African Standard as well as the WHO guidelines for drinking water have stated the maximum allowable limits for sodium as 200 mg/L therefore, all the sampled boreholes met this criteria. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes.

4.17 Concentration of potassium in the samples

The potassium content in all the samples was ascertained using the AAS in the emission mode. The emission values obtained from the respective potassium calibration standards are shown in Table 4.22.

Table 4.22: Emission vs conc. of potassium calibration standards

Std Conc (mg/L)	Emission
2.00	0.3988
3.00	0.4899
4.00	0.5789
5.00	0.6587
6.00	0.7277
8.00	0.8710
10.00	0.9991

The calibration curve drawn from the concentration of the potassium standards and the emission values obtained (Table 4.22) is shown in Figure 4.13.

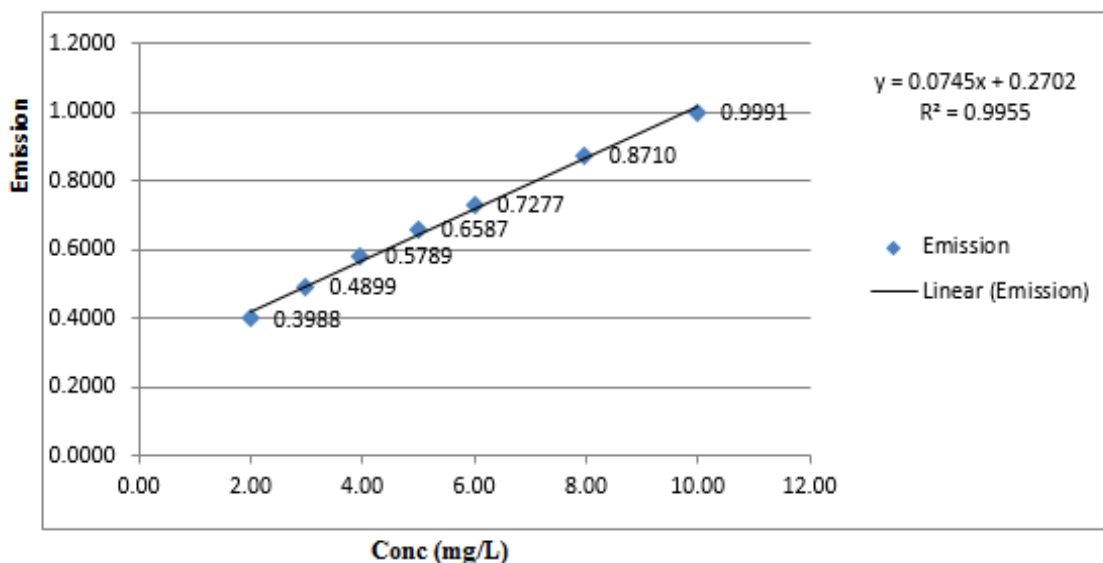


Figure 4.13: Calibration curve for potassium standards

The calculated amounts of potassium in the borehole samples are shown in Table 4.23.

Table 4.23: Actual amount of potassium in the samples

Sampling point (Borehole)	Emission (y- Axis)	Actual Conc. (mg/L) $x = \frac{y - 0.2702}{0.0745}$	Limit of Detection LOD	EAS/WHO guideline value
Matangi Nne	1.1491	11.80	0.3242	Not Indicated
Koinange Car Wash	1.3654	14.70		
Ushirika Water Project	1.5715	17.47		
Shamba House	1.2637	13.34		
Joywel School	1.5726	17.48		
Geoffrey Kinyanjui	1.2887	13.67		
Keroche borehole	1.5672	14.40		
Bottled water (control)	0.6587	5.21		

From the analysis of potassium (Table 4.23), the borehole with the least amount of potassium was Matangi Nne borehole with 11.80 mg/L while the highest amount was obtained from Joywel School borehole which had 17.48 mg/L of potassium. The values obtained may have been an indication of long term use of potassium based fertilizers in the area which over time leach into the underground aquifers. The maximum allowable amount of potassium has not been stated by neither the East African Standard nor the WHO guidelines for drinking water.

4.18 Concentration of manganese in the samples

The manganese content for each of the samples was determined using an atomic absorption spectrophotometer at 279.5 nm. The absorbance values obtained from the respective manganese standard concentration values are shown in Table 4.24.

Table 4.24: Absorbance vs conc. of manganese standard concentrations

Std Conc (mg/L)	Absorbance
0.20	0.0427
0.30	0.0654
0.40	0.0862
0.60	0.1304
0.80	0.1720
1.20	0.2546
2.00	0.4185

The calibration curve drawn from the concentration of the manganese standards and the absorbance values obtained (Table 4.24) is shown in Figure 4.14.

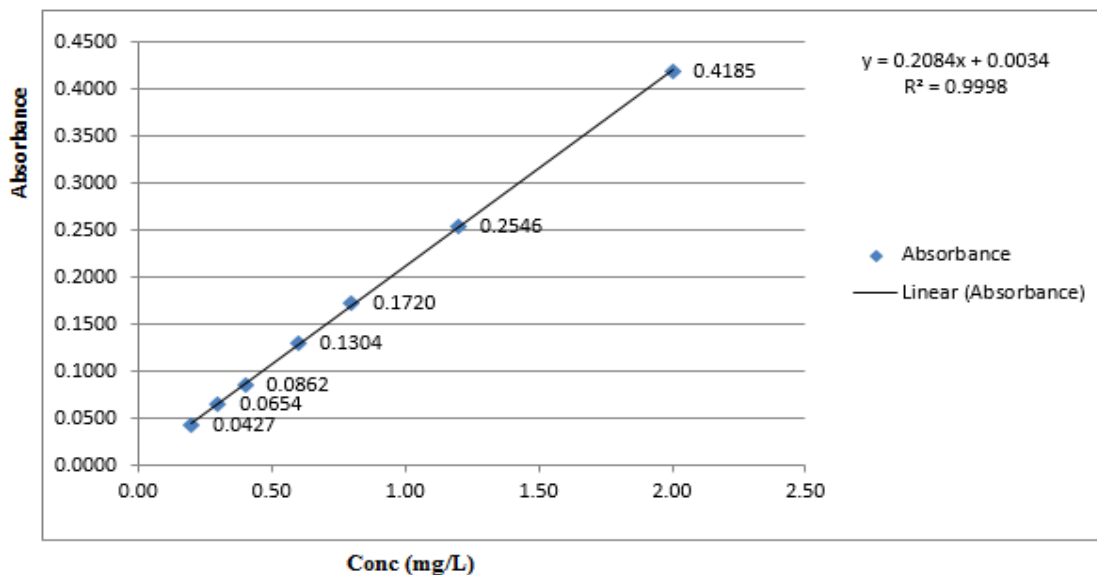


Figure 4.14: Calibration curve for manganese standards.

The calculated amounts of manganese in the borehole samples are shown in Table 4.25.

Table 4.25: Actual amount of manganese in the samples

Sampling point (Borehole)	Absorbance (y- Axis)	Actual Conc. (mg/L) $x = \frac{y - 0.0034}{0.2084}$	Limit of Detection LOD	EAS/WHO guideline value
Matangi Nne	0.0009	-0.0120	0.0873	0.1 mg/L
Koinange Car Wash	0.0016	-0.0086		
Ushirika Water Project	0.0026	0.0038		
Shamba House	0.0011	-0.0110		
Joywel School	0.0019	-0.0072		
Geoffrey Kinyanjui	0.0011	-0.0110		
Keroche borehole	0.0023	-0.0053		
Bottled water (control)	0.0012	-0.0106		

From the analysis of manganese above (Table 4.25), all the boreholes assessed had levels that were below the detection limit of Manganese which was 0.0873. This means that manganese release in the underground water was minimal indicating the of presence of dissolved oxygen in water and therefore the Mn(IV) present in the bedrocks was not being reduced to the soluble form Mn(II). The East African Standard as well as the WHO guideline value for manganese is set at 0.1 mg/L whereby all the sampled points met this criteria. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes.

4.19 Concentration of copper in the samples

The amount of copper in the samples was determined by use of the atomic absorption spectrophotometer at 324.8 nm. The absorbance values obtained from the respective copper calibration standards are shown in Table 4.26.

Table 4.26: Absorbance vs conc. of copper standards

Std Conc (ppm)	Absorbance
0.20	0.0116
0.40	0.0294
0.60	0.0646
0.80	0.0917
2.00	0.2696
2.50	0.3589

The calibration curve drawn from the concentration of the copper standards and the absorbance values obtained (Table 4.26) is shown in Figure 4.15.

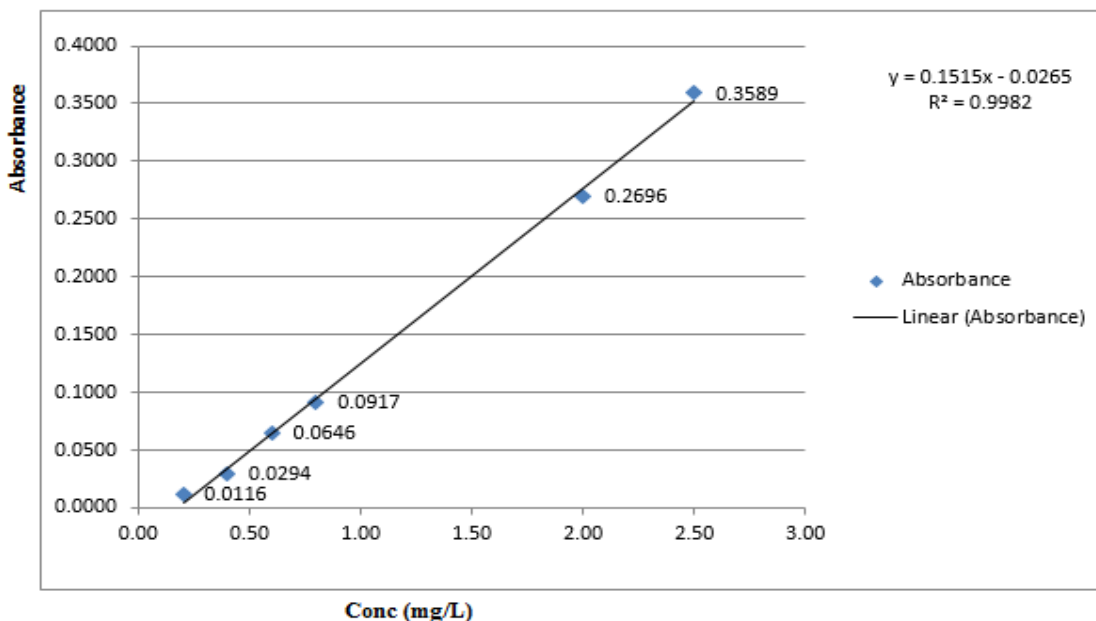


Figure 4.15: Calibration curve for copper standards

The calculated amounts of copper in the borehole samples are shown in Table 4.27.

Table 4.27: Actual amount of copper in the samples

Sampling point (Borehole)	Absorbance (y- Axis)	Actual Conc. (mg/L) $x = \frac{y + 0.0265}{0.1515}$	Limit of Detection LOD	EAS/WHO guideline value
Matangi Nne	0.0056	0.2119	0.0911	2 mg/L
Koinange Car Wash	-0.0042	0.1472		
Ushirika Water Project	-0.0050	0.1419		
Shamba House	0.0013	0.1835		
Joywel School	0.0049	0.2073		
Geoffrey Kinyanjui	0.0027	0.1927		
Keroche borehole	0.0059	0.2139		
Bottled water (control)	0.0047	0.2059		

From the analysis of copper above (Table 4.27), the borehole with the least amount of copper was Ushirika Water Project borehole with 0.1419 mg/L of copper while the highest amount was obtained from Keroche borehole which had 0.2139 mg/L of copper. The East African Standard and WHO guideline value for copper is set at 2 mg/L whereby all the sampled points were well below this set criteria Based on this parameter, water from all the sampled boreholes was safe for drinking purposes.

4.20 Concentration of iron in the samples

The iron content for the borehole samples was done using the atomic absorption spectrophotometer at 248.3 nm. The absorbance versus iron concentration values of standards are shown in Table 4.28.

Table 4.28: Absorbance vs conc. of iron standards

Std Conc (mg/L)	Absorbance
0.4	0.0272
0.6	0.0447
0.8	0.0593
1.0	0.0779
1.4	0.1086
1.8	0.1413
2.0	0.1575

The calibration curve drawn from the iron standards concentration and the absorbance values obtained (Table 4.28) is shown in Figure 4.16.

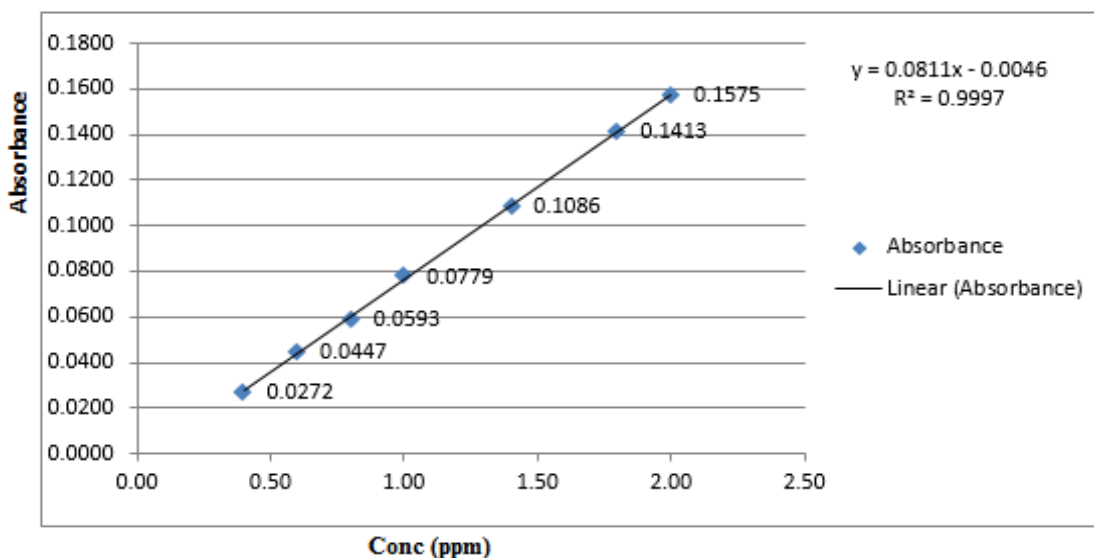


Figure 4.16: Calibration curve for iron standards.

The calculated amounts of iron in the borehole samples are shown in Table 4.29.

Table 4.29: Actual amount of iron in the samples

Sampling point (Borehole)	Absorbance (y- Axis)	Actual Conc. (mg/L) $x = \frac{y + 0.0046}{0.0811}$	Limit of Detection LOD	EAS/WHO guideline value
Matangi Nne	0.0034	0.0986	0.0551	0.3 mg/L
Koinange Car Wash	-0.0008	0.0469		
Ushirika Water Project	-0.0028	0.0222		
Shamba House	-0.0029	0.0210		
Joywel School	0.0002	0.0592		
Geoffrey Kinyanjui	0.0065	0.1369		
Keroche borehole	-0.0012	0.0419		
Bottled water (control)	0.0013	0.0727		

From the analysis of iron content, the borehole with the least amount of iron was Shamba House borehole with 0.0210 mg/L of iron while the highest amount was obtained from Geoffrey Kinyanjui's borehole which had 0.1369 mg/L of iron. Iron may have resulted from corrosion of iron sheets that leach underground overtime. East African Standard and the WHO guideline value for iron is set at 0.3 mg/L whereby all the sampled points were well below this set criteria. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes.

4.21 Concentration of cadmium in the samples

Cadmium content in the samples was determined at 228.8 nm.

The absorbance values versus concentration of cadmium standards are shown in Table 4.30.

Table 4.30: Absorbance vs conc. of cadmium standards

Std Conc (ppm)	Absorbance
0.20	0.0703
0.30	0.1101
0.40	0.1531
0.60	0.2211
0.80	0.2969
1.20	0.4315

The calibration curve drawn from the concentration of the cadmium standards and the absorbance values obtained (Table 4.30) is shown in Figure 4.17.

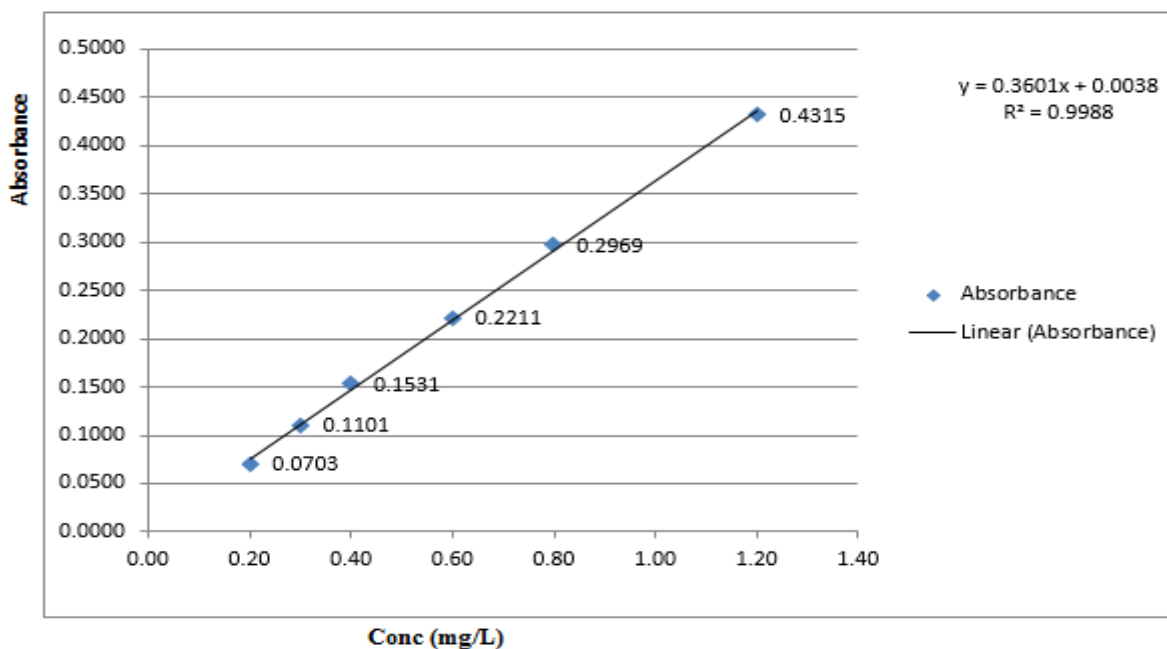


Figure 4.17: Calibration curve for cadmium standards.

The calculated amounts of cadmium in the borehole samples are shown in Table 4.31.

Table 4.31: Actual amount of cadmium in the samples

Sampling point (Borehole)	Absorbance (y- Axis)	Actual Conc. (mg/L) $x = \frac{y - 0.0038}{0.3601}$	Limit of Detection LOD	EAS/WHO guideline value
Matangi Nne	-0.0006	-0.0122	0.2640	0.003 mg/L
Koinange Car Wash	-0.0002	-0.0111		
Ushirika Water Project	-0.0014	-0.0144		
Shamba House	-0.0015	-0.0147		
Joywel School	-0.0016	-0.0150		
Geoffrey Kinyanjui	-0.0016	-0.0150		
Keroche borehole	-0.0019	-0.0158		
Bottled water (control)	-0.0014	-0.0144		

From the analysis of cadmium above (Table 4.31), all the sampled boreholes had undetectable amounts of cadmium the limit of detection being 0.2640. The East African Standard and the WHO guideline value for cadmium is set at 0.003 mg/L whereby all the sampled points were well below this set value. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes.

4.22 Concentration of lead in the samples

Lead content for each of the samples was done using atomic absorption spectrophotometer at 283.3 nm. The absorbance values versus the concentration of the lead standards are shown in Table 4.32.

Table 4.32: Absorbance vs conc. of lead standards

Std Conc (mg/L)	Absorbance
0.20	0.0011
0.30	0.0027
0.40	0.0049
0.60	0.0071
0.80	0.0114
1.20	0.0175
2.00	0.0295
2.50	0.0377

The calibration curve drawn from the concentration of the lead standards and the absorbance values obtained (Table 4.32) is shown in Figure 4.18.

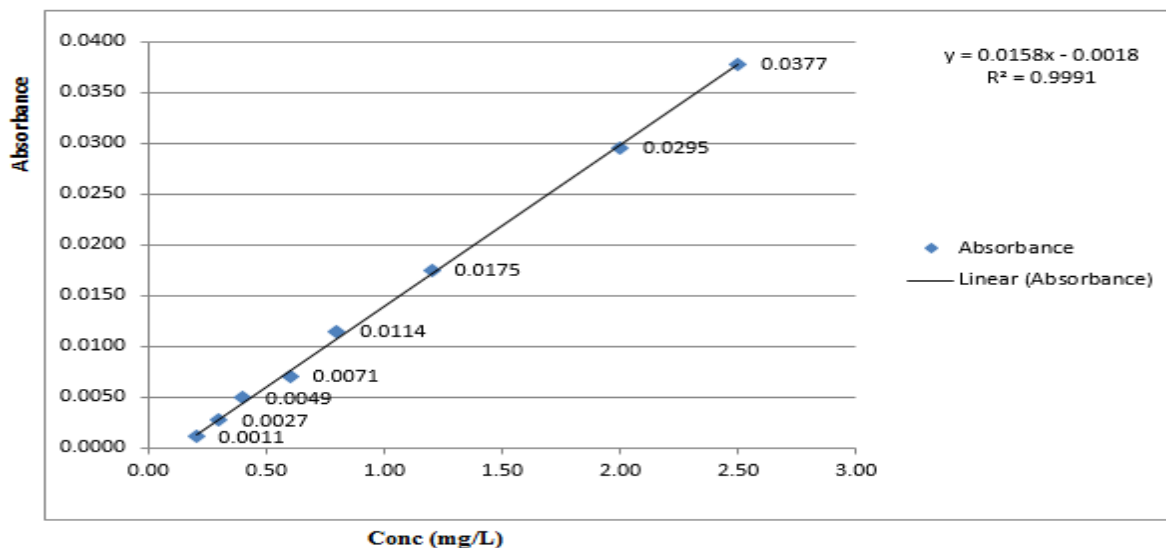


Figure 4.18: Calibration curve of lead standards

The calculated amounts of lead in the borehole samples are shown in Table 4.33.

Table 4.33: Actual amount of Lead in the samples

Sampling point (Borehole)	Absorbance (y- Axis)	Actual Conc. (mg/L) $x = \frac{y + 0.0018}{0.0158}$	Limit of Detection LOD	EAS/WHO guideline value
Matangi Nne	0.0013	0.1962	0.0261	0.01 mg/L
Koinange Car Wash	-0.0003	0.0949		
Ushirika Water Project	-0.0009	0.0570		
Shamba House	-0.0003	0.0949		
Joywel School	-0.0004	0.0886		
Geoffrey Kinyanjui	0.0009	0.1709		
Keroche borehole	-0.0008	0.0633		
Bottled water (control)	-0.0019	-0.0063		

From the analysis of lead above (Table 4.33), the borehole with the least amount of lead was Ushirika Water Project borehole with 0.0570 mg/L of lead while the highest amount was obtained from Matangi Nne borehole which had 0.1962 mg/L of lead. The high values may have been due to the long term use of lead based paints, pesticides and improper disposal of lead acid batteries. The East African Standard and the WHO guideline value for lead is set at 0.01 mg/L. All the samples had lead values above the WHO guideline value. Based on this parameter, water from all the sampled boreholes was not safe for drinking purposes.

4.23 Concentration of chromium in the samples

The chromium determination was performed at 357.9 nm. The absorbance versus concentration of chromium standards are shown in Table 4.34.

Table 4.34: Absorbance vs conc. of chromium calibration standards

Std Conc (ppm)	Absorbance
0.20	0.0087
0.30	0.0138
0.50	0.0222
0.80	0.0360
1.00	0.0445
1.60	0.0683
2.00	0.0848

The calibration curve drawn from the chromium standards concentration and the absorbance values obtained (Table 4.34) is shown in Figure 4.19.

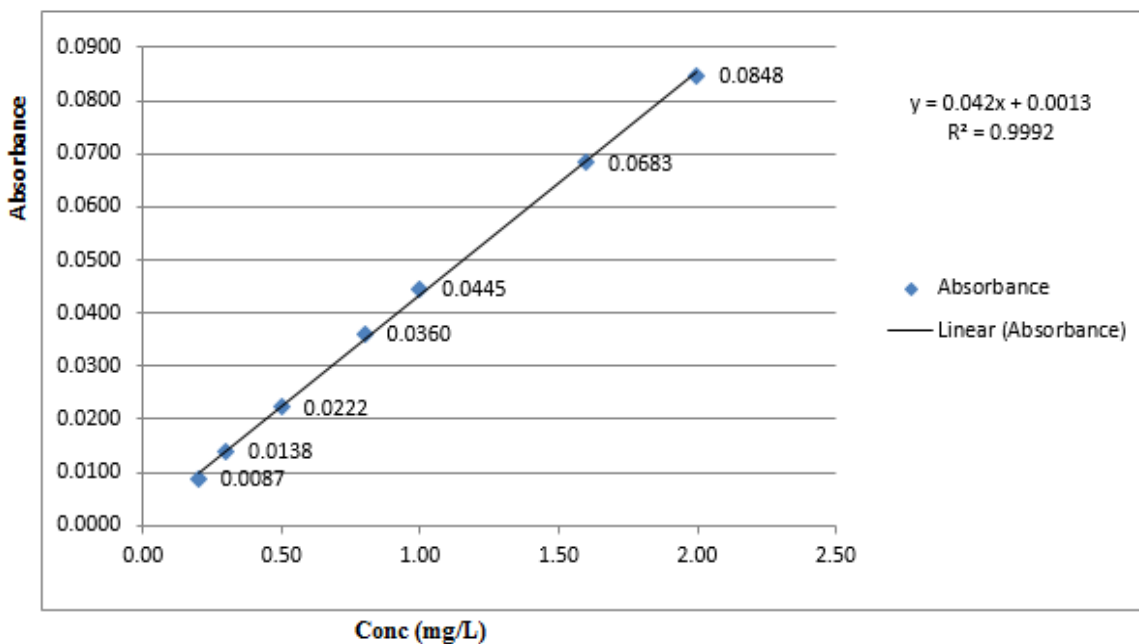


Figure 4.19: Calibration curve for chromium standards.

The calculated amounts of chromium in the borehole samples are shown in Table 4.35.

Table 4.35: Actual amount of chromium in the samples

Sampling point (Borehole)	Absorbance (y- Axis)	Actual Conc. (mg/L) $x = \frac{y - 0.0013}{0.042}$	Limit of Detection LOD	EAS/WHO guideline value
Matangi Nne	-0.0006	-0.0452	0.0554	0.05 mg/L
Koinange Car Wash	0.0007	-0.0143		
Ushirika Water Project	0.0006	-0.0167		
Shamba House	0.0002	-0.0262		
Joywel School	-0.0007	-0.0476		
Geoffrey Kinyanjui	0.0006	-0.0167		
Keroche borehole	0.0000	-0.0310		
Bottled water(control)	0.0005	-0.0190		

From the analysis of chromium, all the samples had undetectable amounts of the cation. The limit of detection was 0.0554.

The East African Standard and the WHO guideline value for chromium is set at 0.05 mg/L. Therefore, all of the samples had chromium amounts lower than this set value. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes

4.24 Concentration of zinc in the samples

The zinc content for the borehole samples was determined by the AAS. The absorbance values obtained from the respective zinc standards are shown in Table 4.36.

Table 4.36: Absorbance vs conc. of zinc standards

Std Conc (ppm)	Absorbance
0.20	0.0221
0.30	0.0298
0.40	0.0426
0.60	0.0547
0.80	0.0687
1.20	0.0966
2.00	0.1544
2.50	0.1901

The calibration curve drawn from the zinc standards concentration and the absorbance values obtained (Table 4.36) is shown in Figure 4.20.

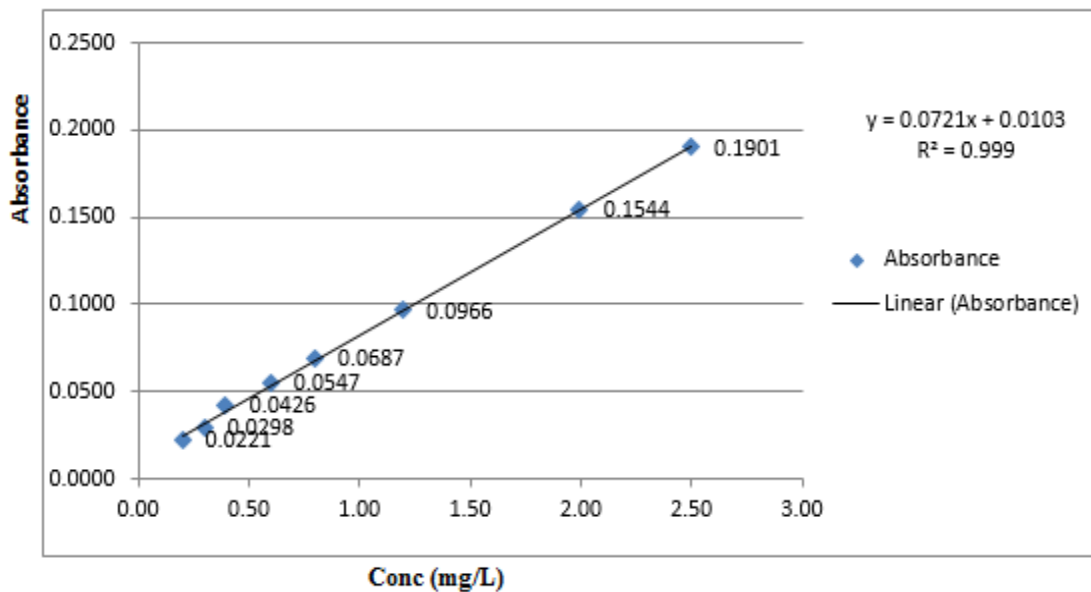


Figure 4.20: Calibration curve for zinc standards.

The calculated amounts of zinc in the borehole samples are shown in Table 4.37.

Table 4.37: Actual amount of zinc in the samples

Sampling point (Borehole)	Absorbance (y- Axis)	Actual Conc. (mg/L) $x = \frac{y - 0.0103}{0.0721}$	Limit of Detection LOD	EAS/WHO guideline value
Matangi Nne	0.0128	0.0347	0.0713	5 mg/L
Koinange Car Wash	0.0121	0.0251		
Ushirika Water Project	0.0124	0.0291		
Shamba House	0.0125	0.0305		
Joywel School	0.0126	0.0319		
Geoffrey Kinyanjui	0.0130	0.0374		
Keroche borehole	0.0120	0.0236		
Bottled water(control)	0.0114	0.0153		

From the analysis of zinc (Table 4.37), the borehole with the least amount was Keroche Borehole with 0.0236 mg/L while the highest amount was obtained from Geoffrey Kinyanjui Borehole which had 0.0374 mg/L. Long term use of galvanized roofing sheets may have been a major contributor to the values obtained. Erosion of these sheets over a prolonged time period may have caused zinc to leach into the underground water. The East African Standard and the WHO guideline value for zinc is 5.0 mg/L. Thus the samples were within the specified guideline value. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes.

4.25 *Escherichia coli* (*E.coli*)

The test was done by use of the multiple tube fermentation technique. None of the tested samples showed evidence of gas production or turbidity change in the presumptive test. However, the confirmed test was performed for each of the samples to eliminate doubt whereby none of the samples failed. Table 4.38 shows the results recorded for the presence of *E. coli*.

Table 4.38: Presence of *E.coli* in the samples

Sampling point (Borehole)	<i>E.coli</i> Presence (counts/100 mL)
Matangi Nne	Nil
Koinange Car Wash	Nil
Ushirika Water Project	Nil
Shamba House	Nil
Joywel School	Nil
Geoffrey Kinyanjui	Nil
Keroche borehole	Nil
Bottled water (control)	Nil

There was no *E.coli* present in any of the samples. The WHO guideline assert that there should not be any *E.coli* present in drinking water. All the samples had no *E.coli*. Based on this parameter, water from all the sampled boreholes was safe for drinking purposes

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The water quality parameters such as: pH, electrical conductivity, turbidity, water color, total dissolved solids, alkalinity, water hardness, chloride, chlorine, sulfates, nitrates, sodium, potassium, iron, cadmium, chromium, zinc and copper levels for the sampled boreholes were within the East African Standard and the WHO guideline values for drinking water. There was no *E.coli* present in the tested boreholes. The fluoride concentrations in all the sampled boreholes except Keroche borehole (1.2 mg/L) were higher than the East African Standard and the WHO guideline value (1.5 mg/L). The lead amount in all the sampled boreholes were higher than the East African Standard and the WHO guideline value (0.01 mg/L). Suspended solids were present in all the sampled boreholes despite the fact that, East African Standard and the WHO guideline states that suspended solids should not be present.

The high fluoride levels in the water samples may have been due to the disintegration of the naturally occurring fluoride minerals (fluorspar, fluoroapatite and cryolite) into the underground water. Mining and salinity buildup due to irrigation may also have made a contribution. The volcanic and alkaline soils found in this area are quite permeable and contain high amounts of sodium, fluoroapatite, fluorspar, zeolite, and ammonia among other minerals (Becht *et al.*, 2005). However, in the case of Keroche borehole where fluoride

concentration was low, may have been due to some control measure that may have been installed by the industry in the area.

The high lead concentrations for the boreholes may have been as a result of large scale use of lead based pesticides from large scale horticultural farming. Improper disposal of lead acid batteries over a prolonged time period may also have caused lead to leach into the underground water. The suspended solids may have been as a result of algae and sediments or silt present in the underground water. The results obtained from the assessment revealed that none of the sampled borehole water was of good quality for drinking purposes based on the East African Standard and the WHO guidelines for drinking water. Therefore, appropriate treatment methods are required for each of the boreholes to make the water suitable for drinking.

5.2 Recommendations

Therefore from this study, it is recommended that:

1. Water purification methods such as boiling, use of iodine solution, tablets or crystals; use of chlorine drops, water filter, use of ultraviolet light, distillation and other adsorption techniques be used to make water safe drinking.
2. Biopesticides and bioherbicides be used in floricultural farming to reduce the amount of lead and other heavy metals that may leach into the underground water.
3. Frequent water quality testing be conducted on the borehole waters.
4. Testing be conducted on other boreholes within the area that were not covered during the study.

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APPENDICES

Appendix AI: Calculation of water hardness for Matangi Nne borehole

The formula (5.1) was used to compute the water hardness in mg/L as CaCO₃

$$\left(\frac{mg}{L}\right) = M \text{ of EDTA} \times \frac{\text{Av.vol of EDTA}}{1000 \text{ mL}} \times M. \text{Mass of CaCO}_3 \times \frac{1000 \text{ mL}}{\text{Vol of Sample}} \quad (5.1)$$

The titre values for hardness determination for Matangi Nne borehole are shown in Table 5.1.

Table 5.1: Matangi Nne borehole water hardness determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of EDTA (mL)
		Final	Initial	
1	20	20.9	20.0	0.9
2	20	21.9	21.0	0.9
3	20	22.9	21.9	1.0
Av. Vol. of EDTA (mL) = $\frac{0.9 + 0.9 + 1.0}{3} = 0.9333 \text{ mL} \pm 0.058$				

Volume of sample used = 20 mL

Molar mass of CaCO₃ = 100.09 g/mole

Molarity of EDTA = 0.01009M

Av. Vol. of EDTA used = 0.9333 mL

Therefore using the formula (5.1), the hardness for Matangi Nne borehole

$$= 0.01009M \times (0.9333 \text{ mL}/1000 \text{ mL}) \times (100.09 \text{ g/mole} \times 1000 \text{ mg/g}) \times 1000 \text{ mL}/20 \text{ mL}$$

Hardness for Matangi Nne borehole = **47.13 mg/L** as CaCO₃

Appendix AII: Calculation of water hardness for Shamba House borehole

The titre values for hardness determination for Shamba house borehole are shown in Table 5.2.

Table 5.2: Shamba House borehole water hardness determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of EDTA (mL)
		Final	Initial	
1	20	2.6	2.0	0.6
2	20	3.2	2.6	0.6
3	20	3.9	3.2	0.7
$\text{Av. Vol. of EDTA (mL)} = \frac{0.6 + 0.6 + 0.7}{3} = 0.6333 \text{ mL} \pm 0.058$				

Av. Vol. of EDTA used = 0.6333 mL

Therefore using the formula (5.1), the hardness for Shamba House borehole

$$= 0.01009\text{M} \times (0.6333 \text{ mL}/1000 \text{ mL}) \times (100.09 \text{ g/mole} \times 1000 \text{ mg/g}) \times 1000 \text{ mL}/20 \text{ mL}$$

Hardness for Shamba House borehole = 31.97 mg/L as CaCO₃

Appendix AIII: Calculation of water hardness for Ushirika Water Project borehole

The titre values for hardness determination for Ushirika water project borehole are shown in Table 5.3.

Table 5.3: Ushirika water project borehole water hardness determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of EDTA (mL)
		Final	Initial	
1	20	17.9	17.0	0.9
2	20	18.8	18.0	0.8
3	20	19.7	18.8	0.9
$\text{Av. Vol. of EDTA (mL)} = \frac{0.9 + 0.8 + 0.9}{3} = 0.8667 \text{ mL} \pm 0.058$				

Av. Vol. of EDTA used = 0.8667 mL

Therefore using the formula (5.1), the hardness for Ushirika Water Project borehole

$$= 0.01009\text{M} \times (0.8667 \text{ mL}/1000 \text{ mL}) \times (100.09 \text{ g/mole} \times 1000 \text{ mg/g}) \times 1000 \text{ mL}/20 \text{ mL}$$

Hardness for Ushirika Water Project borehole = 43.76 mg/L as CaCO₃

Appendix AIV: Calculation of water hardness for Joywel School borehole

The titre values for hardness determination for Joywel School borehole are shown in Table 5.4.

Table 5.4: Joywel school borehole water hardness determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of EDTA (mL)
		Final	Initial	
1	20	10.5	10.0	0.5
2	20	11.1	10.5	0.6
3	20	11.7	11.1	0.6
Av. Vol. of EDTA (mL) = $\frac{0.5 + 0.6 + 0.6}{3}$ = 0.5667 mL \pm 0.058				

Av. Vol. of EDTA used = 0.5667 mL

Therefore using the formula (5.1), the hardness for Joywel School borehole

$$= 0.01009\text{M} \times (0.5667 \text{ mL}/1000 \text{ mL}) \times (100.09 \text{ g/mole} \times 1000 \text{ mg/g}) \times 1000 \text{ mL}/20 \text{ mL}$$

Hardness for Joywel School borehole = 28.62 mg/L as CaCO₃

Appendix AV: Calculation of water hardness for Keroche borehole

The titre values for hardness determination for Keroche borehole are shown in Table 5.5.

Table 5.5: Keroche borehole water hardness determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of EDTA (mL)
		Final	Initial	
1	20	5.7	4.0	1.7
2	20	7.5	5.7	1.8
3	20	9.1	7.5	1.6
Av. Vol. of EDTA (mL) = $\frac{1.7 + 1.8 + 1.6}{3}$ = 1.7 mL \pm 0.10				

Av. Vol. of EDTA used = 1.7 mL

Therefore using the formula (5.1), the hardness for Keroche borehole

$$\text{Hardness} = 0.01009\text{M} \times (1.7 \text{ mL}/1000 \text{ mL}) \times (100.09 \text{ g/mole} \times 1000 \text{ mg/g}) \times 1000 \text{ mL}/20 \text{ mL}$$

Hardness for Keroche borehole = 85.84 mg/L as CaCO₃

Appendix AVI: Calculation of water hardness for Geoffrey Kinyanjui borehole

The titre values for hardness determination for Geoffrey Kinyanjui borehole are shown in Table 5.6.

Table 5.6: Geoffrey Kinyanjui borehole water hardness determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of EDTA (mL)
		Final	Initial	
1	20	12.6	12.0	0.6
2	20	13.3	12.6	0.7
3	20	13.9	13.3	0.6
$\text{Av. Vol. of EDTA (mL)} = \frac{0.6 + 0.7 + 0.6}{3} = 0.6333 \text{ mL} \pm 0.058$				

Av. Vol. of EDTA used = 0.6333 mL

Therefore using the formula (5.1), the hardness for Geoffrey Kinyanjui borehole

$$= 0.01009\text{M} \times (0.6333 \text{ mL}/1000 \text{ mL}) \times (100.09 \text{ g/mole} \times 1000 \text{ mg/g}) \times 1000 \text{ mL}/20 \text{ mL}$$

Hardness for Geoffrey Kinyanjui borehole = 31.97 mg/L as CaCO₃

Appendix AVII: Calculation of water hardness for Koinange Car wash borehole

The titre values for hardness determination for Koinange Car Wash are shown in Table 5.2.

Table 5.7: Koinange Car Wash borehole water hardness determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of EDTA (mL)
		Final	Initial	
1	20	14.8	14.0	0.8
2	20	15.7	14.8	0.9
3	20	16.6	15.7	0.9
$\text{Av. Vol. of EDTA (mL)} = \frac{0.8 + 0.9 + 0.9}{3} = 0.8667 \text{ mL} \pm 0.058$				

Av. Vol. of EDTA used = 0.8667 mL

Therefore using the formula (5.1), the hardness for Koinange car wash borehole

$$= 0.01009\text{M} \times (0.8667 \text{ mL}/1000 \text{ mL}) \times (100.09 \text{ g/mole} \times 1000 \text{ mg/g}) \times 1000 \text{ mL}/20 \text{ mL}$$

Hardness for Koinange car wash borehole = 43.76 mg/L as CaCO₃

Appendix AVIII: Calculation of water hardness for Bottled water (control sample)

The titre values for hardness determination for Bottled water (control) are shown in Table 5.8.

Table 5.8: Bottled water hardness determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of EDTA (mL)
		Final	Initial	
1	20	1.55	1.50	0.05
2	20	2.55	2.50	0.05
3	20	2.65	2.60	0.05

Av. Vol. of EDTA (mL) = $\frac{0.05 + 0.05 + 0.05}{3}$ = 0.05 mL \pm 0.00

Av. Vol. of EDTA used = 0.05 mL

Therefore using the formula (5.1), the hardness for Bottled water (control sample)

$$= 0.01009\text{M} \times (0.05 \text{ mL}/1000 \text{ mL}) \times (100.09 \text{ g/mole} \times 1000 \text{ mg/g}) \times 1000 \text{ mL}/20 \text{ mL}$$

Hardness for Bottled water (control sample) = **2.52 mg/L as CaCO₃**

Appendix BI: Calculations for the alkalinity of Matangi Nne borehole

The formula (5.2) was used to calculate the Phenolphthalein/Total (P/T) alkalinity of the water samples:

$$\left(\frac{\text{mg}}{\text{L}}\right) = M \text{ of } H_2SO_4 \times \frac{\text{Av.vol of } H_2SO_4}{1000 \text{ mL}} \times M. \text{ Mass of } Na_2CO_3 \times \frac{1000 \text{ mL}}{\text{Vol of Sample}} \quad (5.2)$$

Phenolphthalein Alkalinity

The titration for P.A determination for Matangi Nne borehole is shown in Table 5.9.

Table 5.9: Matangi Nne borehole phenolphthalein alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	0.8	0.0	0.8
2	20	10.5	9.9	0.6
3	20	20.6	20.0	0.6
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{0.8 + 0.6 + 0.6}{3} = 0.6667 \text{ mL} \pm 0.115$				

Molar mass of Na₂CO₃ = 105.987

Volume of borehole water taken = 20 mL

Concentration of H₂SO₄ = 0.0103743M

Av. Vol. of H₂SO₄ used = 0.6667 mL

Therefore using the formula (5.2), the phenolphthalein alkalinity for Matangi Nne borehole:

= 0.0103743M x (0.06667 mL/1000 mL) x (105.987 g/mole x 1000 mg/g) x (1000 mL/20 mL)

Phenolphthalein Alkalinity for Matangi Nne borehole = **36.65 mg/L as Na₂CO₃**

Total Alkalinity

The titration for T.A determination for Matangi Nne borehole is shown in Table 5.10.

Table 5.10: Matangi Nne borehole Total alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	9.9	0.8	9.1
2	20	20.0	10.5	9.5
3	20	29.9	20.6	9.3
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{9.1 + 9.5 + 9.3}{3} = 9.3 \text{ mL} \pm 0.20$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 9.3 \text{ mL}$$

Therefore using the formula (5.2), the total alkalinity for Matangi Nne borehole:

$$= 0.0103743\text{M} \times (9.3 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

Total Alkalinity for Matangi Nne borehole:= **511.29 mg/L as Na₂CO₃**

Appendix BII: Calculations for the alkalinity of Shamba House borehole

Phenolphthalein Alkalinity

The titration for P.A determination for Shamba House borehole is shown in Table 5.11.

Table 5.11: Shamba House borehole phenolphthalein alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	0.6	0.0	0.6
2	20	6.8	6.3	0.5
3	20	13.2	12.7	0.5
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{0.6 + 0.5 + 0.5}{3} = 0.5333 \text{ mL} \pm 0.058$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 0.5333 \text{ mL}$$

Therefore using the formula (5.2), the phenolphthalein alkalinity for Shamba House borehole:

$$= 0.0103743\text{M} \times (0.5333 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

Phenolphthalein Alkalinity for Shamba House borehole = **29.32 mg/L as Na₂CO₃**

Total Alkalinity

The titration for P.A determination for Shamba House borehole is shown in Table 5.12

Table 5.12: Shamba House borehole Total alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	6.3	0.6	5.7
2	20	12.7	6.8	5.9
3	20	19.1	13.2	5.9
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{5.7 + 5.9 + 5.9}{3} = 5.833 \text{ mL} \pm 0.115$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 5.833 \text{ mL}$$

Therefore using the formula (5.2), the total alkalinity for Shamba house borehole:

$$= 0.0103743\text{M} \times (5.833 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Total Alkalinity Shamba house borehole} = \underline{\underline{320.68 \text{ mg/L as Na}_2\text{CO}_3}}$$

Appendix BIII: Calculations for the alkalinity for Ushirika water project borehole

Phenolphthalein Alkalinity

The titration for P.A determination for Ushirika water project borehole are shown in Table 5.13

Table 5.13: Ushirika water project borehole phenolphthalein alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	0.3	0.0	0.3
2	20	7.2	6.8	0.4
3	20	14.0	13.7	0.3
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{0.3 + 0.4 + 0.3}{3} = 0.3333 \text{ mL} \pm 0.058$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 0.3333 \text{ mL}$$

Therefore using the formula (5.2), the P. alkalinity for Ushirika water project borehole:

$$= 0.0103743\text{M} \times (0.3333 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Phenolphthalein Alkalinity for Ushirika water project borehole} = \underline{\underline{18.32 \text{ mg/L as Na}_2\text{CO}_3}}$$

Total Alkalinity

The titration for T.A determination for Ushirika water project borehole are shown in Table 5.14

Table 5.14: Ushirika water project borehole Total alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	6.8	0.3	6.5
2	20	13.7	7.2	6.5
3	20	20.4	14.0	6.4
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{6.5 + 6.5 + 6.4}{3} = 6.466 \text{ mL} \pm 0.058$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 6.466 \text{ mL}$$

Therefore using the formula (5.2), the total alkalinity for Ushirika water project borehole:

$$= 0.0103743\text{M} \times (6.466 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Total Alkalinity for Ushirika water project borehole} = \underline{\underline{355.48 \text{ mg/L as Na}_2\text{CO}_3}}$$

Appendix BIV: Calculations for the alkalinity for Geoffrey Kinyanjui borehole

Phenolphthalein Alkalinity

The titration for P.A determination for Geoffrey Kinyanjui borehole is shown in Table 5.15

Table 5.15: Geoffrey Kinyanjui borehole phenolphthalein alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	36.3	36.0	0.3
2	20	42.5	42.1	0.4
3	20	0.3	0.0	0.3
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{0.3 + 0.4 + 0.3}{3} = 0.3333 \text{ mL} \pm 0.058$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 0.3333 \text{ mL}$$

Therefore using the formula (5.2), the phenolphthalein alkalinity for Geoffrey Kinyanjui borehole:

$$= 0.0103743\text{M} \times (0.3333 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Phenolphthalein Alkalinity for Geoffrey Kinyanjui borehole} = \underline{\underline{18.32 \text{ mg/L as Na}_2\text{CO}_3}}$$

Total Alkalinity

The titration for T.A determination for Geoffrey Kinyanjui borehole is shown in Table 5.16

Table 5.16: Geoffrey Kinyanjui borehole total alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	42.1	36.3	5.8
2	20	48.2	42.5	5.7
3	20	6.0	0.3	5.7
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{5.8 + 5.7 + 5.7}{3} = 5.7333 \text{ mL} \pm 0.058$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 5.7333 \text{ mL}$$

Therefore using the formula (5.2), the total alkalinity for Geoffrey Kinyanjui borehole:

$$= 0.0103743\text{M} \times (5.7333 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Total Alkalinity for Geoffrey Kinyanjui} = \underline{\underline{315.20 \text{ mg/L as Na}_2\text{CO}_3}}$$

Appendix BV: Calculations for the alkalinity for Koinange car wash borehole

Phenolphthalein alkalinity

The titration for P.A determination for Koinange Car Wash borehole is shown in Table 5.17

Table 5.17: Koinange Car Wash borehole phenolphthalein alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	14.5	14.0	0.5
2	20	21.7	21.0	0.7
3	20	29.0	28.3	0.7
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{0.5 + 0.7 + 0.7}{3} = 0.6333 \text{ mL} \pm 0.115$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 0.6333 \text{ mL}$$

Therefore using the formula (5.2), the P. alkalinity for Koinange car wash borehole:

$$= 0.0103743\text{M} \times (0.6333 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Phenolphthalein Alkalinity for Koinange car wash borehole} = \underline{\underline{34.82 \text{ mg/L as Na}_2\text{CO}_3}}$$

Total Alkalinity

The titration for T.A determination for Koinange Car Wash borehole is shown in Table 5.18

Table 5.18: Koinange Car Wash borehole total alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	21.0	14.5	6.5
2	20	28.3	21.7	6.6
3	20	35.5	29.0	6.5
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{6.5 + 6.6 + 6.5}{3} = 6.533 \text{ mL} \pm 0.058$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 6.533 \text{ mL}$$

Therefore using the formula (5.2), the total alkalinity for Koinange car wash borehole:

$$= 0.0103743\text{M} \times (6.533 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Total Alkalinity for Koinange car wash borehole} = \underline{\underline{359.17 \text{ mg/L as Na}_2\text{CO}_3}}$$

Appendix BVI: Calculations for the alkalinity for Keroche borehole

Phenolphthalein Alkalinity

The titration for P.A determination for Keroche borehole is shown in Table 5.19.

Table 5.19: Keroche borehole phenolphthalein alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	26.7	26.5	0.2
2	20	30.1	29.8	0.3
3	20	33.4	33.1	0.3
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{0.2 + 0.3 + 0.3}{3} = 0.2667 \text{ mL} \pm 0.0581$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 0.2667 \text{ mL}$$

Therefore using the formula (5.2), the phenolphthalein alkalinity for Keroche borehole:

$$= 0.0103743\text{M} \times (0.2667 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Phenolphthalein Alkalinity for Keroche borehole} = \underline{\underline{14.66 \text{ mg/L as Na}_2\text{CO}_3}}$$

Total Alkalinity

The titration for T.A determination for Keroche borehole is shown in Table 5.20

Table 5.20: Keroche borehole total alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	29.8	26.7	3.1
2	20	33.1	30.1	3.0
3	20	36.5	33.4	3.1
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{3.1 + 3.0 + 3.1}{3} = 3.0667 \text{ mL} \pm 0.058$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 3.0667 \text{ mL}$$

Therefore using the formula (5.2), the total alkalinity for Keroche borehole:

$$= 0.0103743\text{M} \times (3.0667 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Total Alkalinity for Keroche borehole} = \underline{\underline{168.60 \text{ mg/L as Na}_2\text{CO}_3}}$$

Appendix BVII: Calculations for the alkalinity for Joywel School borehole

Phenolphthalein Alkalinity

The titration for P.A determination for Joywel School borehole is shown in Table 5.21

Table 5.21: Joywel School borehole phenolphthalein alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	6.7	6.0	0.7
2	20	13.5	12.6	0.9
3	20	20.3	19.5	0.8
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{0.7 + 0.9 + 0.8}{3} = 0.800 \text{ mL} \pm 0.10$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 0.800 \text{ mL}$$

Therefore using the formula (5.2), the phenolphthalein alkalinity for Joywel school borehole:

$$= 0.0103743\text{M} \times (0.800 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Phenolphthalein Alkalinity for Joywel school borehole} = \underline{\underline{43.98 \text{ mg/L as Na}_2\text{CO}_3}}$$

Total Alkalinity

The titration for T.A determination for Joywel School borehole is shown in Table 5.22

Table 5.22: Joywel School borehole total alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	12.6	6.7	5.9
2	20	19.5	13.5	6.0
3	20	26.3	20.3	6.0
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{5.9 + 6.0 + 6.0}{3} = 5.966 \text{ mL} \pm 0.058$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 5.966 \text{ mL}$$

Therefore using the formula (5.2), the total alkalinity for Joywel school borehole:

$$= 0.0103743\text{M} \times (5.966 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Total Alkalinity for Joywel school borehole} = \underline{\underline{327.99 \text{ mg/L as Na}_2\text{CO}_3}}$$

Appendix BVIII: Calculations for the alkalinity for Bottled water (control)

Phenolphthalein Alkalinity

The titration for P.A determination for Bottled water (control) is shown in Table 5.23.

Table 5.23: Bottled water (control) phenolphthalein alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	0.00	0.00	0.00
2	20	0.50	0.50	0.00
3	20	0.55	0.55	0.00
Av. Vol. of H ₂ SO ₄ (mL) = $\frac{0.00 + 0.00 + 0.00}{3} = 0.00 \text{ mL} \pm 0.00$				

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 0.5333 \text{ mL}$$

Therefore using the formula (5.2), the phenolphthalein alkalinity for Bottled water (control):

$$= 0.0103743\text{M} \times (0.000 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Phenolphthalein Alkalinity for Bottled water (control)} = \underline{\underline{0.00 \text{ mg/L as Na}_2\text{CO}_3}}$$

Total Alkalinity

The titration for T.A determination for Bottled water (control) is shown in Table 5.24

Table 5.24: Bottled water (control) total alkalinity determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of H ₂ SO ₄ (mL)
		Final	Initial	
1	20	0.05	0.00	0.05
2	20	0.55	0.50	0.05
3	20	0.60	0.55	0.05

Av. Vol. of H₂SO₄ (mL) = $\frac{0.05 + 0.05 + 0.05}{3} = 0.05 \text{ mL} \pm 0.00$

$$\text{Av. Vol. of H}_2\text{SO}_4 \text{ used} = 9.3 \text{ mL}$$

Therefore using the formula (5.2), the total alkalinity for Bottled water (control):

$$= 0.0103743\text{M} \times (0.05 \text{ mL}/1000 \text{ mL}) \times (105.987 \text{ g/mole} \times 1000 \text{ mg/g}) \times (1000 \text{ mL}/20 \text{ mL})$$

$$\text{Total Alkalinity for Bottled water (control)} = \underline{\underline{2.75 \text{ mg/L as Na}_2\text{CO}_3}}$$

Appendix CI: Calculations for the chloride for Matangi Nne borehole

The formula (5.3) was used to calculate the amount of chlorides in the borehole samples:

$$\text{Chlorides (mg/L)} = \frac{(V_2 - V_1) \times \text{Eq. of AgNO}_3 \times M \text{ of AgNO}_3 \times 1000 \text{ mL}}{\text{Sample Vol.}} \quad (5.3)$$

Where: Average Vol. of AgNO₃ (V₂)

Average Vol. of the Blank (V₁) = 0.12 mL (Blank correction)

Average Vol. of AgNO₃ used = (V₂ - V₁)

Equivalence of Chloride = 35.45

The titration for chloride determination for Matangi Nne borehole is shown in Table 5.25.

Table 5.25: Matangi Nne borehole chloride determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of AgNO ₃ (mL)
		Final	Initial	
1	50	5.25	4.00	1.25
2	50	3.70	2.50	1.20
3	50	5.00	3.70	1.30
Av. Vol. of AgNO ₃ (mL) = $\frac{1.25 + 1.20 + 1.30}{3} = 1.25 \text{ mL} \pm 0.05$				

Average Vol. of AgNO₃ used = (1.25 – 0.12) mL = 1.13 mL

Therefore using formula (5.3), the amount of chlorides for Matangi Nne borehole:

$$= \frac{1.13 \text{ mL} \times 35.45 \times 0.09959 \text{ M} \times 1000 \text{ mL}}{50 \text{ mL}} = \underline{\underline{79.78 \text{ mg/L}}}$$

Appendix CII: Calculations for the chloride for Koinange Car wash borehole

The titration for chloride determination for Koinange car wash borehole is shown in Table 5.26

Table 5.26: Koinange Car Wash borehole chloride determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of AgNO ₃ (mL)
		Final	Initial	
1	50	2.85	2.00	0.85
2	50	4.90	4.00	0.90
3	50	0.85	0.00	0.85
Av. Vol. of AgNO ₃ (mL) = $\frac{0.85 + 0.90 + 0.85}{3} = 0.8667 \text{ mL} \pm 0.03$				

Average Vol. of AgNO₃ used = (0.8667 – 0.12) mL = 0.7467 mL

Therefore using formula (5.3), the amount of chlorides for Koinange car wash borehole:

$$= \frac{0.7467 \text{ mL} \times 35.45 \times 0.09959\text{M} \times 1000 \text{ mL}}{50 \text{ mL}} = \underline{\underline{52.80 \text{ mg/L}}}$$

Appendix CIII: Calculations for the chloride for Ushirika Water Project borehole

The titration for chloride determination for Ushirika Water Project borehole is shown in Table 5.27

Table 5.27: Ushirika Water Project borehole chloride determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of AgNO ₃ (mL)
		Final	Initial	
1	50	1.45	1.00	0.45
2	50	2.00	1.45	0.55
3	50	2.45	2.00	0.45
Av. Vol. of AgNO ₃ (mL) = $\frac{0.45 + 0.55 + 0.45}{3} = 0.4833 \text{ mL} \pm 0.06$				

Average Vol. of AgNO₃ used = (0.4833 – 0.12) mL = 0.3633 mL

Therefore using formula (5.3), the amount of chlorides for Ushirika Water Project borehole:

$$= \frac{0.3633 \text{ mL} \times 35.45 \times 0.09959\text{M} \times 1000 \text{ mL}}{50 \text{ mL}} = \underline{\underline{25.65 \text{ mg/L}}}$$

Appendix CIV: Calculations for the chloride for Geoffrey Kinyanjui borehole.

The titration for chloride determination for Geoffrey Kinyanjui borehole is shown in Table 5.28.

Table 5.28: Geoffrey Kinyanjui borehole chloride determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of AgNO ₃ (mL)
		Final	Initial	
1	50	3.15	2.50	0.65
2	50	3.65	3.15	0.50
3	50	4.40	3.65	0.75
Av. Vol. of AgNO ₃ (mL) = $\frac{0.65 + 0.50 + 0.75}{3} = 0.6333 \text{ mL} \pm 0.126$				

Average Vol. of AgNO₃ used = (0.6333 – 0.12) mL = 0.5133 mL

Therefore using formula (5.3), the amount of chlorides for Geoffrey Kinyanjui borehole:

$$= \frac{0.5133 \text{ mL} \times 35.45 \times 0.09959 \text{ M} \times 1000 \text{ mL}}{50 \text{ mL}} = \underline{\underline{36.24 \text{ mg/L}}}$$

Appendix CV: Calculations for the chloride for Shamba House borehole

The titration for chloride determination for Shamba House borehole is shown in Table 5.29.

Table 5.29: Shamba House borehole chloride determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of AgNO ₃ (mL)
		Final	Initial	
1	50	0.95	0.00	0.95
2	50	1.90	1.00	0.90
3	50	2.80	2.00	0.80
Av. Vol. of AgNO ₃ (mL) = $\frac{0.95 + 0.90 + 0.80}{3} = 0.8833 \text{ mL} \pm 0.076$				

Average Vol. of AgNO₃ used = (0.8833 – 0.12) mL = 0.7633 mL

Therefore using formula (5.3), the amount of chlorides for Shamba House borehole:

$$= \frac{0.7633 \text{ mL} \times 35.45 \times 0.09959 \text{ M} \times 1000 \text{ mL}}{50 \text{ mL}} = \underline{\underline{53.98 \text{ mg/L}}}$$

Appendix CVI: Calculations for the chloride for Keroche borehole

The titration for chloride determination for Keroche borehole is shown in Table 5.30.

Table 5.30: Keroche borehole chloride determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of AgNO ₃ (mL)
		Final	Initial	
1	50	0.65	0.20	0.45
2	50	1.25	0.65	0.60
3	50	1.85	1.25	0.60
Av. Vol. of AgNO ₃ (mL) = $\frac{0.45 + 0.60 + 0.60}{3} = 0.55 \text{ mL} \pm 0.087$				

Average Vol. of AgNO₃ used = (0.55 – 0.12) mL = 0.43 mL

Therefore using formula (5.3), the amount of chlorides for Keroche borehole:

$$= \frac{0.43 \text{ mL} \times 35.45 \times 0.09959\text{M} \times 1000 \text{ mL}}{50 \text{ mL}} = \underline{\underline{30.36 \text{ mg/L}}}$$

Appendix CVI: Calculations for the chloride for Joywel School borehole

The titration for chloride determination for Joywel School borehole is shown in Table 5.31

Table 5.31: Joywel school borehole chloride determination

Titration No.	Vol. of Sample (mL)	Burette Reading (mL)		Volume of AgNO ₃ (mL)
		Final	Initial	
1	50	2.50	2.00	0.50
2	50	2.95	2.50	0.45
3	50	3.60	2.95	0.65
Av. Vol. of AgNO ₃ (mL) = $\frac{0.50 + 0.45 + 0.65}{3} = 0.5333 \text{ mL} \pm 0.104$				

Average Vol. of AgNO₃ used = (0.5333 – 0.12) mL = 0.4133 mL

Therefore using formula (5.3), the amount of chlorides for Joywel school borehole:

$$= \frac{0.4133 \text{ mL} \times 35.45 \times 0.09959\text{M} \times 1000 \text{ mL}}{50 \text{ mL}} = \underline{\underline{29.18 \text{ mg/L}}}$$

Appendix DI: Values for Matangi Nne borehole compared to WHO and EAS

Borehole Name	MATANGI NNE BOREHOLE
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TEST PARAMETER	UNITS	TEST RESULTS	GUIDELINE VALUE	
			WHO	EAS
pH	-	8.402	6.5-8.5	6.5-8.5
Elect. Conductivity	µS/cm	1218	2500	2500
Turbidity	NTU	0.135	1	1
Water Color	TCU	10	15	15
TSS	mg/L	3.33	ND	ND
TDS	mg/L	421	1500	1500
Total Hardness	mg/L	47.09	300	300
Alkalinity (P.A)	mg/L	36.66	-	-
(T.A)	mg/L	511.35	-	-
Chloride	mg/L	79.9	250	250
Chlorine	mg/L	0.01	5	5
Fluoride	mg/L	4.63	1.5	1.5
Sulfates	mg/L	263.88	-	-
Nitrates	mg/L	6.12	50	45
Sodium	mg/L	14.58	-	200
Potassium	mg/L	11.8	-	-
Manganese	mg/L	ND	0.4	0.4
Copper	mg/L	0.2119	2	2
Iron	mg/L	0.0986	0.3	0.3
Cadmium	mg/L	ND	0.003	0.003
Lead	mg/L	0.1962	0.01	0.01
Chromium	mg/L	ND	0.05	0.05
Zinc	mg/L	0.0347	5	5
<i>E.coli</i>	-	Nil	Nil	Nil

Comments: All parameters comply except TSS, Fluorides and Lead which are outside the guideline values.

Appendix DII: Values for Ushirika Water Project borehole compared to WHO and EAS

Borehole Name		USHIRIKA WATER PROJECT BOREHOLE		
TEST PARAMETER	UNIT S	TEST RESULTS	GUIDELINE VALUE	
			WHO	EAS
pH	-	8.042	6.5-8.5	6.5-8.5
Elect. Conductivity	µS/cm	677	2500	2500
Turbidity	NTU	0.099	1	1
Water Color	TCU	5	15	15
TSS	mg/L	12.43	ND	ND
TDS	mg/L	246	1500	1500
Total Hardness	mg/L	43.73	300	300
Alkalinity (P.A)	mg/L	18.33	-	-
(T.A)	mg/L	355.53	-	-
Chloride	mg/L	25.7	250	250
Chlorine	mg/L	0.01	5	5
Fluoride	mg/L	2.43	1.5	1.5
Sulfates	mg/L	234.38	-	-
Nitrates	mg/L	9.90	50	45
Sodium	mg/L	17.81	-	200
Potassium	mg/L	17.47	-	-
Manganese	mg/L	0.0038	0.4	0.4
Copper	mg/L	0.1419	2	2
Iron	mg/L	0.0222	0.3	0.3
Cadmium	mg/L	ND	0.003	0.003
Lead	mg/L	0.0570	0.01	0.01
Chromium	mg/L	ND	0.05	0.05
Zinc	mg/L	0.0291	5	5
<i>E.coli</i>	-	Nil	Nil	Nil

Comments: All parameters comply except TSS, Fluorides and Lead which are outside the guideline values.

Appendix DIII: Values for Koinange Car Wash borehole compared to WHO and EAS

Borehole Name		KOINANGE CAR WASH BOREHOLE		
TEST PARAMETER	UNITS	TEST RESULTS	GUIDELINE VALUE	
			WHO	EAS
pH	-	8.035	6.5-8.5	6.5-8.5
Elect. Conductivity	µS/cm	887	2500	2500
Turbidity	NTU	0.116	1	1
Water Color	TCU	4	15	15
TSS	mg/L	23.30	ND	ND
TDS	mg/L	43	1500	1500
Total Hardness	mg/L	43.73	300	300
Alkalinity (P.A)	mg/L	34.83	-	-
(T.A)	mg/L	359.23	-	-
Chloride	mg/L	52.8	250	250
Chlorine	mg/L	0.01	5	5
Fluoride	mg/L	5.0	1.5	1.5
Sulfates	mg/L	208.00	-	-
Nitrates	mg/L	9.84	50	45
Sodium	mg/L	16.63	-	200
Potassium	mg/L	14.40	-	-
Manganese	mg/L	ND	0.4	0.4
Copper	mg/L	0.1472	2	2
Iron	mg/L	0.0469	0.3	0.3
Cadmium	mg/L	ND	0.003	0.003
Lead	mg/L	0.0949	0.01	0.01
Chromium	mg/L	ND	0.05	0.05
Zinc	mg/L	0.0251	5	5
<i>E.coli</i>	-	Nil	Nil	Nil

Comments: All parameters comply except TSS, Fluorides and Lead which are outside the guideline values.

Appendix DIV: Values for Geoffrey Kinyanjui borehole compared to WHO and EAS

Borehole Name		GEOFFREY KINYANJUI BOREHOLE		
TEST PARAMETER	UNIT S	TEST RESULTS	GUIDELINE VALUE	
			WHO	EAS
pH	-	8.452	6.5-8.5	6.5-8.5
Elect. Conductivity	µS/cm	667	2500	2500
Turbidity	NTU	0.095	1	1
Water Color	TCU	6	15	15
TSS	mg/L	34.97	ND	ND
TDS	mg/L	211	1500	1500
Total Hardness	mg/L	31.95	300	300
Alkalinity (P.A)	mg/L	18.33	-	-
(T.A)	mg/L	315.24	-	-
Chloride	mg/L	36.3	250	250
Chlorine	mg/L	0.08	5	5
Fluoride	mg/L	4.82	1.5	1.5
Sulfates	mg/L	229.75	-	-
Nitrates	mg/L	8.41	50	45
Sodium	mg/L	11.15	-	200
Potassium	mg/L	13.67	-	-
Manganese	mg/L	ND	0.4	0.4
Copper	mg/L	0.1927	2	2
Iron	mg/L	0.1369	0.3	0.3
Cadmium	mg/L	ND	0.003	0.003
Lead	mg/L	0.1709	0.01	0.01
Chromium	mg/L	ND	0.05	0.05
Zinc	mg/L	0.0374	5	5
<i>E.coli</i>	-	Nil	Nil	Nil

Comments: All parameters comply except TSS, Fluorides and Lead which are outside the guideline values.

Appendix DV: Values for Shamba House borehole compared to WHO and EAS

Borehole Name		SHAMBA HOUSE BOREHOLE		
TEST PARAMETER	UNIT S	TEST RESULTS	GUIDELINE VALUE	
			WHO	EAS
pH	-	8.235	6.5-8.5	6.5-8.5
Elect. Conductivity	µS/cm	755	2500	2500
Turbidity	NTU	0.108	1	1
Water Color	TCU	4	15	15
TSS	mg/L	1.93	ND	ND
TDS	mg/L	291	1500	1500
Total Hardness	mg/L	31.95	300	300
Alkalinity (P.A)	mg/L	29.32	-	-
(T.A)	mg/L	320.72	-	-
Chloride	mg/L	53.9	250	250
Chlorine	mg/L	0.01	5	5
Fluoride	mg/L	4.6	1.5	1.5
Sulfates	mg/L	249.13	-	-
Nitrates	mg/L	6.04	50	45
Sodium	mg/L	12.04	-	200
Potassium	mg/L	13.34	-	-
Manganese	mg/L	ND	0.4	0.4
Copper	mg/L	0.1835	2	2
Iron	mg/L	0.0210	0.3	0.3
Cadmium	mg/L	ND	0.003	0.003
Lead	mg/L	0.0949	0.01	0.01
Chromium	mg/L	ND	0.05	0.05
Zinc	mg/L	0.0305	5	5
<i>E.coli</i>	-	Nil	Nil	Nil

Comments: All parameters comply except Fluorides and Lead which are outside the guideline values.

Appendix DVI: Values for Keroche borehole compared to WHO and EAS

Borehole Name		KEROCHE BOREHOLE		
TEST PARAMETER	UNIT S	TEST RESULTS	GUIDELINE VALUE	
			WHO	EAS
pH	-	7.028	6.5-8.5	6.5-8.5
Elect. Conductivity	µS/cm	412	2500	2500
Turbidity	NTU	0.210	1	1
Water Color	TCU	9	15	15
TSS	mg/L	48.0	ND	ND
TDS	mg/L	179	1500	1500
Total Hardness	mg/L	85.78	300	300
Alkalinity (P.A)	mg/L	14.66	-	-
(T.A)	mg/L	168.62	-	-
Chloride	mg/L	30.4	250	250
Chlorine	mg/L	0.01	5	5
Fluoride	mg/L	1.2	1.5	1.5
Sulfates	mg/L	154.88	-	-
Nitrates	mg/L	8.69	50	45
Sodium	mg/L	8.74	-	200
Potassium	mg/L	14.40	-	-
Manganese	mg/L	ND	0.4	0.4
Copper	mg/L	0.2139	2	2
Iron	mg/L	0.0419	0.3	0.3
Cadmium	mg/L	ND	0.003	0.003
Lead	mg/L	0.0633	0.01	0.01
Chromium	mg/L	ND	0.05	0.05
Zinc	mg/L	0.0236	5	5
<i>E.coli</i>	-	Nil	Nil	Nil

Comments: All parameters comply except TSS and Lead which are outside the guideline values.

Appendix DVII: Values for Joywel School borehole compared to WHO and EAS

Borehole Name		JOYWEL SCHOOL BOREHOLE		
TEST PARAMETER	UNIT S	TEST RESULTS	GUIDELINE VALUE	
			WHO	EAS
pH	-	8.317	6.5-8.5	6.5-8.5
Elect. Conductivity	µS/cm	648	2500	2500
Turbidity	NTU	0.335	1	1
Water Color	TCU	2	15	15
TSS	mg/L	2.00	ND	ND
TDS	mg/L	261	1500	1500
Total Hardness	mg/L	28.60	300	300
Alkalinity (P.A)	mg/L	43.99	-	-
(T.A)	mg/L	328.03	-	-
Chloride	mg/L	29.2	250	250
Chlorine	mg/L	0.06	5	5
Fluoride	mg/L	3.5	1.5	1.5
Sulfates	mg/L	223.63	-	-
Nitrates	mg/L	9.94	50	45
Sodium	mg/L	16.43	-	200
Potassium	mg/L	17.348	-	-
Manganese	mg/L	ND	0.4	0.4
Copper	mg/L	0.2073	2	2
Iron	mg/L	0.0592	0.3	0.3
Cadmium	mg/L	ND	0.003	0.003
Lead	mg/L	0.0886	0.01	0.01
Chromium	mg/L	ND	0.05	0.05
Zinc	mg/L	0.0319	5	5
<i>E.coli</i>	-	Nil	Nil	Nil

Comments: All parameters comply except TSS, Fluorides and Lead which are outside the guideline values.

Appendix DVIII: Borehole sample information form

Borehole sample information form

1. Name and location of Borehole: _____

2. Borehole Ref No: _____

3. Date of Sample collection: _____

4. Amount of Sample collected: _____

5. Depth in Meters: _____

6. Date of Drilling: _____

7. Open or Closed:

Is the Borehole covered or Open?

Yes

No

8. Date of Construction: _____

9. Population the Borehole serves: _____

10. Economic activities around the Borehole:

i. _____

11. Uses of the Borehole water:

i. _____

12. Test conducted in the past:

Have quality tests been conducted in the past?

Yes

No

13. Presence of a water tower:

Is a water tower present?

Yes

No

14. Tests conducted on Site:

i. pH -----

ii. Conductivity -----

iii. Temperature -----

iv. Others -----

Name and Signature: _____