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FACULTY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF CHEMISTRY

ASSESSMENT OF WATER QUALITY FROM SHALLOW WELLS IN INFORMAL SETTLEMENTS IN KENYA: A CASE OF NYALENDA ESTATES, KISUMU COUNTY, KENYA

BY

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I56/80849/2015

Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Environmental Chemistry of the University of Nairobi
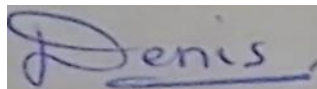
AUGUST, 2023

DECLARATION

This Thesis is my original work, and it has not been submitted elsewhere for examination, award of degree or publication. Where other people's work has been used, it has been properly acknowledged and referenced in accordance with the University of Nairobi's requirements.

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DEDICATION

I dedicate this work to my wife Vivian and our daughters Melissa and Rose for their continued encouragement and support in my pursuit of this Master's program.

ACKNOWLEDGEMENT

ABSTRACT

The study assessed the physico-chemical and bacteriological water quality parameters from shallow wells in Nyalenda A and B Estates in Kisumu County. The purpose was to evaluate the quality of water used by the residents of these estates. Water samples were collected in February and April 2017 representing the dry and wet seasons respectively. Ten sampling sites were randomly selected for the study based on their closeness to pit latrines or domestic solid waste disposal sites. The parameters analyzed were colour, pH, turbidity, total dissolved solids (TDS) and electrical conductivity, nitrates, nitrites, fluoride, sulphate and phosphates, alkalinity, total hardness, calcium hardness, magnesium hardness and salinity, total and feacal coliforms bacteria. The metals ions analysed were copper, lead, cadmium, zinc and chromium. Colour was recorded at below 4 Hazen units in all the ten sampling sites. pH ranged from 6.8 ± 0.1 to 9.2 ± 0.04, turbidity was between 0.344 ± 0.02 mg/L and 23.7 ± 0.1 mg/L; alkalinity values were between 40 ± 4.0 mg/L and 550 ± 4.0 mg/L; total hardness ranged from 85.0 ± 3.0 mg/L to 600.0 ± 5.0 mg/L; electrical conductivity was recorded at a minimum of 328.0 ± 1.0 μScm^{-1} and a maximum of 2820.0 ± 6.00 μScm^{-1}. TDS ranged between 156.0 ± 2.0 mg/L and $1,356.0 \pm 3$ mg/L as magnesium concentration was recorded at between 0.2 ± 0.01 mg/L and 2.7 ± 0.1 mg/L. Calcium values ranged from 1.4 ± 0.1 mg/L to 25.7 ± 0.1mg/L as chloride minimum value was 5.00 ± 1.0 mg/L with a maximum of 190.0 ± 4.0 mg/L. The highest phosphate level was recorded at 1.61 ± 0.01 mg/L while the lowest was 0.5 ± 0.01 mg/L. Nitrates minimum concentration was 0.2 ± 0.01 mg/L with a maximum of 5.16 ± 0.04 mg/L. Nitrite's concentration ranged between 9.0 ± 1.0 μg/L and 290.0 ± 10.0 μg/L. Fluoride's concentration ranged between 720.0 ± 10.0 μg/L and $1,650.0 \pm 50.0$ μg/L. Total coliform count was recorded at a minimum of 78 c.f. u /100 with a maximum of TNTC/100 (too numerous to count/100 ml). Minimum feacal coliform count in the shallow wells was recorded at nil with a maximum of 68.0 ± 5.0 c.f. u /100 ml. Zinc ion concentration ranged from $0.20\pm?$ μg/L to $1.438.3 \pm 0.4$ 1 μg/L. Cadmium was recorded at below 0.2 ± 0 μg/L in all the sampling sites; manganese levels ranged from < 0.1 μg/L and 440.0 ± 0.2 μg/L while lead was recorded at > 0.3 μg/L maximum of $1,383.0\pm$ μg/L, a value beyond the WHO stipulated limit of 50 μg/L). Nickel minimum concentration was 12.0 ± 1.0 μg/L with a maximum of 694.0 ± 1.0 μg/L Copper minimum value recorded was 1.1 ± 0.2 μg/L and a maximum of 438.0 ± 1.0 μg/L The shortest distance between a water well and a latrine was 12 metres while the longest was 18 metres away. The wells were protected using concrete and metal plate covers of iron sheets while only one well was left open. Eighty percent of well owners chlorinated their water before drinking. Disposal of domestic solid and animal waste were done at dumping sites twenty metres or less away from the water well at a frequency of eighty percent. Sixty percent of the respondents agreed that a member of their family had suffered from diarrheal disease in the past six months. Seasonal flooding was the main challenge to the provision of safe well water quality, followed by the contamination of vessels for drawing water, poor siting of pit latrines and dumpsites by neighbours. Stringent management and public awareness are required to enforce the protection of shallow well in order to safeguard water quality and environment pollution in Kisumu City

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LIST OF ABBREVIATIONS AND ACRONYMS

AOAC   Association of official analytical chemists

A.P.H.A.   American Public Health Association

A.S.M   American Society for Microbiology

BDL   Below Detection Limit

CDC.   Centers for Disease Control

CFU   Colony Forming Units

GIS   Geographic Information System

KCIDP   Kisumu County Integrated Development Plan.

KEBS   Kenya Bureau of Standards

K.N.B. S   Kenya National Bureau of statistics

KPHC   Kenya Population& Housing Census

NTU   Nephelometric Turbidity Units

SSA   Sub Saharan Africa

T.D. S   Total Dissolved Solids.

U.N.I.C.E. F United Nations Children's Fund.

USEPA   United States Environmental Protection Agency

W.H. O   World Health Organization\

CHAPTER ONE

INTRODUCTION

1.1   Background information.

Lack of clean and fresh water contributes to many health problems globally (Montgomery & Elimelech, 2007). Rapid population growth and increasing demand for clean and adequate water for domestic use require urgent attention. Groundwater continues to be an important water source globally (Baker *et al.,* 2016). Groundwater accounts for 97% of freshwater globally and is a highly utilized natural resource (Baker *et al.,* 2016). Groundwater acts as an alternative water resource during the drought seasons. (Foster & Tuinhof, 2005)

More than 60% of Sub-Saharan urban populations live in informal settlements and slums (UN Habitat, 2010). The demand for safe drinking water in these settlements surpass the supply from centralized distribution systems. Residents are forced to obtain water from vendors, wells, surface waters and illegal connections to the main distribution systems. (Gronwall *et al.*, 2010). Many slum residents find groundwater affordable and readily available. However, the quality may be compromised due to contamination from surface waste, nearby pit latrine and other hazards. Diarrheal diseases and increased infant mortality rates have been caused by use of contaminated ground water (Bartram & Cairncross, 2010).

According to a (Dzwaziro *et al*., 2006) who conducted a research on the impact of pit latrines on the quality of ground water from Marondera District, Zimbabwe the results indicated that pit latrines contributed to microbiological pollution up to 25 m lateral distance. Nitrates were within WHO acceptable levels.

Kimani-Murage & Ngindu (2007) conducted a research in Lange's Estate, Eldoret, Kenya on the quality of water the slum dwellers use and found the water to be polluted by thermo-tolerant bacteria.

According to Ondieki *et al*., (2007) in their research on bacteriological and physico-chemical quality of household drinking water in Kisii Town, Kisii County, Kenya they found that most physico chemical parameters were within WHO acceptable limits but the microbiological contamination total coliforms and *Escherichia coli* was high

The construction of shallow wells in Kisumu town and its neighbourhood could have begun in 1930s. More wells were constructed between 1940 and 2001 bringing the number to 2,250 wells. (Foster & Tuinhof, 2005). The Kisumu Water and Sewerage Company (KIWASCO) supplies water to Nyalenda, Manyatta, Nyamasaria, Obunga, Kondele and Bandani Estates in Kisumu town. The water supply from KIWASCO has been unreliable over the years (Ong'or & Long-cang, 2007). Water for domestic use is primarily supplied from hand-dug wells because there is inadequate supply of piped water and sewerage system in the area. Contaminated water, poor sanitation and lack of hygiene leads to 50 per cent of all preventable illnesses in Kenya. (WHO, 2005). Availability of water supply and waste disposal systems like sewer connections are low at household level. (Mairura, 2010)

1.2   Statement of the problem

Water from shallow wells is used to supplement partial or intermittent water supply in many urban settlements in Sub-Saharan Africa. Such wells are often contaminated. (Okotto *et al.*, 2015). Total coliforms, faecal coliforms and *Escherichia coli* from nearby pit latrines and solid waste sites do contaminate well water in informal settlements during rainy seasons through seepage and surface run-offs (Kimani-Murage & Ngindu, 2007). Water testing is not conducted regularly as required. Since the wells have been used as water source over a long period the users believe that the water is therefore safe. (Awuah *et al.*, 2009). Hence the problems associated with waterborne diseases which are common in informal settlements in the country cannot be addressed adequately unless frequent testing is conducted on the water used by the residents of such areas. If the well water is found not potable then disinfection would be recommended. If pit latrines and solid waste disposal sites are close to water points then either the wells or the latrines would be closed on advice to public health office. Medical preparedness would also be recommended to county and national governments to handle any outbreak of the contagious water borne diseases.

1.3   General objective

The general objective of this study was to assess the quality of water from selected ten shallow wells in Nyalenda Estates in Kisumu County, Kenya.

1.3.1　Specific objectives

The specific objectives were to:

(i) Determine the physico-chemical, bacteriological and anion water quality parameters from selected ten shallow wells in Nyalenda A and B Estates, Kisumu County in the dry and wet seasons

(ii) Determine metal levels in water from selected ten shallow wells in Nyalenda A and B Estates in the dry and wet seasons

(iii) Assess the effect of proximity of pit latrine and domestic solid wastes disposal sites on the shallow wells water quality in Nyalenda A and B Estates and compare with World Health Organization (WHO) and Kenya Standards (KEBS) recommended limits and to conduct a survey on the use and care of the well water by the users/owners.

1.4　Justification and Significance of the study

Shallow wells are an alternative source of domestic water supply in informal settlements over the years to many residents who cannot get piped treated water from water service providers due to lack of water supply infrastructure, water supply unreliability and cost. Most of the time, the water from these shallow wells is contaminated chemically and bacteriologically thereby compromising the quality of water and human health (WHO, 2017).

The data gathered from this research could be used to advise the shallow well users and Kisumu County Government on the water quality in Nyalenda A and B Estates to ensure ground water safety, environmental impact assessments on pit latrine construction, and domestic waste disposal. This will further enhance formulation of relevant policies to sensitize the residents on environmental protection and hygiene.

CHAPTER TWO

LITERATURE REVIEW

2.1   Sources of water in the Kisumu County

Shallow wells provide water for domestic use and drinking in Kisumu County, among springs and boreholes that are classified as ground water (Kimani & Ngindu, 2007)

2.2   Physico- chemical parameters

Monitoring of the physical and chemical quality parameters of water are important in the assessment of hydrochemistry, water environment, ecology, ecosystem and the restoration of water quality. (Bhuyan *et al*., 2019). In physical analysis of water, the potential of hydrogen (pH), colour, turbidity, electrical conductivity (EC), total dissolved solids (TDS) were determined. In chemical analysis nitrates, nitrites, chlorides, fluorides, sulphates, phosphates, alkalinity, hardness, salinity together with bacterial parameters and metal ions like copper, lead, zinc, iron, chromium, cadmium, nickel and manganese were assessed. The data obtained will help to establish health-based summary statements and guideline values to the well owners and county water authority in provision and usage of water that has uniform quality.

2.2.1   Colour

Suspended and dissolved particles in water can change the colour of water. Suspended material in water bodies may come from natural and anthropogenic activities (Bennett & Drikas, 1993). Dissolved organic matter for example, peat, humus and decaying plant material can induce brown or yellow colour. Some algae produce red or yellow colour. Other algae and phytoplankton appear green. Soil runoffs exhibits yellow, red, brown and grey colours. Weathered rocks, soils and land use and trees can influence the types and amount suspended and dissolved material found in water bodies.

2.2.2   pH

This is a measure of hydrogen ion concentration (APHA, 1989). It is expressed as follows:

$$pH = -\log (H^+) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2.1}$$

Potential of hydrogen (pH) is a measure of the acidity of water. Its scale starts from 0 - 14. pH of 7.0 is considered neutral, acidic range is below 7.0 and alkaline range is higher than 7.0. Aquatic animals prefer a pH range of 6.5 – 9.0 for their survival. (Kleinhappel *et al.,* 2019). Lower pH causes tissue damage in fish. (Mota *et al.*, 2018). Most metals do dissolve at lower pH and are likely to enter water bodies on dissolution (Jezierska & Witeska, 2006). A pH of 6.5 - 8.5 is recommended for drinking water and to prevent corrosion in water pipes (WHO, 1989). Ammonia is toxic to aquatic animals at high pH levels (US EPA, 2013).

2.2.3   Turbidity

This relative clarity or cloudiness of water is considered to be turbidity. High number of individual particles invisible to the naked eye contributes to high turbidity. The particles include clay, organic matter, silt, planktons and microorganisms which usually gets suspended in water and can reduce the passage of light. (APHA, 2005). Turbidity affects disinfection of water and can enhance microbial growth. It is an indicator of the presence of microorganisms, soil erosion; broken septic systems and urban runoffs. (APHA, 1998)

2.2.4   Total Dissolved Solids (TDS)

This refer to all ion particles in solution that are smaller than 2microns. (USEPA, 1986). The well water's TDS levels increase with increase in rainfalls and surface run offs into the wells. (USEPA, 1986). Low concentration of TDS in water may have beneficial effects. Water containing 1000 mg/L is acceptable for consumption. (APHA, 1998)

2.2.5   Electrical Conductivity (EC)

Water can conduct an electric current. This is referred to as electrical conductivity. It is measured in micro-Siemens per centimeter (μS/cm). The total ion concentration Hi in water is a factor of Specific conductivity of water and can be used to estimate the number of dissolved solids. Electrical conductivity is affected by charge, concentration and mobility of ions in water. (Golnabi et *al.*, 2009)

2.2.6   Anions

Anions are ions with net negative charge and have more electrons than protons. They would be attracted to the anode in electrolysis. (APHA, 1989)

2.2.6.1 Nitrates

High accumulation of nitrates (NO_3^-) and phosphates (PO_4^{2-}) in water bodies leads to eutrophication. This promotes growth of algae; which later decompose into organic matter takes up much oxygen leading to death of aquatic animals like fish. Lack of oxygen is anoxia and causes death to invertebrates. (Riedel *et al.,* 2014). High nitrate levels interfere with blood cells' ability to carry oxygen and infants are more at risk on exposure to high levels. (Crain *et al.,* 1981)

2.2.6.2 Nitrites

These are salts or ester ions of nitrous acid that naturally or artificially occur in ground water. Excess nitrites (NO_2^-) can stimulate the growth of bacteria in high levels and disrupts oxygen delivering ability in humans and other animals (WHO, 1989)

2.2.6.3 Chlorides

Chlorides in surface and ground water come from both natural and man-made sources, for example use of fertilizers, septic tanks, leachates from landfills, effluents from factories and surface runoffs. (Backshi. *et al.*, 2021). Weathering of rocks containing chlorides release the chlorides into soil and water. The concentration of chlorides in natural water is usually below 10 mg/L. (Backshi *et al.*, 2021)

2.2.6.4 Fluoride (F^-)

Fluorides (F^-) can be present naturally due to specific geologic environment. Ninety-nine per cent of fluorides in the body occur in bones and teeth. Ingestion of excess fluorides can cause fluorosis in teeth and bones. 1.5 mg/L of fluoride of water is the World Health Organization maximum intake recommended level for drinking water. (Peckah & Awofeso, 2014)

2.2.6.5 Sulphate (SO_4^{2-})

Sulphates are a combination of Sulphur and oxygen. Minerals containing sulphates are easily hydrated with the increase in water volume leading to disintegration of the rocks as outlined in Equations 2.2 (Serafeimidis and Anagnostou, 2013).

$$CaSO_{4\,(s)} + 2H_2O_{\,(l)} \rightarrow CaSO_4.2H_2O_{(s)} \qquad (2.2)$$

Sulphur reducing bacteria breaks down sulphur to provide energy. Hydrogen sulphide is a byproduct of this reaction. The bacteria inhabit oxygen deficient environment such as plumbing

systems, deep wells and water heaters. Sulphate mineral cause scale-build up and leads to bitter taste of water or dark slime coating that is indicative of sulphur oxidizing bacteria. Sulphates have laxative effect in livestock and that is important for their digestion. (Dahl, 2020).

2.2.6.6 Phosphate

Phosphates enter water bodies from human and animal wastes, bedrocks rich in phosphorus, detergents used in laundry, effluents from industries and fertilizer from farms. Phosphate become a problem when they over-fertilize the aquatic plants and cause eutrophication leading to decreased dissolved oxygen and algal toxins. Phosphates are suspected to cause heart disease, decreased bone density, induce premature aging and kidney issues (Calvo, 2013).

2.2.7   Alkalinity

The ability of water to neutralize acid is referred to as its alkalinity. It is determined by the soil and bedrock that contains hydroxides, carbonates and bicarbonates. Drinking alkaline water leads to digestion malfunction, cardiovascular problems and other metabolic abnormalities. Alkalinity is related to hardness. Calcium carbonate ($CaCO_3$) contributes to alkalinity. Acid rain leads to fluctuations in alkalinity (Martins *et al.*, 2018).

2.2.8   Hardness

Water described as hard (120-180 mg/L) contains high amount of dissolved minerals especially magnesium and calcium ions. Hard water causes mineral buildup on fixture and reduces the leathering of soaps and detergent (Koçak, 2011).

Table 2.0.1: Classification of hardness in water

Classification	Concentration (mg/ L or ppm)
Soft	0- 17.5
Slightly hard	17.1-60
Moderately hard	60-120
Hard	120-180
Very hard	≥ 180

(Kumari, 2016)

2.2.9 Calcium hardness

Lack of calcium in diet exposes people to osteoporosis, coronary artery disease, kidney stones, hypertension, obesity, colorectal cancer, stroke, and insulin resistance. The human body stores about 1200 g of calcium with 99% occurring in bones and teeth. 1, 25-dihydroxyvitamin D controls absorption and elimination of calcium (Beto *et al.*, 2015).

2.2.10 Magnesium hardness

Magnesium cation ranks fourth in abundance in human body and second in the fluid within the human cells. (Swaminathan, 2003). Magnesium helps in protein and nucleic acid synthesis. It is also required for optimum blood flow in blood vessels and proper sensing of insulin to allow for glucose uptake by body cells. (Rincon et *al.*, 2018). The body stores about 25g with about 60% in bone. Low magnesium causes high blood pressure, cholesterol build up in arteries and diabetes mellitus. Drinking water in which both magnesium and sulphate are present at high concentration have laxative effect. (Dupont *et al.,* 2014)

2.2.11 Salinity

The concentration of salts in water or soils is called salinity. Dissolved salts in natural water are necessary for aquatic plants and animals' life. However high salinity and acidity can be harmful. Salinity can result from accumulation of salts from rainfall over many of years or from weathering of rocks. (Guizani. *et al.,* 2016)

2.2.12 Bacteriological parameters

Bacteriological water analysis endeavor to estimate the number of bacteria present in water samples. The importance of bacteriological analysis of drinking water assists in determining the presence of potential water-borne pathogens and provides the most sensitive quality parameter (USEPA, 2008).

2.2.12.1 Total Coliforms Count

Generally, include bacteria that occur in water and soil and is influenced by surface water containing human or animal waste. Total coliforms are not harmful to humans but are indicative of possible presence of disease-causing bacteria and are only mildly infectious. Coliforms can be tested using membrane filter, multiple tube fermentation (MPN) and Colilert method. High coliform count shows high probability of other pathogenic organism present for example,

Cryptosporidium and Giardia being present. (Edberg *et al.,* 2000). Coliforms, feacal coliforms and *Escherichia* coliform numbers decline after disinfection but still impact negatively on ground water. (Edberg *et al.,* 2000).

2.2.12.2   Feacal coliforms

These are facultative anaerobic, rod shaped, gram-negative, non-spore forming bacteria. (Edberg *et al*, 2000). Feacal coliforms have the ability to grow at temperatures of 44°C. At this temperature non-feacal coliforms do not grow and this property makes it possible to enumerate feacal coliforms in absence of other coliforms. (Edberg *et al.*, 2000)

2.3   Metal

A number of metals, such as copper (Cu), zinc (Zn) and manganese (Mn) are found in water. They are essential for living organisms' life processes. However, in high concentrations these metals and others can be toxic to organisms that depend on the water. Heavy metals on the surface of the water can be due to weathering of rocks that contain metals, volcanic eruptions and forest fires. (US EPA, 2002)

2.3.1   Copper

Copper (Cu) is an essential element and is important for human and animal health. In water bodies it can emanate from rocks through leaching or corrosion of copper pipes and fixtures (Ignacio T. *et al.,* 2017). Elevated copper level is detrimental to humans and other animals' health and can cause liver damage, vomiting, cramps, nausea and diarrhea. (Gotteland *et al.*, 2001) Concentration above 1300 micrograms per liter (µg/L) of copper calls for action to reduce the levels. A person with Wilson's disease has a problem maintaining copper balance (Olivares & Uauy, 1996)

2.3.2   Lead

Lead (Pb) is found in water, soils and air. It can get to human body through drinking water or other contaminated foods. Limits of 15 micrograms per liter (µg/L) is recommended (USEPA, 2012). Lead competes with the absorption of calcium by the body. When cells in the brain absorb lead, they tend to affect the central and peripheral nervous system. Centers for Disease Control (CDC) recommend that public actions be initiated when the level of lead in a child is 5 micrograms per deciliter or more. Excess lead causes memory problems, kidney disease, cancer,

and high blood pressure. (Jadhav *et al.,* 2007). At household level, lead enters through plumbing of pipes (Edwards *et al* 2014).

2.3.3 Zinc

Zinc (Zn) occurs naturally in water. 5ppb to 10 ppb zinc levels have been detected in river water. A maximum limit of 5mg/L Zn^{2+} level is recommended (WHO, 2003). Zinc ions form a protective, water insoluble zinc hydroxide ions according to the equation 2.3

$$Zn^{2+}_{(aq)} + 2OH^-_{(aq)} \rightarrow Zn\,(OH)_2(s) \hspace{4cm} (2.3)$$

Zinc causes milky turbidity in higher concentration. pH and temperature affect solubility of Zinc. Zinc ores include sphalerite (ZnS) and Smithsonite (ZnO_2). Zinc is an important trace element in human diet. It acts in enzymatic process and DNA replication. (Roohani *et al.,* 2013)

2.3.4 Iron

Iron (Fe) concentration in wells and aquifer is typically 0.5 mg/L and 10 mg/L. In well water, iron occurs in its ferrous state (Fe^{2+}). The water is usually clear when drawn, but on exposure to air, the iron is oxidized into ferric state (Fe^{3+}) and appears red. On heating the water, iron turns red and forms insoluble rust particles. Iron exists in the following forms: clear water, red water and organic iron and tannins. Iron bacteria consume iron to survive and produce deposits of iron and are brown slime called "biofilm". High levels of iron can be fatal, but the amount of iron in drinking water is too low to be dangerous. (Yuen *et al.*, 2023)

2.3.5 Chromium

Chromite ore is the main source of chromium and is found in South Africa, Turkey and Karzastan. Hexavalent chromium enters water bodies through industrial discharges of chrome plating, dye and paint pigments, leaching from hazardous waste sites and wood preservatives. (Zhitkovich, 2011).

Chromium (Cr^{+3}) and (Cr^{+6}) are covered under the total chromium in drinking water standard. Chromium (Cr^{+3}) is an important trace element for organisms' life. However, chromium (Cr^{+6}) is toxic to plants and animals. Chromium (Cr^{+3}) acts by aiding insulin activity and enhance protein, lipid breakdown in the body. (Cersosimo & De-Fronzo, 2006). The safe level of chromium is 0.01mg/L (Thomas *et al.,* 2019).

2.3.6   Cadmium

Cadmium occurs naturally in fossil fuels, coal, copper, lead and zinc. It can also be released through Vulcanicity where it can come in contact with ground and surface water. (Kubier, 2019). Cadmium (Cd) is a heavy metal and can cause poisoning to lungs, kidneys and bones. It is a neurotoxin and affects enzymes synthesis. It accumulates in the body on continuous exposure. The safe level of cadmium in portable water is 0.005mg/L. (USEPA, 2022). In groundwater, levels of 1.0 to 77µg/L have been determined. (Jafaraghaee *et al*, 2017)

2.3.7   Nickel

Nickel can be introduced in water bodies by leaching from metals (pipes and fittings) and leaching from rocks bearing nickel ore. (WHO, 2004). In the human body, nickel assists in the absorption of iron, adrenaline and glucose metabolism, cell membrane, hormone and lipids, production of red blood cells, improvement of bone strength. It functions in the RNA and DNA where it functions with nucleic acids. Nickel is responsible for allergic contact dermatitis in the general population. (Giuseppe *et al.*, 2020).

2.3.8   Manganese

Manganese is found in soil, rocks, surface water, groundwater, and food and is a human dietary requirement. It can also be brought by pollution sources. (WHO, 2004). Low levels of manganese are important for human health. (US EPA, 1993). Manganese concentration above 0.12mg/L may cause brain impairment in young children. (Malecki *et al*, 1994) Manganese can also cause discolouration (for example, purple, dark brown or blackish) and impart unpleasant taste in drinking water. It can also stain clothing during washing. In bottled drinking water the manganese level is recommended below 0.05 mg/L. (USEPA, 1993).

2.4   Other Mineral Associated With Pit Latrine And Domestic Solid Waste Sites.

Feacal matter and decomposing organic waste usually increases the levels of nitrates, chlorides, nitrites, sulphates, potassium, and sodium in nearby ground water and soil with increase in turbidity (Dzwairo *et al.*, 2006). The hazards contaminating water in hand dug wells are shown in Figure 2.1
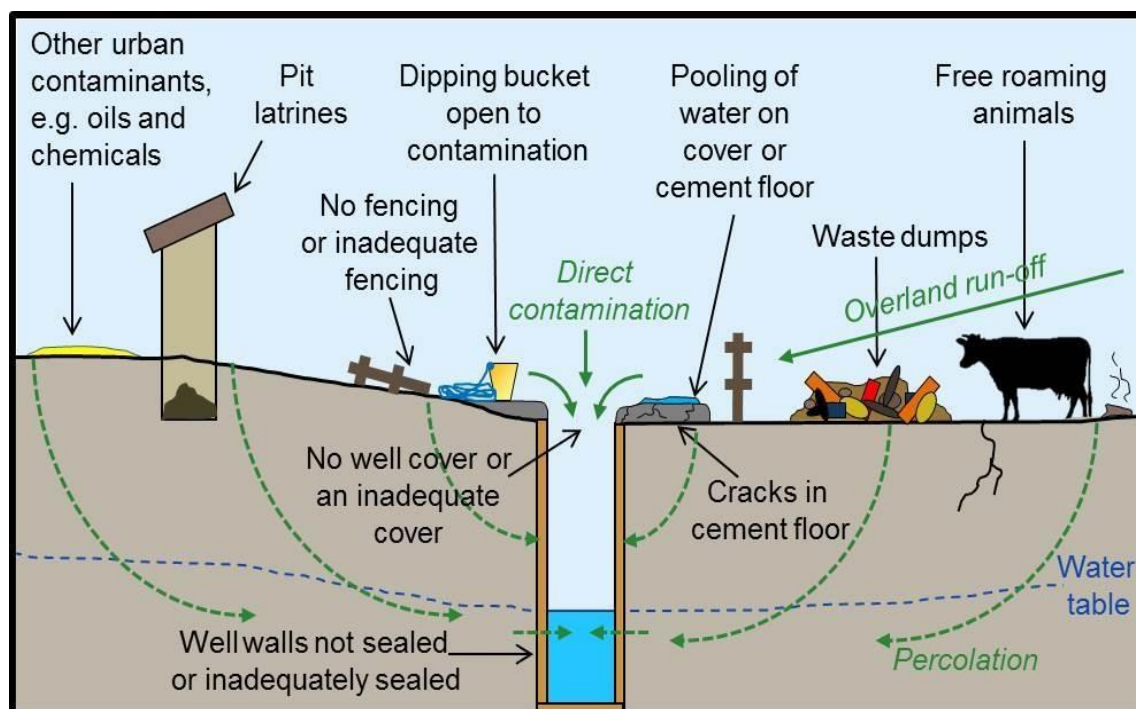
Figure 2.1: Model showing contamination pathways for water in hand dug wells.

Source: (Okotto-Okotto *et al.*, 2015)

2.5   Atomic Absorption Spectrometry (AAS)

AAS technique is based on electronic transitions between electronic energy levels of atoms. The technique involves absorption of electromagnetic radiation by atoms of a sample which are at the ground state. The sample is held by the flame as the light passes through the atoms and the flame simultaneously. (Harvey, 2000). The information about the sample is obtained by ascertaining the radiation released as the excited atoms revert to the ground state. During the interaction of the atoms and the photon, the energy carried by the photon is absorbed by the atom, promoting the valence electron to an excited state. (Lauri & Lajunen, 2004).

The absorbing atom do not absorb the whole range of the electromagnetic radiation, hence some of the radiation is transmitted; the level of absorption is proportional to the number of atoms in the ground state present in the flame hence the amount of the energy absorbed is directly proportional to the concentration of the absorbing atoms in the sample. Quantitative measurements in atomic absorption are based on Beer's Law, which states that concentration is proportional to absorbance (C = kA). Figure 2.2 shows Contr AA 700 High Resolution Continuum Source (AAS) which was used for the analysis of the metal ions.

Figure 2.2: Contr AA 700 High Resolution Continuum Source (AAS)

2.5.1 Detector

The detector technology is based on charged coupled device (CCD) chip. The charged coupled device is capable of turning light photons into an electrical signal. A CCD is sensitive to very low light levels and has a quantum efficiency of about 70%. The photons free electrons and so the more photons land, the more electrons are released. The greater the number of pixels, the better the resolution. A photon of light which falls within the area defined by one of the pixels is converted into one or more electrons and the number of electrons will be directly proportional to the intensity. A CCD consists of millions of tiny photosites which generate and store charge when photons land on them. (Janesick, 2001).

Table 2.0.2: Optimum conditions for AAS operations

Element	Wavelength (nm)	Burner height (mm)	Acetylene-air flow rate (L/h)
Copper	324.7540	6	50
lead	217.0005	6	65
Zinc	217.0005	6	50
Iron	213.8570	6	60
Chromium	248.3270	6	100
Cadmium	357.8687	6	50
Nickel	228.8018	6	55
Manganese	232.0030	6	65

Source: Contr AA 700 High Resolution Continuum Source (AAS) operating manual.

CHAPTER THREE

MATERIALS AND METHODS

3.1   Study area

The study was conducted in Nyalenda A and B Estates of Kisumu County, Kenya. The study covered an area of 3.7 km^2 and 5.7 km^2 respectively of the estates. The total study area is shown in Figure 3.1 with a population of A (30,019) and B (34,905) (Kenya population and Housing Census). Nyalenda A and B are fast-developing peri-urban settlement estates within Kisumu County. Nyalenda A is located on latitude 0° 7'0" S and longitude 34° 47'0" E while Nyalenda B is located on 0° 7'0" S and 34° 46'0" E. (KCIDP, 2013). The area has two rainy seasons; the short rainy season between September to November and the long one from April to May. The dry season starts in December to March (KMS, 2014). Samples were collected in the months of February (dry) and May (wet) seasons in 2017. The sampling sites and their coordinates are shown in Table 3.1.
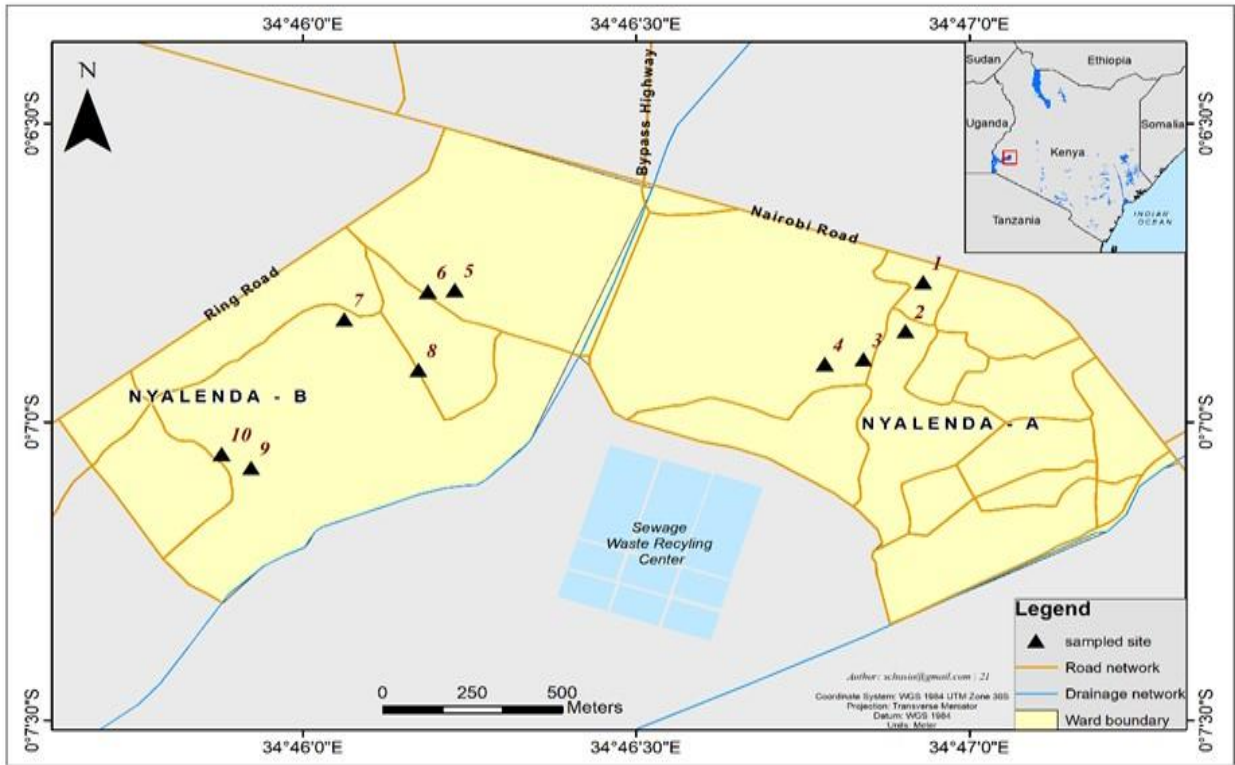
Figure 3.1: Map of Nyalenda A and B Estates showing sampling sites

Table.3.1: Sampling site location and distance from contamination sources.

Site	Shallow well owner	Location	GPS		Pit latrine distance (m)	Domestic waste disposal site (m)
			Latitude	Longitude		
1	Fredrick Otieno	B	0° 6' 46"	34° 45' 48"	10	none
2	George Otieno	B	0° 6' 54"	34° 46' 43"	20	8
3	Wilson Ogola Oyugi	B	0° 6' 45"	34° 36' 27"	18	5
4	Sylvanus Nyamwenga	B	0° 6' 48"	34° 46' 9"	17	none
5	St. Edward Church	A	0° 6' 30"	34° 46' 48"	16	13
6	KUAP Nyalenda	A	0° 6' 47"	34° 36' 10"	15	none
7	John Ojwang	A	0° 6' 46"	34° 45' 50"	10	7
8	Johnstone Mando	A	0° 6' 42"	34° 45' 27"	10	none
9	Tom Nyamanga	A	0° 7' 2"	34° 45' 40	20	none
10	Stephen Guya Wasawo	A	0°6' 53"	34° 45' 48"	13	5

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3.2   Climate of Kisumu County

Kisumu is situated near Equator. This makes it hot and humid throughout the year. The mean annual maximum temperature ranges between 25°C to 35°C and the mean annual minimum temperature ranges between 9°C to 35°C (Ochieng & Koskei, 2013).

Kisumu has two rainy seasons; long from March to June and short in September to November with average annual rainfall of 1280 mm. The altitude varies from 1,144 m on the Kano plains and to 1,525 m in Maseno and lower Nyakach respectively, above sea level (Ajwang *et al.*, 2016)

3.3   Geology of Nyalenda

Nyalenda forms part of the Kano plains that is a tectonic feature. It is a down pressed valley resulting from the minor east west, Nyanza rifts and faults. The soils are dominated by dark cotton soils commonly associated with swamps, (KCIDP, 2013)

3.4   Site selection, sampling plan and pit latrine distance measurements

The sampling sites are shown in Figure 3.1. The field visits to the study area were made to identify the sampling sites. Familiarization with the County authorities and wells owners was done during the month of September 2016. Feasibility study to determine the resource requirements was conducted.

A hand- held Global Position Information System (GPS) receiver was used to find the coordinates of the selected ten sampling sites in the hand dug wells in Nyalenda A and B Estates. Samples were collected in the months of February (dry) and May (wet) seasons in 2017. Distance measurement between the pit latrine or domestic solid waste disposal and the water sampling sites was done using a measuring tape (Table 3.1). The sampling sites were selected based on accessibility and distance of the well from the nearest pit latrine and domestic solid disposal site. The sampling wells are shown in appendix 1, Figures 1A- 1J. A questionaire was used to obtain more information about the well and the well owner.

3.5   Chemicals and reagents

The chemicals and Reagents that were used in this study include; Pb (NO_3) (99.9% purity), $MnCl_2.4H_2O$ (99.9% purity), Cu $(NO_3)_2.3H_2O$ (99.99% purity), Ni $(NO_3)_2.6H_2O$ (99.1% purity), Cr $(NO_3)_3.9H_2O$ (99.99% purity), zinc metal, $FeCl_3.6H_2O$ (98% purity), $Na_2B_4O_7$ (99.5% purity).

Devarda's alloy, methyl red indicator, Nessler's reagent, Conc. Sulphuric acid (98% purity), sodium hydroxide, silver nitrate (99.9% purity), sulphanilamide solution, N-(1-naphthyl) ethylenediamine dihydrochloride (99% purity), barium chloride (99% purity), potassium chromate indicator (99% purity), hydrazine sulphate (99%) and hexamethyltetramine, Whatman filter paper with a 47mm diameter, $0.45\mu m \pm 0.02\mu m$ pore size.

3.6   Equipment and apparatus used

In the current study the following Equipment and apparatus were used; pH, conductivity and TDS meter (Jenway instrument 3540 model). Analytical balance (Sartorius 1213 model), turbidity meter (Hach 2100 Q model), 2.0 litre sampling plastic containers and colour meter (Lovibond comparator 2000), hot plate, Atomic Absorption Spectrophotometer (Analytic jena Contra 700AA model), SP 600 Spectrophotometer, ammonium distillation apparatus, water bath, sterile forceps, a sterile blotter pad, petri dishes, Bunsen burner, white grid, sterilized pore size.

3.7   Water samples collection

2.0 Litre plastic sampling containers for physico-chemical water quality parameters were cleaned with 8M HNO_3 followed by washing with de-ionized distilled water and rinsed thrice using sample water before collection. 1.0 litre amber glass bottles were cleaned and sterilized for bacteriological water sample collection. Each well water sample was collected separately for chemical and microbiological analyses, labeled and transported to the Government Chemists Department laboratory, Nairobi for physico-chemical water analysis and to Kisumu laboratory for water bacteriological analysis. The water samples for bacteriological analysis were stored in a refrigerator and analysed within six hours while water samples for physico-chemical analysis were analysed within four days.

3.8   Parameters analysed

The parameters analyzed included; colour, pH, turbidity, TDS, electrical conductivity, NO_3^-, NO_2, Cl^-, F^-, SO_4^{2-}, PO_4^3, salinity, total hardness, magnesium hardness and calcium hardness, alkalinity, total coliforms and feacal coliforms, Cu, Pb, Zn, Fe, Cr, Cd, Mn and Ni. The parameters analysed would establish the suitability of the water for domestic use and drinking and also indicate levels of pollution.

3.9 Colour determination

50 ml of the supernatant sample was taken into a 50ml Nessler cylinder and placed into the right compartment of the Lovibond tintometer (comparator). 50ml of deionized water was put into the left compartment and the colour matched using colour disc. If the colour was outside the highest range i.e., 70 Hazen units, the dilutions that gave the colour within the range, was made the disc reading, then multiplied by the number of times the sample was diluted

3.10 pH Determination

100 ml of the water sample was taken into a 100 ml beaker and placed in a water bath at 25°C. The Jenway 3540 pH and conductivity meter was calibrated with standard buffer solutions of pH 4.0, 7.0 and 10. Measurement was done and a stable reading shown was recorded.

3.11 Turbidity Determination

3.11.1 Preparation of the Nephelometric Turbidity Units standard and turbidity measurement

Solution 1: 10g of hexamethylenetetramine was dissolved in deionized water and diluted to 100 mL in a volumetric flask. Solution 2: 1 g hydrazine sulphate was dissolved in deionized water and diluted to 100 mL in a volumetric flask. Into a 100 mL volumetric flask, 5ml of solution 1 was added, followed by 5 mL of solution 2 and mixed. This was allowed to stand for 24 hours at 25°C and then diluted to the mark with distilled water. The resulting turbidity was 400 NTU. From the

400 NTU standard solution, standards ranging from 5.0 NTU – 100 NTU were prepared Distilled water was used to calibrate the reading to zero. The 20 NTU standard was used to calibrate the Nephelometers reading to 20. 25 mL of each water sample was measured with turbidity meter (Hach 2100 Q model) and the readings recorded.

3.12 TDS and Electrical Conductivity Determination

Lovibond Datronix with two scale readings for conductivity and the TDS measurement was used. Calibration was done by immersing the electrode in various standard s concentrations solutions and the analyzer readings matched with the conductivity of the standards. 50 mL of sample was taken and the electrode connected to the meter. The electrode was dipped into the sample and stable readings for electrical conductivity and TDS recorded.

3.13   Nitrate Determination

Nessler's reagent (Potassium iodomercuriate) was prepared by mixing 2 g potassium iodide with 5 mL deionized water. 3 g of mercury (II) iodide was added to this solution and the resulting solution made up to 20 mL using deionized water. 40 g potassium hydroxide (30%) was then added to provide the alkaline base.

500 mL of sample water was taken into ammonia distillation apparatus; 50 mL of 10 % (w/v) NaOH solution was added and evaporated to about 200 mL then cooled. 3 g of Devarda's reagent (copper/aluminum/zinc alloy) and 30 mL of 10% NaOH was added and then connected to the flask with a condenser whose outlet drained into a receiver containing 200 mL of 0.2 N H_2SO_4. The mixture was distilled for 1 hour then the receiver was disconnected from the distillation apparatus.

$$3NO_3^-{}_{(aq)} + 8Al_{(s)} + 5OH^-{}_{(aq)} + 2H_2O_{(l)} \longrightarrow 3NH_{3\ (g)} + 8AlO_2^-{}_{(aq)}$$
(3.1)

The volume of the distillate was made up to 250 mL. Using a pipette 10 mL was added into a 50 mL volumetric flask and neutralized to pH of 4.5 using 0.2 N H_2SO_4. Nessler's reagent was added.

The reaction proceeds as outlined in equation 3.2

$$2K_2HgI_4 + NH_3 + 3KOH \longrightarrow NH_2HgOHgI + 7KI + 2H_2O \tag{3.2}$$
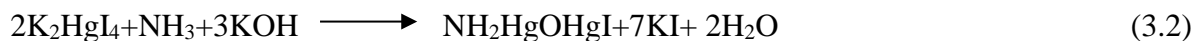
The reddish-brown complex product from Nessler's reaction with ammonia was determined colorimetrically by spectrophotometer absorbance at 420 nm against standards of between 0.2 mg/L to 6.0m/L.

3.14   Nitrite Determination

Into a 250 mL conical flask, 40 mL of water sample was carefully added and the pH adjusted to 7.0 using 0.2N NaOH or 0.2N H_2SO_4. 2mL of sulphanilamide solution (50 g in 500 mL of 1.2 N HCl) was added, shaken and allowed to stand for ten minutes. 2 ml of Griess reagent N-(1-Naphthyl) ethylenediamine dihydrochloride (0.83 g in 200 ml cold distilled water cooled, filtered and diluted to 250 mL with glacial acetic acid) was added and diluted to 50 mL in a volumetric flask and mixed thoroughly. The mixture was left to stand for one hour and the resulting purple azo dye measured using a spectrophotometer at 543 nm, against standards between the ranges of 1 µg/L to 25 µg/L.

3.15   Salinity determination

A digital refractometer was used for analysis. In the lid that protects the angled lens, three drops of the water sample liquid were placed. Results appeared in along a scale in the eyepiece and the measurements recorded. The lens was rinsed with a few drops of distilled water and dried using a microfiber (Napoleao *et al.,* 2018).

3.16   Chlorides Determination (Mohr method)

50 mL water sample was taken into a porcelain dish and 1mL of 5% potassium chromate added. The mixture was titrated with standard silver nitrate solution until the slight reddish colour appeared due to the formation of silver chromate.

3.16.1 Preparation of Reagents for chloride titration

3.16.1.1   Silver nitrate solution preparation:

4.71 g silver nitrate was dried at 105°C, dissolved in distilled water and the volume made up to 1000 mL in a volumetric flask.

$$1 \text{ ml} = 1 \text{ mg Cl}^- \tag{3.3}$$

3.16.1.2   Sodium chloride standard solution preparation:

0.1649 g pure (99%) sodium chloride was dried at 105°C and dissolved in distilled water and made up to 1000 mL

3.16.1.3   Potassium chromate solution: preparation:

5 g potassium chromate was dissolved in distilled water and made up to 100 mL. 0.2 mL silver nitrate solution was added to produce a slight red precipitate and filtered.

Calculation:

$$\text{Chloride} = \frac{(\text{ml silver nitrate - 0.2 ml}) \times 1000)}{\text{Volume of sample taken}} \tag{3.4}$$

Where 0.2 mL was the volume of silver nitrate required to form the reddish colour or precipitate due to the formation of silver chromate.

3.17   Fluoride Determination

3.17.1 Fluoride's standards solution preparation

0.221 g of sodium fluoride was dissolved in water and diluted to 1000 ml

3.17.2 Acid zirconium-alizarin solution preparation

Solution A: 0.7 g alizarin red solution (Sodium alizarin sulphate) was dissolved in 100 mL water. Solution B: 0.45 g zirconium chloride was dissolved in 100 mL water. Solution C: 70 mL concentrated H_2SO_4 was carefully added to 700 mL distilled water and then cooled. The three solutions A, B and C were mixed and diluted to 1000 mL and then stored in the dark for 24 hours.

50 mL of water sample was each placed in a series of 50 mL Nessler's cylinder. 0.5 mL of fluoride standard solution was added into the respective Nessler's cylinders to give a range of solutions containing 0.01 mg to 0.05 mg fluoride. Some 50 mL distilled water was used as a blank. 1mL of acid zirconium-alizarin solution was added to each cylinder, mixed well and the colours compared after 5 minutes with the fluoride solutions. Fluorides was reported as F^- mg/L.

3.18   Sulphate Determination

3.18.1 Conditioning reagent preparation for Sulphate analysis

75 g of sodium chloride (Analytical grade) was dissolved in 300 mL water. 30 mL of concentrated HCl, 100 mL 95% isopropyl alcohol, 50 mL of glycerol and 3g barium chloride crystals were then added respectively and mixed well.

3.18.2 Sulphate standard solution preparation

1.479 g anhydrous sodium sulphate was dissolved in water and made up to 1000 mL

Calculation: $1mL = 100\ \mu l\ SO_4 = 0.1\ mg\ SO_4$ (3.5)

3.18.3 Removing turbidity in water samples before sulphate determination

For turbid water samples, the turbidity of the water samples was first removed by adding a few drops of concentrated HCl (36% purity) to the water then boiled. On cooling, the colloidal matter settled at the bottom of the beaker. Filtering was done using Whatman filter paper and the required amount taken.

100 mL of sample was taken into100 mL Nessler's cylinder. 100 mL-distilled water was used as a blank. In each cylinder 5ml of the conditioning reagent and 0.5g barium chloride crystals were added, mixed thoroughly and the optical density measured at a wavelength of 420 nm using SP 600 Spectrophotometer. A calibration curve was prepared for the standards in the range of 0.5

mg/L to 20 mg/L using the spectrophotometer. The sulphate concentration was read directly from the graph.

Sulphate was reported as SO_4^{2-} .

3.19 Phosphate Determination

100 ml of sample water was taken in a beaker and digested using 1ml concentrated H_2SO_4 and 5ml of concentrated HNO_3; and then evaporated to dryness. The digestion and evaporation were repeated. The residue was leached with 5ml 5N HNO_3 and transferred to a 50ml volumetric flask. 5ml of 10% ammonium Molybdate was then added, followed by 5ml of 25% ammonium vanadate in 6N HCl, diluted to the mark and left to stand for 10 minutes. Distilled water (a blank) was taken through the same process as the samples were analysed. The absorbance of the resulting yellow coloured liquid was measured at 460 nm. A calibration curve was prepared based on a series of standard solutions of phosphates made from 0.220g KH_2PO_4 previously dried at 105ºC for 1 hour in distilled water and diluted to 1 litre. The standard solutions were prepared in the range of 0 to 1.5 mg/L.

Calculation

$$1 \text{ ml} = 50 \text{ } \mu g \text{ } PO_4^{3-} \tag{3.6}$$

3.20 Alkalinity Determination

3.20.1 Preparation of 0.2 N hydrochloric acid

0.2 N hydrochloric acid was prepared from 1N HCl previously prepared from a 100 ml ampoule.

3.20.2 Sodium carbonate solution preparation for acid standardization

5.3 g anhydrous sodium carbonate dried at 250 °C was dissolved in water and made up to 1000 ml to make 0.1 N concentration used to standardize 0.2 N hydrochloric acid

3.20.3 Procedure of Alkalinity determination

50 ml of sample water was filtered and poured into a porcelain dish using a pipette. If the pH was above 8.2, three drops phenolphthalein were added and titrated with the standard acid until a pink colour discharged. This alkalinity was the phenolphthalein alkalinity. Without adjusting the volume to zero, three drops of Bromocresol green indicator were added and titrated until the

colour turned from green to grey. This alkalinity was the total alkalinity and was calculated using equation 3.7

1ml 0.2 N HCl = 1mg $CaCO_3$

Alkalinity as $CaCO_3$ = $\underline{\text{Titre (ml of 0.2N HCl) x 1000}}$ (3.7)

Volume of sample taken.

3.21   Total hardness Determination

3.21.1 Calcium chloride solution preparation

1g of pure $CaCO_3$ was added to 50 ml water in a conical flask and mixed. 20.5 ml Normal HCl was cautiously added to the flask then the solution warmed on a hot plate until boiling. The mixture was cooled and poured to 1000 ml flask and the volume made up to the mark.

1 ml = 1 mg of $CaCO_3$

(3.8)

3.21.2 Buffer solution preparation

40 g borax (sodium tetra borate dehydrates) was dissolved in 800 ml water. 10g NaOH pellets and 5g sodium sulphides were each dissolved in 200 ml water. When cool the two solutions were mixed and diluted to 1 litre.

3.21.3 EDTA buffer solution preparation

4.0 g of EDTA was dissolved in 800 ml water to give 0.2 N concentration. 21.5 ml of 1 N NaOH solution and 0.1 g magnesium chloride were then added. The solution was titrated against standard calcium chloride solution and adjusted so that 1ml = 1mg $CaCO_3$. EDTA indicator for total hardness was used.

3.21.4 Procedure for Total hardness determination

50 ml of sample water was poured into a porcelain dish.1ml of borax buffer solution, one tablet of total hardness and methyl red indicator were added and let to dissolve. The mixture was titrated with 0.2 N EDTA from a burette until the colour changed from red to blue**.** The total hardness was calculated using equation 3.9.

Total Hardness (ppm) = $\underline{\text{ml of EDTA X1000}}$ (3.9)

Volume of sample taken.

3.22   Total coliform and feacal coliforms Determination

The total coliform bacteria and feacal coliform were analyzed using the membrane filter technique to determine the number of colonies forming units per 100 ml (C.F.U/100 ml) of water sample (APHA, 1998).

Using sterile forceps, a sterile blotter pad was placed at the bottom of a petri plate. 2ml of Endo broth-MF was pipetted onto each pad and covers replaced. The filter funnel was assembled on the flask. A sterile membrane filter was placed using sterile forceps with the grid side up. The filter was centered and 10 ml buffer added. 20ml volume of the sample was then added, filtered under gentle vacuum condition. With the vacuum still applied, the filter was removed with sterile forceps and placed on the 2 ml medium. After incubation for 1 day, the bacterial colonies were counted to determine the concentration of organisms in the original water sample

3.23   Determination metal ions

3.23.1 Sample digestion for heavy metal determination

100 ml well water sample was poured in a 250 ml beaker. 25 ml solution of 10% hydrochloric acid (2.5 ml concentrated Nitric acid mixed with 22.5 ml deionized water) was added to the beaker. The contents were filtered through a Whatman filter paper No.1. The filtrate was collected in a 250 ml beaker. The residue in the filter paper was washed with 50 ml hot deionized water. The washing was collected in the 250 ml beaker and then cooled. The solution in the beaker was transferred into a corresponding 250 ml volumetric flask. The beaker was rinsed and the volume of the solution in the volumetric flask made to the 250 ml mark using deionized water. (AOAC, 1995),

3.23.2 Metal standards solutions calibration curve

Stock solution for each of 1000 ppm copper, lead, ferrous, ferric, chromium, cadmium, manganese, zinc and nickel were prepared and the respective calibration curves made from the metal standard solutions. The calibration curves are presented in appendix 3.

3.23.3 Preparation of Copper standard solution

1000 ppm copper solution was made by dissolving 3.798 g of copper nitrate (Cu $(NO_3)_2.3H_2O$) in 250 ml deionized water. The solution was diluted to 1000 ml mark in a volumetric flask using deionized water.

3.23.4 Preparation of lead standard solution

1000 ppm lead standard solution was made by dissolving 1.5980 g of lead nitrate (Pb $(NO_3)_2$) in 100 ml of deionized water. The solution was made to 1000 ml in a volumetric flask using deionized water.

3.23.5 Preparation of Zinc standard solution

1000-ppm zinc standard stock solution was prepared by dissolving 1.000 g zinc metal in 30 ml of 5 Molar hydrochloric acid. The zinc solution was then topped up with deionized water to 1000 ml to the mark.

3.23.6 Preparation of Iron (II) standard solutions

To prepare 1000ppm iron (II) stock solution 0.8635g ferrous ammonium sulphate was dissolved in 5ml of concentrated sulphuric acid and made up with deionized water in 100ml standard flask

3.23.7 Preparation of Iron (III) standard solutions

1000-ppm standard solution of iron was prepared by dissolving 4.8400 g of iron (III) chloride ($FeCl_3.6H_2O$) in 200 ml of deionized water then diluted to 1000 ml in a volumetric flask using deionized water.

3.23.8 Preparation of Chromium standard solution

8.79 mg of dried potassium dichromate was dissolved in 100 ml water. 80.4 ml of this solution was diluted to 100 ml mark in volumetric flask; producing a 25 mg/l chromium stock solution. Standard solutions were obtained from this solution to prepare a calibration curve.

3.23.9 Preparation of Nickel standard solution

Nickel standard solution was made by dissolving 4.9530 g of nickel nitrate [Ni $(NO_3)_2.6H_2O$] in 1000 ml volumetric flask with deionized water.

3.23.10 Preparation of Manganese standard solution

1000-ppm manganese standard solution was made by dissolving 3.6077g of manganese chloride ($MnCl_2.4H_2O$) in 50 ml concentrated hydrochloric acid. The solution was then diluted with deionized water to 1000 ml in volumetric flask.

3.23.11 Preparation of Cadmium standard solution

1000 ppm of Cadmium was made by dissolving 2.036 g Cadmium chloride ($CdCl_2$) in 1 litre of deionized water.

3.24 Statistical Data analysis

Analysis of the data obtained was carried out using Microsoft excel, Statistical package for social sciences tool (SPSS). Correlations between the wet and dry season data, the levels of selected physicochemical parameter, anions, cations and feacal coliforms were determined. The results obtained are presented by use of graphs, statistical tables and text to show the interrelationships of various variables.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

In this section the data obtained from the analysis of physico-chemical parameters, bacteriological parameters, anions and metal ions in the well water samples and the response to the questionnaire by the owners and users in Nyalenda Estate, Kisumu County in Kenya are captured. The results obtained from the study are presented here in Tables and Figures

4.2 Results for physico-chemical parameters

Table 4.1 shows the values of colour, pH, turbidity, TDS and electrical conductivity of water samples from shallow wells in Nyalenda A and B Estates

4.2.1 Colour

The colour of Nyalenda water from the selected ten shallow wells were recorded at below 0 Hazen unit in both dry and wet seasons except for Site 6 (0.04 Hazen unit) These levels were much lower than the recommended values for WHO (APHA, 1992) and KEBS (KS EAS 12: 2014) values of 4.0 Hazen units and 15.0 Hazen units respectively. This shows good protection of shallow wells from water runoffs that would introduce eroded material into the shallow wells.

4.2.2 pH

The pH levels ranged from 6.80 ± 0.01 to 9.29 ± 0.04 with a mean of 7.89 ± 0.69 in the dry season in Sites 8 and 1 respectively. In the wet season, the pH ranged from 7.25 ± 0.02 to 9.58 ± 0.01 with a mean of 8.13 ± 0.72 (Table 4.1). There was an increase in pH values in all the sites from dry to wet season except in site 10 that recorded a drop from pH 7.5 ± 0.01 to 7.25 ± 0.01 (Figure. 4.1). In site 1 the pH values of 9.29 ± 0.04 and 9.58 ± 0.01 obtained in dry and wet seasons respectively were above the 9.2 and 9.5 values recommended by (WHO,1996) and KEBS (KS EAS 12: 2014) respectively (Table 4.1). In the wet season higher pH values were recorded compared to the dry season (Figure 4.1). This shows that no acidic rains were experienced in Nyalenda Estates and the well water did not come into contact with acidic wastes (Shriner & Johnson, 1987).

Table 4. 1: Physicochemical parameter from the ten selected shallow well water sites

Site	Colour (Hazen units)	pH	Turbidity (NTU)	TDS (mg/L)	EC (µs/cm)
Dry Season					
1	0	9.29 ± 0.04	2.53 ± 0.02	450 ± 6.0	977.0 ± 3.0
2	0	8.45 ± 0.02	0.34 ± 0.1	746 ± 2.0	1558.0 ± 2.0
3	0	8.11 ± 0.01	0.74 ± 0.1	292 ± 3.0	611.0 ± 3.0
4	0	8.04 ± 0.01	0.41 ± 0.1	640 ± 2.0	1,348.0 ± 2.0
5	0	7.56 ± 0.01	1.22 ± 0.01	680 ± 4.0	1,439.0 ± 3.0
6	0.04	7.76 ± 0.01	1.73 ± 0.01	296 ± 4.0	694.0 ± 6.0
7	0	7.25 ± 0.02	0.62 ± 0.1	380 ± 7.0	785.0 ± 2.0
8	0	6.80 ± 0.1	1.74 ± 0.02	247 ± 3.0	500.0 ± 4.0
9	0	8.14 ± 0.01	0.64 ± 0.1	407 ± 2.0	851.0 ± 1.0
10	0	7.50 ± 0.01	0.53 ± 0.01	156 ± 2.0	328.0 ± 1.0
Mean ± SD	0	7.89 ±0.69	1.05 ± 0.73	429 ± 2.0	909.0 ± 4.0
Wet Season					
1	0	9.58 ± 0.01	2.37 ± 0.10	345± 3.0	720.0 ± 4.0
2	0	8.76 ± 0.01	0.848± 0.02	791 ± 2.0	1650.0 ± 2.0
3	0	8.33 ± 0.01	1.67 ± 0.02	281 ± 3.0	586.0 ± 1.0
4	0	8.41 ± 0.01	0.466 ± 0.1	711 ± 6.0	1475.0 ± 1.0
5	0	7.78 ± 0.01	1.33 ± 0.01	1356 ±3.0	2820.0 ± 0.1
6	0	8.07 ± 0.01	0.78 ± 0.1	521 ± 3.0	1084.0 ± 3.0
7	0	7.45 ± 0.01	1.03 ± 0.01	1055 ± 4.0	2220.0 ± 6.0
8	0	7.33 ± 0.02	0.63 ± 0.01	352 ± 3.0	677.0 ± 2.0
9	0	8.37 ± 0.02	0.52 ± 0.01	604 ± 2.0	1258.0 ± 2.0
10	0	7.25 ± 0.01	0.40 ± 0.02	578 ± 5.0	1204.0 ± 4.0
Mean ± SD	0	8.13 ± 0.72	1.00 ± 0.63	659 .3 ± 37.0	1369.0 ± 7.0
Limit of detection	0	2.0	0.2	0.02	0.01
Recommended values for drinking water					
WHO	4	6.5-9.2	10	1500	2500
KEBS (PTW)	15	6.5-8.5	5	1000	1500
KEBS (PNW)	50	5.5-9.5	25	1500	2500

Key: PTW = Potable treated water, PNW = Potable natural water; Source WHO (APHA, 1992), KEBS (KS EAS 12:2014)
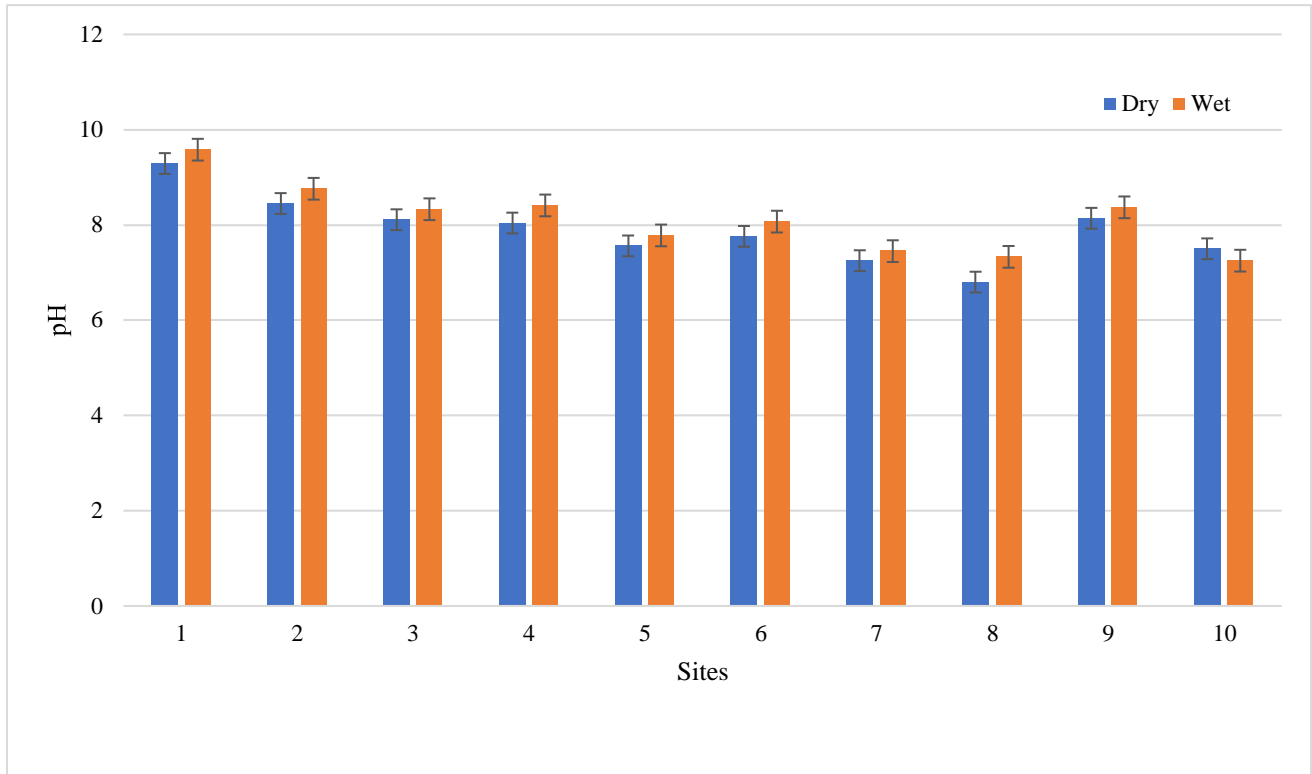
Figure 4.1: Variation of pH levels in the shallow wells water

4.2.3 Turbidity

The highest and lowest turbidity levels were recorded in Sites 1 and 2 in the dry season at 2.53 ± 0.02 NTU and 0.34 ± 0.04 NTU respectively, while Site 1 recorded the highest value of 2.37 ± 0.02 NTU and the lowest of 0.40 ± 0.02 NTU at Site 10 in wet season. The mean turbidity levels were 1.05 ± 0.75 and 1.0 ± 0.63 NTU in dry and wet season respectively (Table 4.1). The low turbidity in Sites 2 and 10 in the dry and wet seasons (Figure 4.2) could be attributed to incident solar radiation entering water in the well. The well was not properly covered (Figure 1B, appendix 1). Presence of light lowers the water turbidity (Llames *et al.*, 2009). The well water was generally less turbid compared to the maximum limit standard recommended by WHO (APHA, 1992) and KEBS (KS EAS 12: 2014) of 10 NTU and 5 NTU respectively (Table 4.1). Figure 4.2 shows the turbidity of selected ten well water in Nyalenda A and B Estates in dry and wet seasons
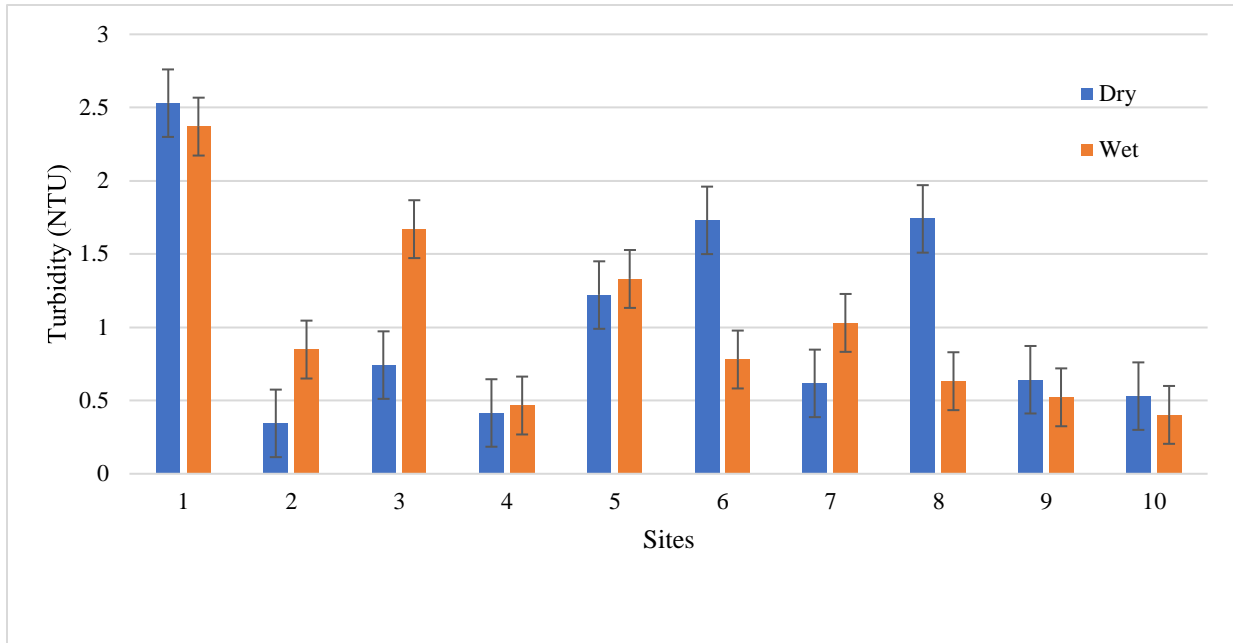
Figure 4.2: Variation of Turbidity levels in the shallow wells water

4.2.4   Total Dissolved Solids

During the dry season, the total dissolved solids (TDS) levels were in the range of 156.0 ± 2.0 mg/L to 746.0 ± 2.0 mg/L, at Sites 10 and 2 respectively. The mean concentration was 429.0 ± 2.0 mg/L. In the wet season the TDS range was from 281.0 ± 3.0 mg/L to $1,356.0 \pm 3.0$ mg/L in Sites 3 and 5 respectively, with a mean of 659.0 ± 37.0 mg/L. (Table 4.1). Total dissolved solids (TDS) value was highest at Site 5, followed by Site 7 with 1055.0 ± 4.0 mg/L in the wet season (Table 4.1). There was an increase in TDS values from the dry to wet season except in Sites 1 and 3 (Figure 4.3). This was attributed to flooding during wet season. This caused dissolved salts and metals in surface run-offs water to drain into the wells (Merriam, 2022). There was a small decrease in TDS in Sites 1 and 3 from dry to wet seasons (Figure 4.3). This could be due to effective well protection of water from surface run-offs as shown in Figures 1A and IC, appendix I, respectively. The well water had lower TDS values compared to WHO (APHA, 1992) and KEBS (KS EAS 12: 2014) maximum limit standard of 1500 mg/L (Table 4.1).
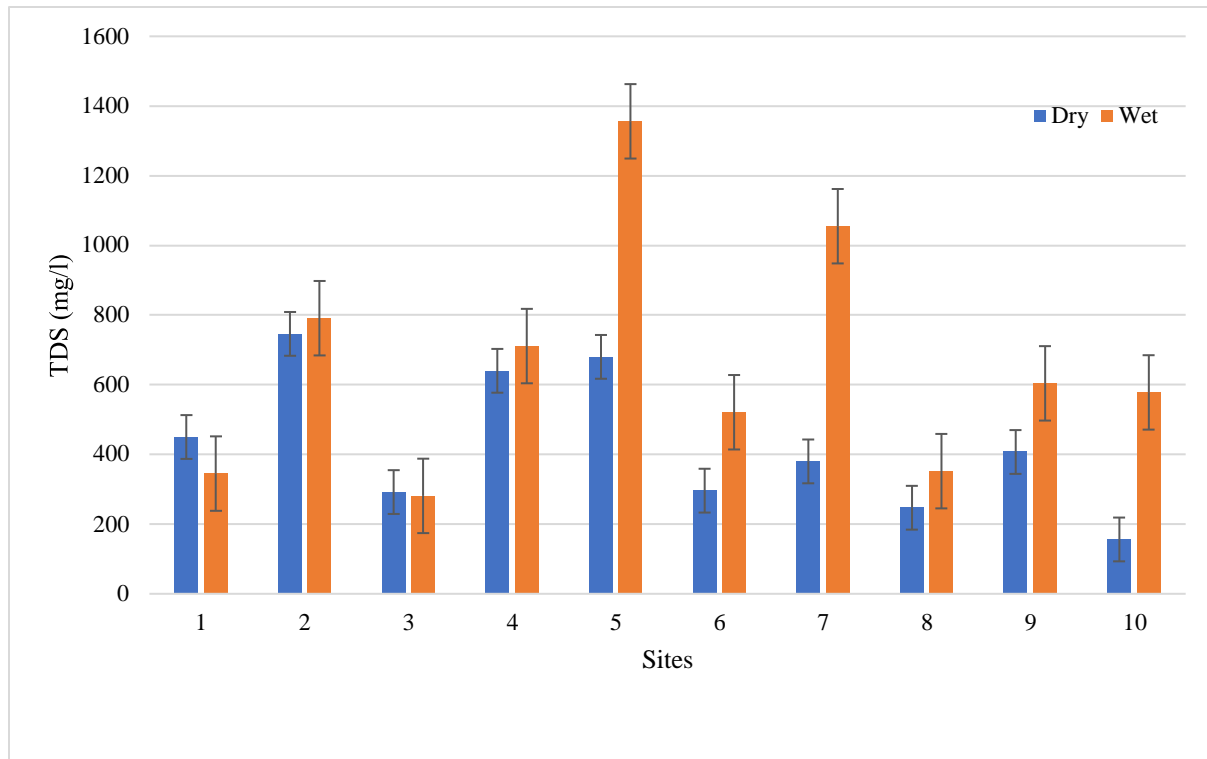
Figure 4.3: Variation of TDS levels in the shallow wells water

4.2.5   Electrical Conductivity

There was a general increase in electrical conductivity (EC) from dry to wet season with increased ionization during the rainy season (Table 4.1). During the dry season, the EC ranged from 328.0 ± 1.0 µS/cm to $1,558.0 \pm 2.0$ µS/cm in Sites 10 and 2 respectively. The mean concentration was 909.0 ± 4.0 µS/cm while in the wet season EC ranged from 586.0 ± 1.0 µS/cm to $2,820.0 \pm 0.1$ µS/cm in Sites 3 and 5 respectively. The mean concentration of $1,369.0 \pm 7.0$ µS/cm (Table 4.1). Site 5 had higher EC values than the WHO (APHA, 1992)   and (KS EAS 12: 2014) maximum limit standards of 2,500.0 µS/cm. (Table 4.1). Figure 4.4 shows the levels of Electrical conductivity in Nyalenda A and B shallow well water. There was a similar trend in the variation of the levels of TDS (Figure 4.3). Electrical Conductivity (EC) is a factor of TDS including salts and metals. This affects the concentration, charge and mobility of ions (Rusydi, 2018).
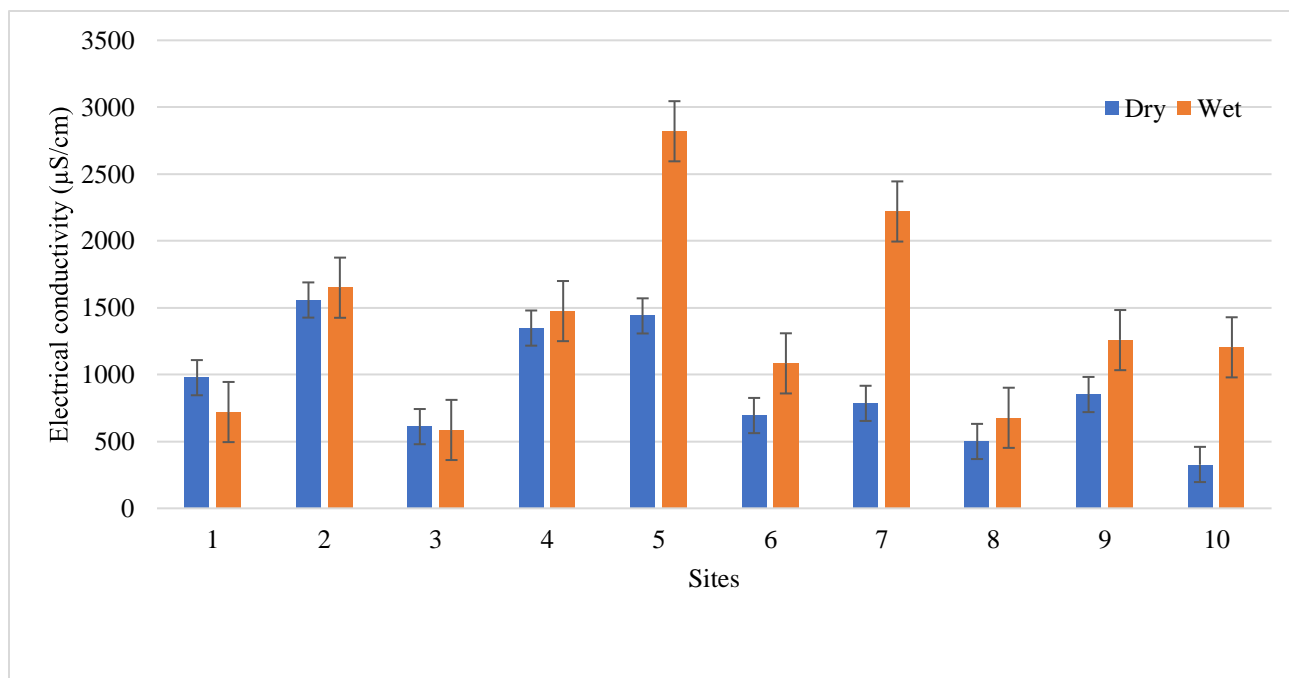
Figure 4.4: Variation of EC levels in the shallow wells water

Table 4.2 : Correlation coefficients for dry and wet season physicochemical parameter values of water samples

Parameter	Colour	pH	Turbidity	TDS	Electrical conductivity
Correlation Coefficient Sig. (2- tailed) N	. . 10	0.961** .000 10	0.370 0.293 10	0.588 0.074 10	0.648* 0.043 10

There was no correlation between dry and wet season's colour values and turbidity values (Table 4.2). A strong correlation between dry and wet seasons' pH values was determined (Figure 4.2). There was moderate correlation between dry and wet TDS and EC values. (Table 4.2).

4.2.6   Nitrates

Figure 4.5 shows the sampling sites and nitrates levels in the dry and wet seasons. Site 4 had the highest nitrates level (3.50 ± 0.01 mg/L) while site 8 showed the lowest value (0.20 ± 0.01 mg/L) in the dry season, with a mean nitrate level of 0.91 ± 0.03 mg/L (Table 4.3). Site 4 had the highest

level (5.16 ± 0.04 mg/L) while site 1 showed the lowest value (0.25 ± 0.02 mg/L) in the wet season, with a mean concentration of 1.46 ± 0.29 mg/L (Table 4.3). The wet season had higher nitrate levels than the dry season except Site 1 (Figure 4.5). Higher nitrates cause eutrophication of water bodies together with phosphates (Adesuyi *et al.*, 2015). However, all the nitrate concentrations were within WHO, and KEBS of 10 mg/L (APHA 1992) and 45 mg/L (KS EAS 12: 2014) respectively (Table 4.3)
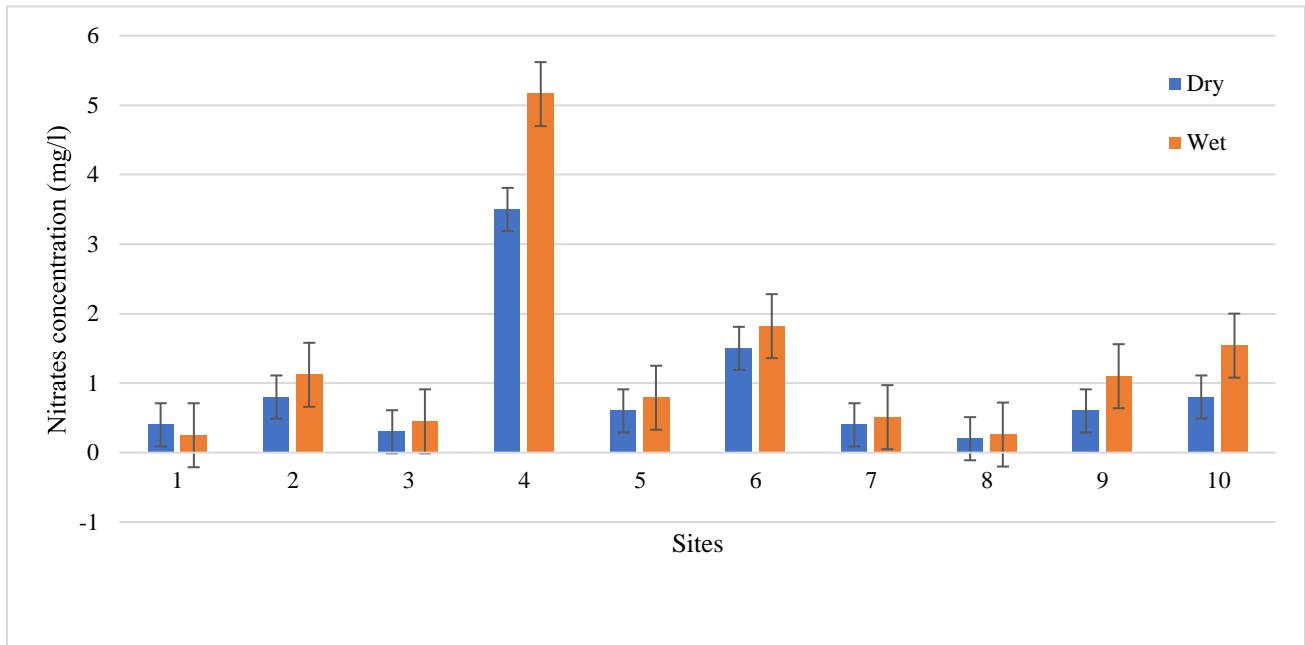
Figure 4.5: Variation of nitrate levels in the shallow wells water

4.2.7 Nitrites

The maximum nitrite level (0.11 ± 0.001 mg/L) was recorded at Site 4, while the minimum (0.0029 ± 0.001 mg/L) at Site 8. Mean value for the dry season was 0.033 ± 0.007 mg/L. Site 4 had the highest concentration of 0.29 ± 0.001 mg/L while Site 9 showed the lowest value 0.013 ± 0.001 mg/L in wet season with the mean levels of 0.091 ± 0.11 mg/L. The nitrite levels recorded fall within maximum WHO and KEBS limits of 0.1 mg/L and 0.9 mg/L respectively in the dry season (Table 4.3). Wet season had higher levels of nitrite of 0.14 ± 0.001 mg/L, 0.29 ± 0.01 mg/L and 0.29 ± 0.01 mg/L in Sites 1, 4 and 5 respectively (Table 4.2). These values were higher than the maximum recommended levels by WHO of 0.1 mg/L in the wet season (Figure 4.6).

Table 4.3: Chemical Parameters in shallow well water samples

Site/ Parameters	Nitrates (mg/L)	Nitrites (mg/L)	Chlorides (mg/L)	Fluorides (mg/L)	Sulphates (mg/L)	Phosphates (mg/L)
Dry season						
1	0.4 ± 0.1	0.023 ± 0.002	25±3.0	1.23 ±0.01	20 ± 2.02	0.9 ± 0.1
2	0.8 ± 0.1	0.022 ± 0.002	130 ±2.10	1.65 ±0.03	25 ± 0.11	0.5 ± 0.02
3	0.3 ± 0.01	0.011 ± 0.001	10 ± 0.1	1.66 ±0.02	10 ± 1.12	0.74 ± 0.04
4	3.5 ± 0.1	0.11 ± 0.001	70 ±3.02	0.94± 0.02	100 ± 4.0	0.99 ± 0.02
5	0.6 ± 0.1	0.02 ± 0.01	190 ± 4.11	1.26 ± 0.02	30 ± 2.21	0.68 ± 0.01
6	1.5 ± 0.01	0.009 ± 0.001	40±2.01	1.02 ± 0.01	40 ± 2.02	0.7 ± 0.02
7	0.4 ± 0.1	0.033 ± 0.001	50 ± 4.21	1.43 ± 0.01	50 ± 2.11	1.28 ± 0.01
8	0.2 ± 0.01	0.0029 ± 0.001	35 ± 2.20	0.72 ± 0.01	20 ±2.13	0.83 ± 0.02
9	0.6 ± 0.1	0.09 ± 0.01	75 ± 2.35	0.84 ± 0.01	30± 2.10	0.71 ± 0.02
10	0.8 ± 0.01	0.009 ± 0.01	15 ± 2.45	0.96 ± 0.02	30± 2.50	1.5 ± 0.01
Mean ± S.D	0.91 ± 0.03	0.033 ± 0.007	64 ± 5.70	1.17 ± 0.33	35.5± 2.5	0.88 ± 0.30
Wet season						
1	0.25 ± 0.02	0.14±0.001	15 ± 2.06	1.22± 0.01	15 ± 1.15	0.77 ± 0.1
2	1.12 ± 0.01	0.048±0.001	150 ± 2.05	1.54 ± 0.01	23±1.23	0.51 ± 0.01
3	0.45 ± 0.01	0.018 ± 0.002	5.01± 1.11	1.64 ± 0.03	5.0 ±0.01	0.66 ± 0.02
4	5.16 ± 0.04	0.29 ± 0.01	50 ± 3.18	0.91 ± 0.02	70 ± 3.15	0.72 ± 0.01
5	0.79 ± 0.01	0. 35 ± 0.02	170 ± 4.20	1.23 ± 0.02	38 ± 3.45	0.66 ± 0.01
6	1.82 ± 0.01	0.027 ± 0.001	35 ±1.14	1.04 ± 0.01	34 ± 1.05	0.71 ± 0.01
7	0.51 ± 0.01	0.015 ± 0.003	45 ± 1.50	1.41 ± 0.01	40 ± 3.05	1.27 ± 0.01
8	0.26 ± 0.01	0.033 ± 0.001	30 ± 0.05	0.77 ± 0.01	14±1.00	0.8 ± 0.01
9	1.1 ± 0.1	0.013 ± 0.001	80 ± 3.01	0.87 ± 0.02	30±2.00	0.64±0.02
10	1.54 ± 0.01	0.033 ± 0.01	30 ± 2.23	1.14 ± 0.01	47±1.00	1.61±0.01
Mean ± S.D	1.46 ± 0.29	0.091 ± 0.11	61 ± 5.6	1.18 ± 0.29	32±1.90	0.84 ± 0.33
D.L	0.01	0.002	0.1	0.2	2.0	0.02
Recommended values for drinking water (mgl[-1])						
WHO	10	0.1	250	1.5	400	0.1

KEBS(PTW)	45	0.9	250	1.5	400	2.2
KEBS(PNW)	45	0.9	250	1.5	400	2.2

KEY: PTW=Potable treated water, PNW=Potable natural water, BDL= below detection limit;
Source: WHO (APHA 1992), KEBS (KS EAS 12: 2014).
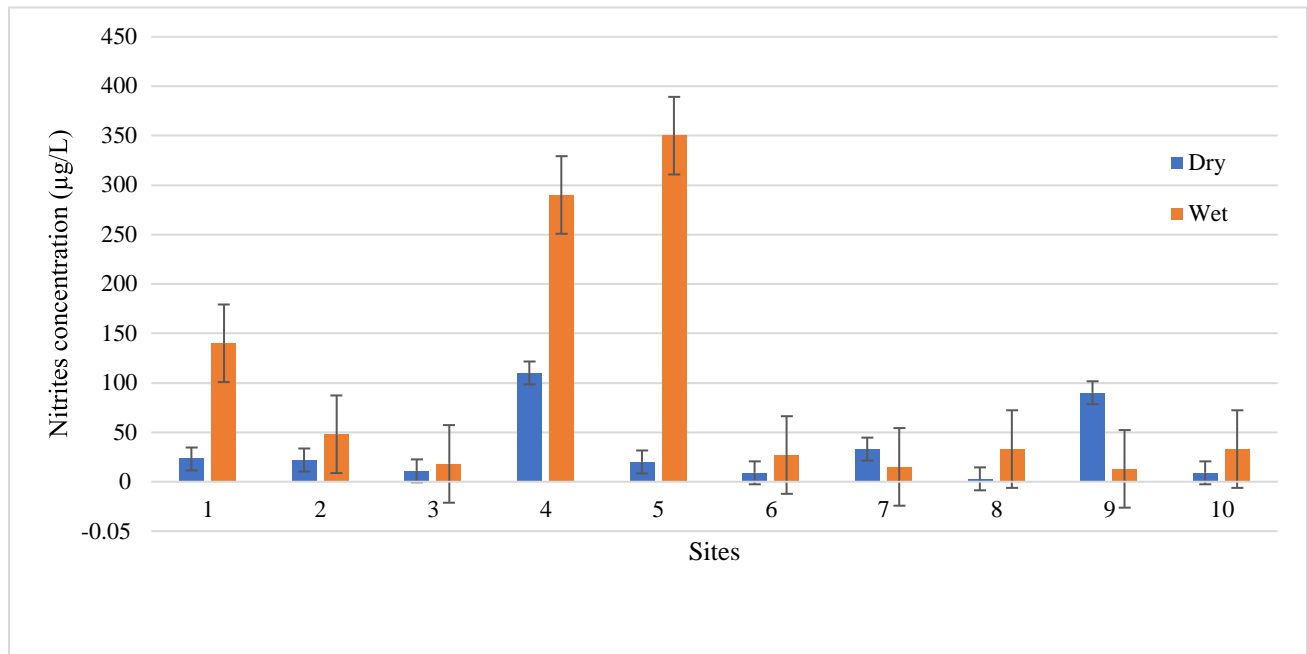
Figure 4..6: Variation of nitrite levels in the shallow wells water

4.2.8   Chlorides

The highest chloride levels were recorded at Sites 5 and Site 2 with values of 190.0 ± 4.0 mg/L
and 130.0 ± 2.0 mg/L respectively with a mean value of 64.0 ± 6.0 mg/L in dry season (Table
4.3). The lowest value obtained was at Site 3 (10.0 ± 0.1 mg/L). In the wet season Sites 5 and 2
recorded the highest values of 170.0 ± 4.0 mg/L and 150.0 ± 2.0 mg/L respectively with a mean
value of 61.0 ± 6.0 mg/L. Site 3 had the lowest level of chlorides at 5.0 ± 1.0 mg/L for the wet
season. All the chloride concentrations determined were within WHO and KEBS recommended
maximum values of 250 mg/L (Kelly *et al.*, 2012) and (KS EAS 12: 2014) respectively (Table
4.3). The high variability in the chloride levels (Figure 4.7) in seasons could be due to the
effectiveness of protection of shallow wells from salts leaching from domestic solid waste sites
(Kelly *et al.*, 2012).
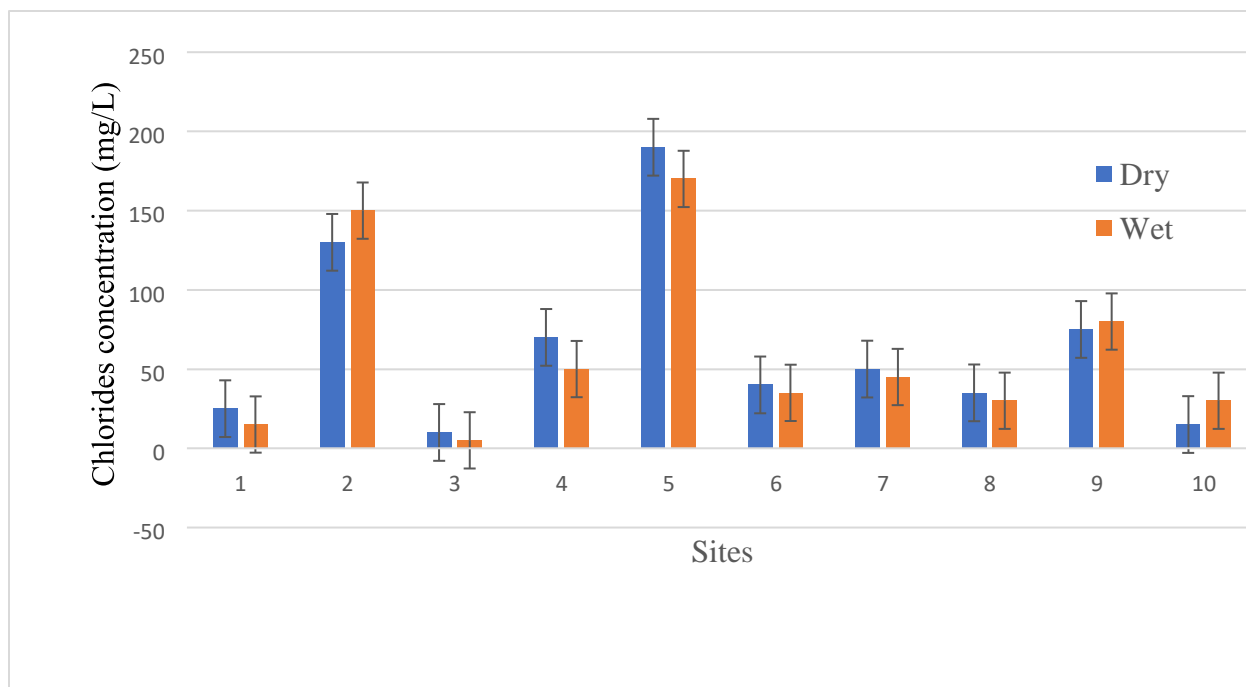
Figure 4.7: Variation of chlorides level in the shallow wells water

4.2.9 Flouride levels

Sites 2 and 3 recorded higher flourides levels of 1.65± 0.03 mg/L and 1.66± 0.02 mg/L respectively while Site 8 had the lowest value of 0.72 ± 0.01 mg/L with mean level of 1.17 ± 0.33 mg/L   in dry season. In the wet, season Sites 2 and 3 also had highest levels of 1.54 ± 0.01 mg/L and 1.64 ± 0.03 mg/L respectively while Site 8 had the lowest value of 0.77 ± 0.01 mg/L with mean level of 1.18 ± 0.29 mg/L. The fluoride levels were above the WHO, and KEBS of 1.5 mg/L (APHA 1992) and 1.5 mg/L (KS EAS 12: 2014) in sites 2 and 3 in both the seasons (Table 4.3). The optimal level is 0.7 mg/L required to prevent tooth decay (Hatlab, 1997). There was a general slight reduction in fluoride levels from dry to wet season except at Site 10 (Figure.4.8)
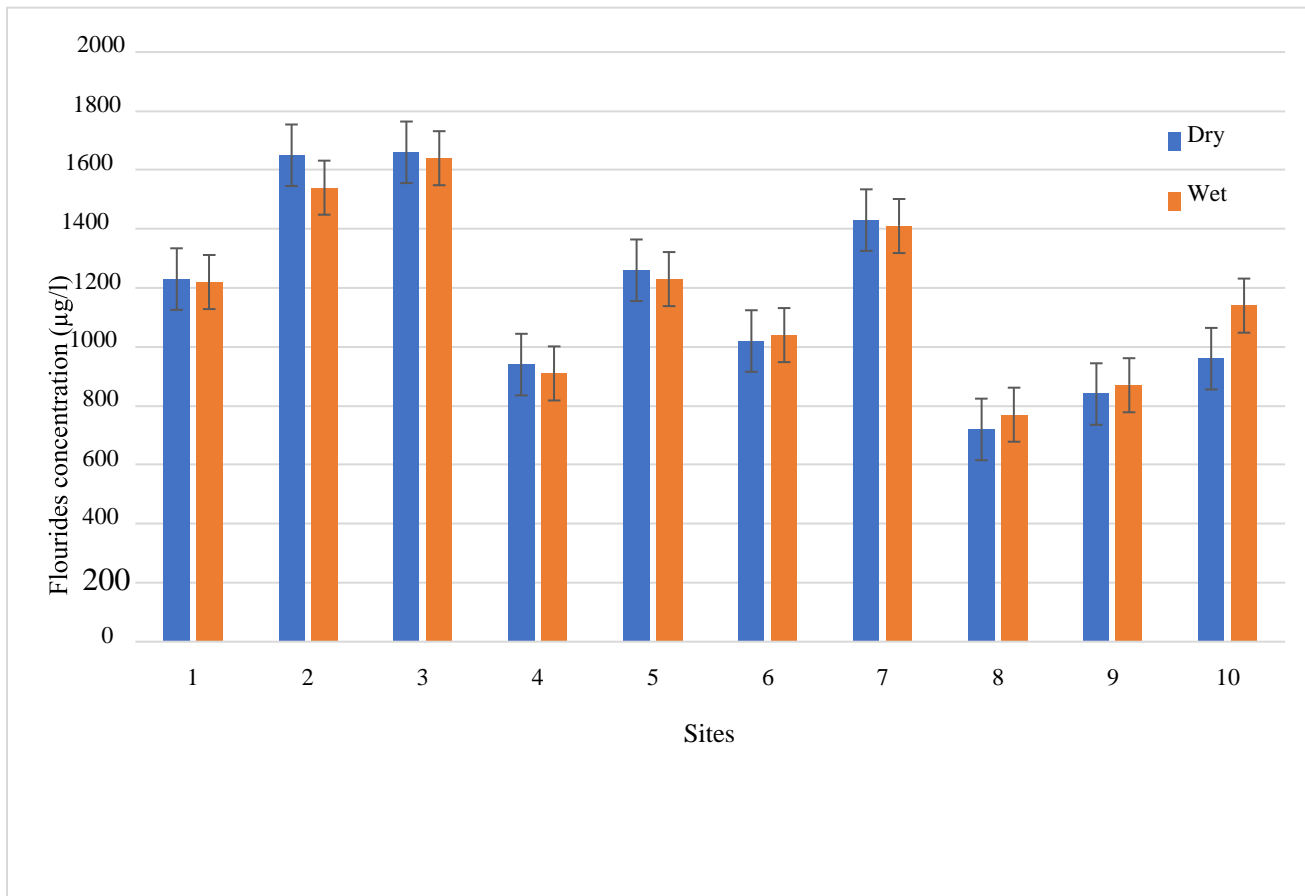
Figure 4.8: Variation of fluoride levels in the shallow wells water

4.2.10 Sulphate levels

Site 4 recorded the highest sulphate levels at 100 ± 4 mg/L while the lowest value was 10 ± 1 mg/L at Site 3 with a mean of 36.0 ± 3.0 mg/L in the dry season. During the wet season, Sites 4 and 3 also had the highest and lowest values of 70.0 ± 3.0 mg/L and 5.0 ± 0.1 mg/L respectively with a mean of 32.0 ± 1.0 mg/L. The sulphate levels in all the shallow wells were below the WHO (APHA, 1992) and KEBS (KS EAS 12: 2014) maximum limit of 400 mg/L. (Table 4.3). In the dry season the maximum value recorded was 100 mg/L, the minimum being 10 mg/L, a mean of 36.0 ± 3.0 mg/L. There was a general decrease in sulphate values from dry to wet season except for Sites 5 and 10 (Figure.4.9). This is consistent with increase in water volumes in the wells resulting to dilution of sulphates ions.
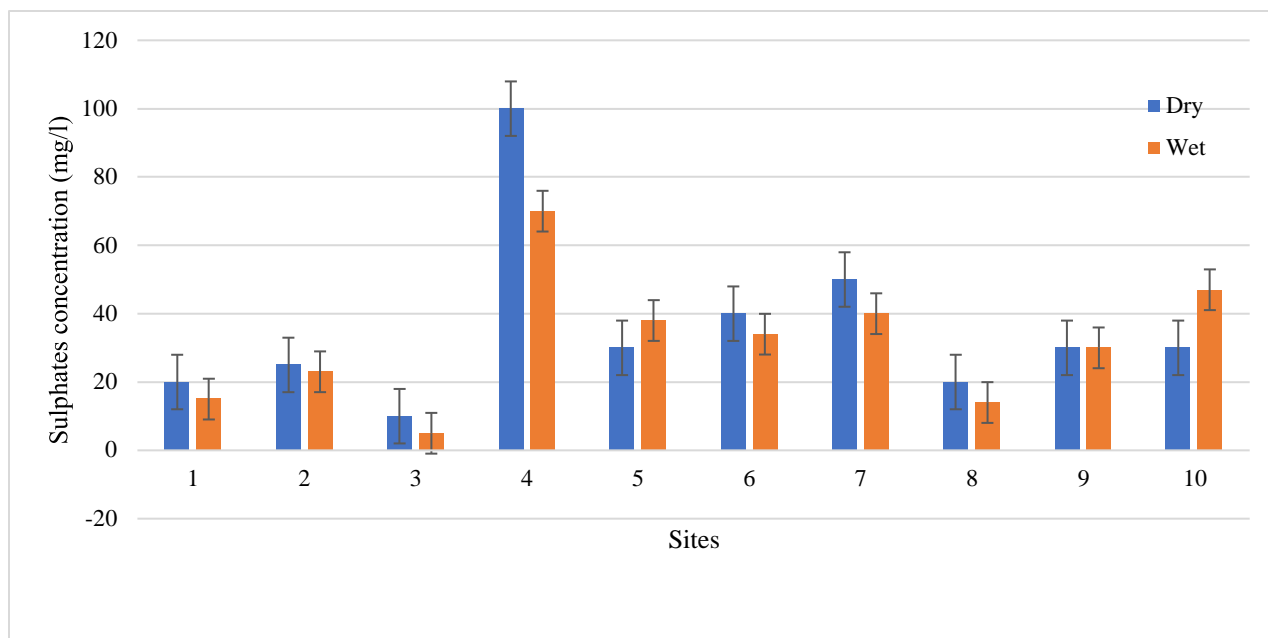
Figure 4.9: Variation of sulphate levels in the shallow wells

4.2.11 Phosphate levels

Sites 10 and 1 had the highest and lowest phosphate level at 1.50 ± 0.01 mg/L and 0.50 ± 0.1 mg/L respectively with mean of 0.88 ± 0.30 mg/L in the dry season. The phosphate level was above WHO (maximum limit of 1.0 mg/L) in site 10 (APHA, 1992) (Table 4.3). This could be attributed to the underlying rocks containing phosphates, use of soaps and detergents in washing clothes and utensils near the well. The water containing the detergents could then seep into the well. High phosphate level indicated poor protection of the shallow well (Figure 1J, appendix I). In the wet season phosphate level were also high and low in Sites 10 and 1 respectively. The highest and lowest values were at 1.61 ± 0.01 mg/L and 0.51 ± 0.01 mg/L respectively with a mean value of 0.84 ± 0.33 mg/L. Phosphates levels from all the wells were above WHO maximum value (APHA 1992) of 0.1 mg/L but lower than KEBS (KS EAS 12: 2014) level at 2.20 mg/L (Figure 4. 10)
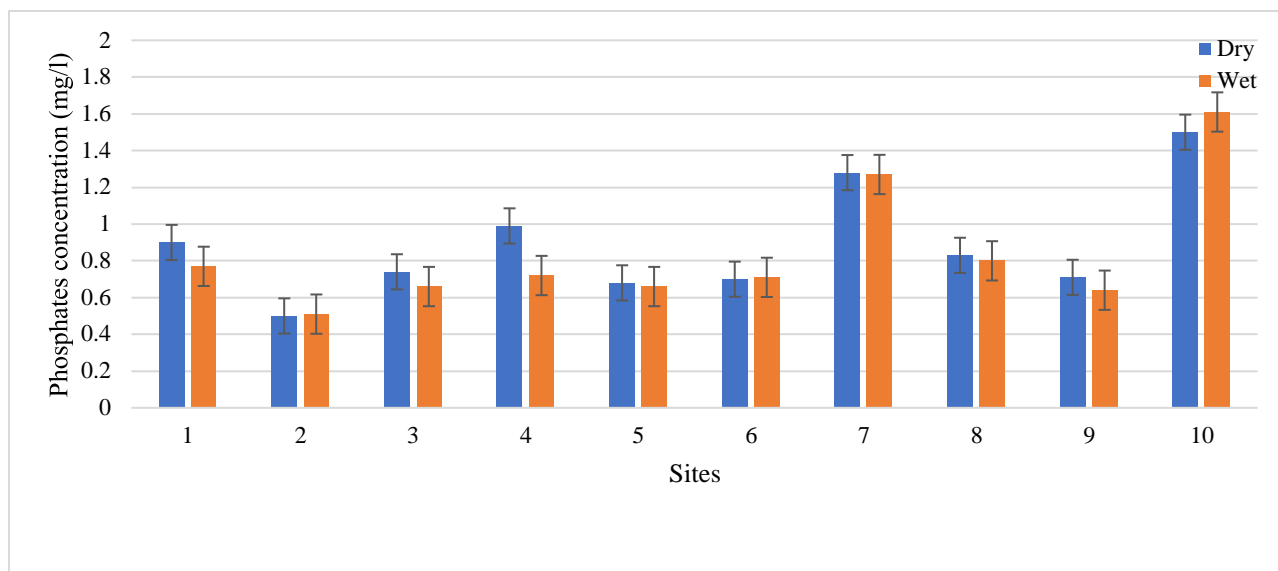
Figure 4.10: Variation in phosphate levels in shallow wells

Table 4.4: Correlation coefficients for dry and wet season for chemical parameters from the shallow well water.

Parameter	Nitrates	Nitrites	Chlorides	Flourides	Sulphates	Phosphates
Correlation Coefficient Sig. (2- tailed) N	0.988** 0.00 10	0.455 0.186 10	0.979** 0.000 10	0.979** 0.000 10	0.888** 0.001 10	0.912** 0.000 10

There was a strong correlation of 0.988 between the nitrate concentration values in the two seasons (Table 4.4). There was a low correlation of 0.455 for nitrites values in the dry and wet season (Table 4.4). There was as a high correlation of 0.979 at 0.01% level for chlorides in dry and wet season's data (Table 4.4). There was a strong correlation of 0.979 in fluorides between the dry and wet season's data (Table 4.4). A very strong correlation coefficient of 0.888 was recorded for sulphates between the two season's data (Table 4.4). A strong correlation of 0.912 at 0.01 level for phosphates was determined between the two seasons (Table 4.4).

4.2.12 Total alkalinity levels

There was a significant decrease in total alkalinity values from the dry season to wet season. (Table 4.5).

This is consistent with the high-water volume from the rainfalls. The highest value recorded was 350.0 ± 4.0 mg/L in the dry season; the minimum value of 5.5 ± 4.0 mg/L and a mean of 198.0 ± 14.8 mg/L. During the wet season, the highest value was 200.0 ± 4.0 mg/L, a minimum of 15 ± 1 mg/L with a mean of 64.0 ± 5.7 mg/L. The total alkalinity in all the shallow wells were below the maximum WHO (APHA, 1992) and KEBS (KS EAS 12: 2014) of 500 mg/L (Figure 4.11). The pH of well water increased from the dry to wet season (Table 4.1).
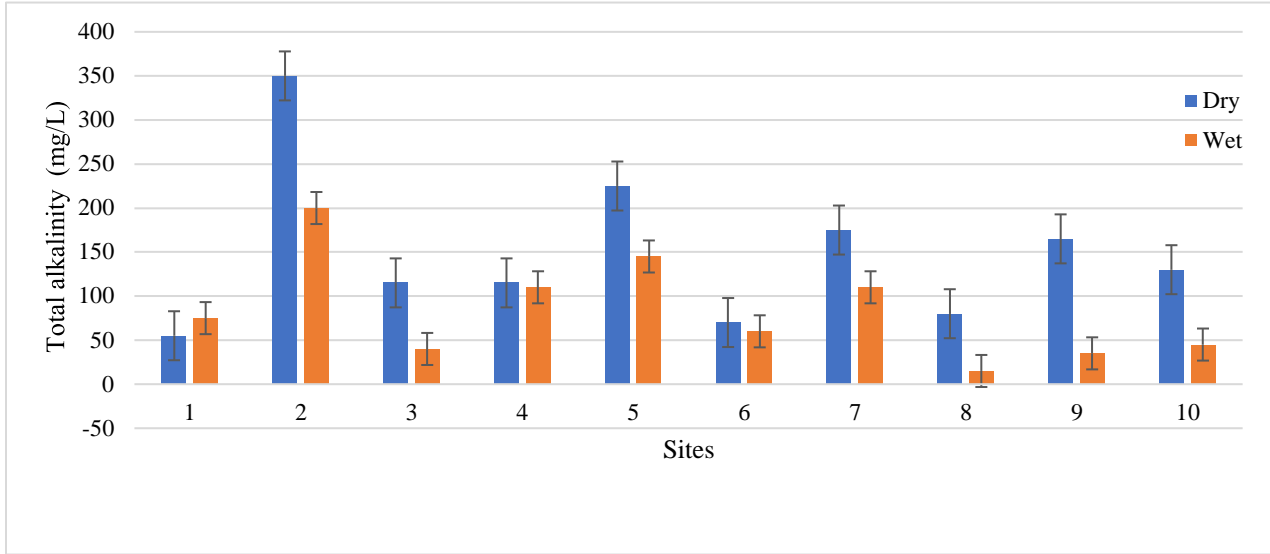
Figure 4.11: Variation of Total Alkalinity in shallow wells water

4.2.13 Total Hardness levels

Sites 1 and 2 recorded 600.0 ± 5.0 mg/L and 760.0 ± 4.0 mg/L values respectively for total hardness. These values were above WHO recommended maximum limit of 500 mg/L (Table 4.5). The minimum value during the dry season was 180.0 ± 2.0 mg/L at Site 10, with the mean of 102.0 ± 19.0 mg/L. In the wet season, the highest level was 370.0 ± 5.0 mg/L at Site 7, while the lowest was 85.0 ± 3.0 mg/L at Site 1 with the mean of 202.0 ± 40.0 mg/L. The total hardness values in all the wells were higher in the dry season than wet seasons except at Site 4. There was high variation of total hardness between dry and wet seasons (Figure 4.12). There was a decrease in total hardness, which is consistent with the dilution factor due to increase in volume as results of rainfall.

Table 4.5: Total Alkalinity, hardness and salinity levels in shallow well water

Site/parameter	Total Alkalinity (mg/L)	Total hardness (mg/L)	Calcium hardness (mg/L)	Magnesium hardness (mg/L)	Salinity (mg/L)
Dry season					
1	55.0 ± 4.0	600.0 ± 5.0	10.2 ± 0.1	1.3 ± 0.1	0.20 ± 0.01
2	350.0 ± 4.0	760.0 ± 4.0	25.7 ± 0.1	2.7 ± 0.1	0.60 ± 0.01
3	115.0 ± 3.0	325.0 ± 3.0	2.2 ± 0.1	0.3 ± 0.01	< 0.01
4	115.0 ± 2.0	205.0 ± 2.0	11.7 ± 0.1	1.7 ± 0.1	0.50 ± 0.11
5	225.0 ± 2.0	250.0 ± 2.0	9.7 ± 0.3	1.4 ± 0.01	0.50 ± 0.12
6	70.0 ± 3.0	285.0 ± 3.0	5.9 ± 0.1	0.8 ± 0.1	< 0.01
7	175.0 ± 3.0	400.0 ± 6.0	7.7 ± 0.1	1.1 ± 0.12	0.10 ± 0.01
8	80.0 ± 5.0	375.0 ± 5.0	4.9 ± 0.1	0.6 ± 0.1	< 0.01
9	165.0 ± 2.0	215.0 ± 2.0	8.5 ± 0.3	1.2 ± 0.1	0.20 ± 0.01
10	130.0 ± 2.0	180.0 ± 2.0	1.4 ± 0.01	0.2 ± 0.01	< 0.01
Mean $\pm$ SD	198.0 ± 14.0	102.0 ± 19.0	8.8 ± 6.8	1.1 ± 0.7	0.21 ± 0.03
Wet season					
1	75.0 ± 3.0	85.0 ± 3.0	7.7 ± 0.1	1.1 ± 0.1	0.10 ± 0.01
2	200.0 ± 4.0	110.0 ± 5.0	17.8 ± 0.1	2.4 ± 0.1	0.70 ± 0.1
3	40.0 ± 2.0	110.0 ± 2.0	1.8 ± 0.1	0.2 ± 0.0	< 0.01
4	110.0 ± 4.0	345.0 ± 2.0	10.8 ± 0.1	1.4 ± 0.1	0.60 ± 0.01
5	145.0 ± 5.0	245.0 ± 3.0	10.3 ± 0.2	1.4 ± 0.0	1.40 ± 0.1
6	60.0 ± 2.0	220.0 ± 5.0	5.81 ± 0.01	0.8 ± 0.0	0.3 ± 0.01
7	110.0 ± 4.0	370.0 ± 5.0	8.4 ± 0.2	1.2 ± 0.1	1.0 ± 0.1
8	15.0 ± 1.0	95.0 ± 2.0	4.8 ± 0.1	0.6 ± 0.1	0.1 ± 0.01
9	35.0 ± 3.0	210.0 ± 2.0	4.8 ± 0.1	1.1 ± 0.1	0.4 ± 0.01
10	45.0 ± 2.0	235.0 ± 2.0	2.1 ± 0.01	0.3 ± 0.1	0.4 ± 0.01
Mean $\pm$ SD	84.0 ± 6.0	202.0 ± 40.0	7.4 ± 4.7	1.1 ± 0.1	0.8 ± 0.30
Limits of detection	0.04	0.05	0.05	0.05	0.005
Recommended values for drinking water.					
WHO limits	500	500	250	250	100
KEBS (PTW)	500	300	150	100	100
KEBS (PNW)	500	600	150	100	100

KEY: PTW = Potable treated water, PNW = Potable natural water,
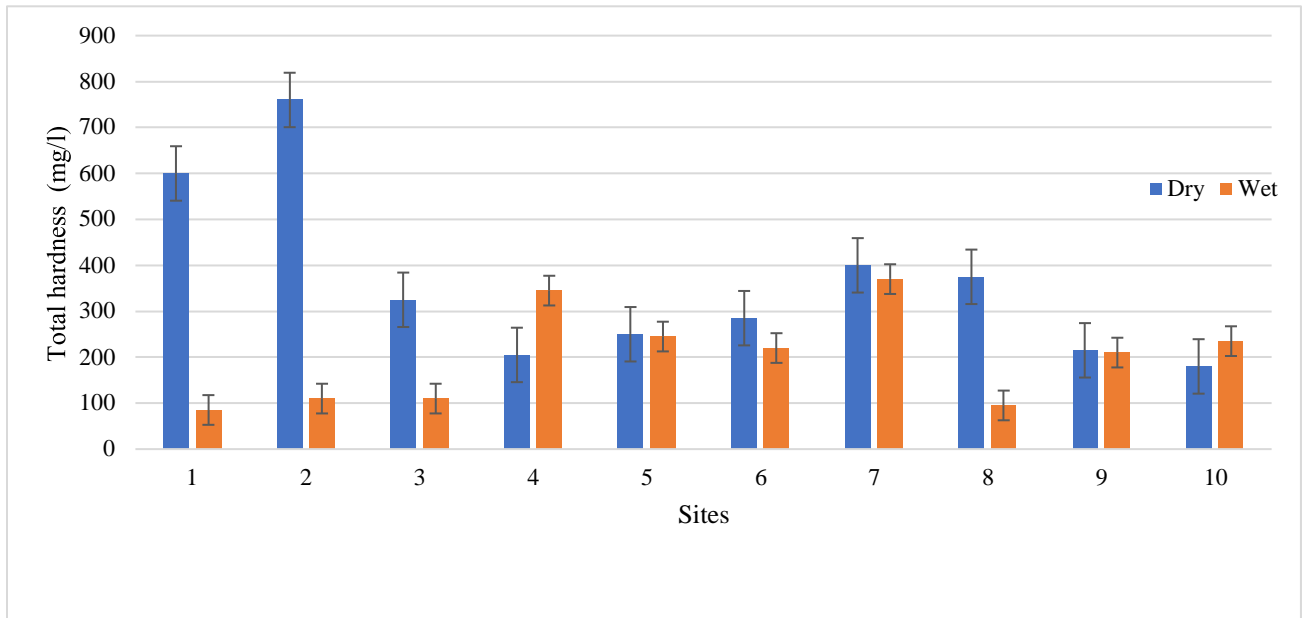
Figure 4.12: Variation of Total hardness levels in shallow wells water

4.2.14 Calcium hardness levels

The calcium hardness levels decreased with the onset of the rains. The highest value recorded is 25.7 ± 0.1 mg/L at Site 2, which was lower than the WHO recommended level of 250 mg/L (APHA, 1992). The lowest level was from Site 10 at 1.40 ± 0.01 mg/L and a mean of 8.8 ± 6.8 mg/L in the dry season. The wet season had the lowest value of 1.8 ± 0.1 mg/L, maximum being 17.8 ± 0.1 mg/L, mean of 7.4 ± 4.8 mg/L. (Table 4.5). Calcium hardness levels increased from dry to wet season (Figure 4.13).
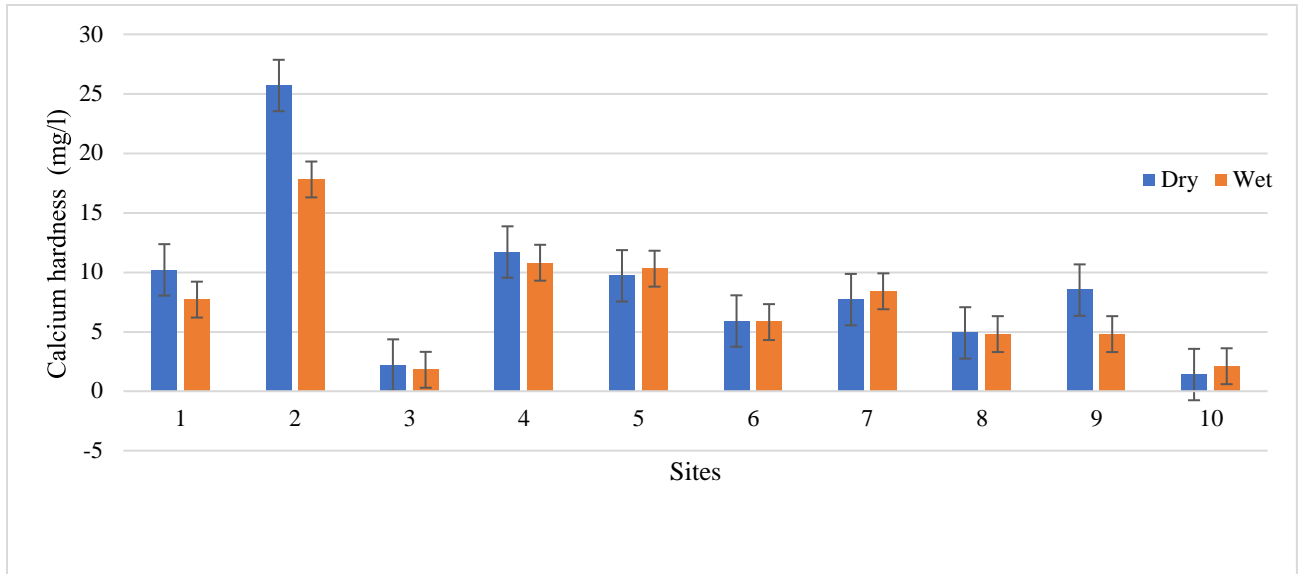
Figure 4.13: Variation of calcium hardness levels in shallow wells water

4.2.15 Magnesium hardness levels

Magnesium hardness values decreased from dry season to wet season except in Sites 7 and 8 (Figure 4.14). Rainwater is soft and usually slightly acidic and would react with underlying rocks containing magnesium carbonates during the heavy rains increasing the magnesium concentration. However, the results showed a general decrease in magnesium hardness. This shows that there was no dissolution of magnesium carbonate rocks. (WHO, 2011). The minimum value determined in the dry season was 0.20 ± 0.01 mg/L in Site 2; while the maximum being 2.70 ± 0.10 mg/L at Site10, the mean level was 1.10 ± 0.70 mg/L. In the wet season, the minimum value was 0.20 ± 0.01 mg/L in Site 3, with a maximum value of 2.40 ± 0.12 mg/L at Site 4. The mean was 1.10 ± 0.1 mg/L. (Table 4.5). The magnesium hardness in all the shallow wells was below the WHO maximum recommended value of 250 mg/L (WHO, 2011) and KEBS (KS EAS 12: 2014) of 100 mg/L (Figure 4.14).

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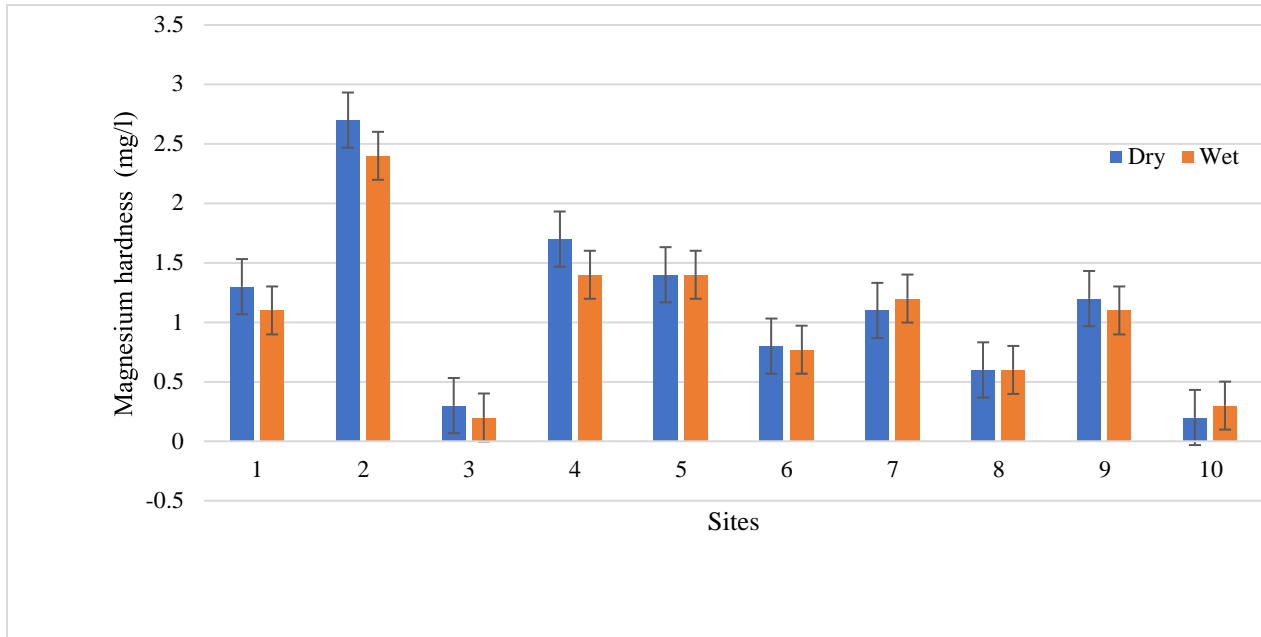
Figure 4.14: Variation of magnesium hardness levels in shallow wells water

4.2.16 Salinity levels

Salinity values obtained in all the sites showed an increasing trend from dry to wet season (Figure 4.15). This observation was contrary to lower salinity expected after dilution by the rain water. The high salinity could be attributed to salts leaching from domestic solid waste sites and the introduction of salty minerals through erosion and deposition (Soucek *et al*, 2011). Salinity in Sites 3, 6, 8 and 10 was recorded at less than 0.5 mg/L in the dry season. However, the values were lower than 100 mg/L maximum WHO and KEBS recommendations for salinity (Table 4.5). The minimum value during the dry season was less than 0.5 mg/L in Sites 3, 6, 8 and 10; maximum being 0.60 ± 0.01 mg/L; and mean of 0.20 ± 0.03 mg/L respectively. The minimum value obtained for the wet season was less than 0.5mg/L at Site 3; with a maximum value being 1.40 ± 0.1 mg/L in site 5 with a mean of 0.80 ± 0.3 mg/L (Table 4.5).
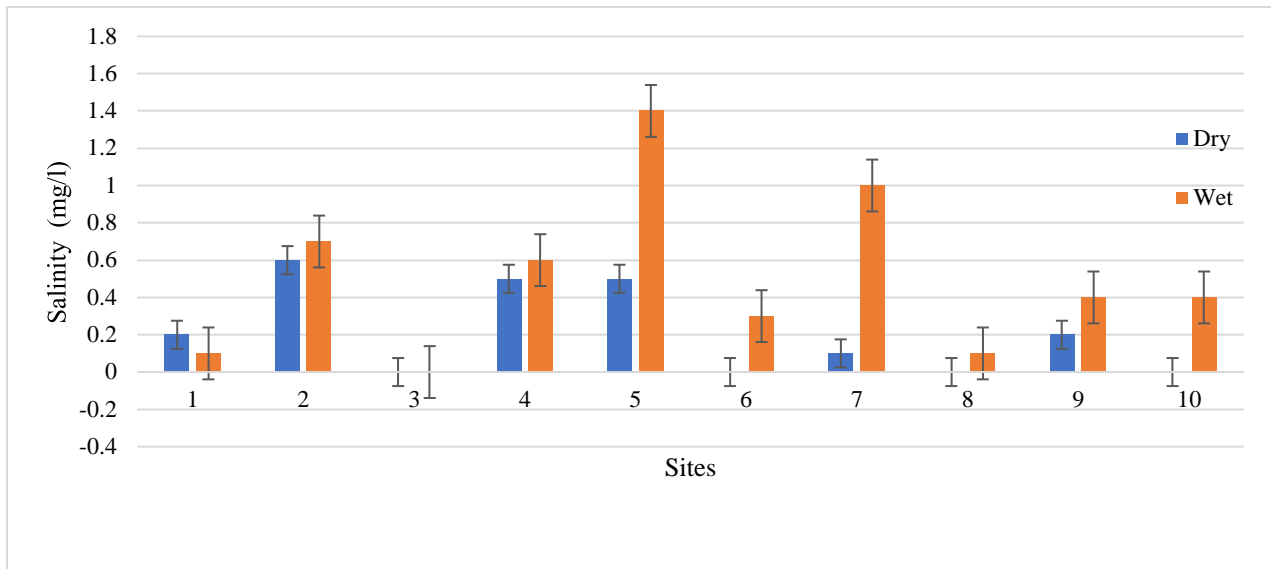
Figure 4.15: Variation of salinity level in shallow wells water

Table 4.6: Correlation coefficients in the dry and wet season for chemical parameters in shallow well water

Parameters	Total alkalinity	Total hardness	Calcium hardness	Magnesium hardness	Salinity
Correlation Coefficient Sig. (2- tailed) N	0.521 0.122 10	-0.535 0.111 10	0.903** 0.000 10	0.945** 0.000 10	0.652* 0.041 10

There was a moderate correlation of total alkalinity between dry and wet season's values at 0.521. (Table 4.6); A general decrease in total alkalinity was recorded from dry to wet season. This was consistent with dilution by the rain water. There was a moderate negative correlation for total hardness between the dry and wet season results of 0.535 (Table 4.6) with a general decrease in total hardness due to increased water volume in the wet season. There was a strong correlation of 0.903 for calcium hardness between the dry and wet season results (Table 4.6). The increased water in the rainy season significantly reduced the calcium concentration. There was a strong correlation of magnesium levels between the dry and wet season data at 0.945 (Table 4.6).

There was a moderate correlation coefficient for salinity in dry and wet seasons of 0.652 (Table 4.6)

4.2.17 Bacteriological Parameters in the shallow wells water sample**s**

The total coliform count largely remained constant at too numerous to count (TNTC) in Table 4.7. In the wet season, water surface runoffs got into the well making Site 7 to have a lower coliform count (78 ± 11 cfu /100 ml). The other sites had too numerous to count (TNTC) while Site 4 had low value of 50 ± 8 cfu /100 ml in the dry season (Table 4.7). Sites 4 and 7 had total coliform counts within the WHO (1997) and KEBS (KS EAS 12: 2014) of 100 cfu /100 ml each as stipulated by WHO and KEBS (Table 4.7). This is due to better well protection and treatment of water through chlorination.

Table 4.7: Bacteriological Parameters in the shallow wells water samples

SITE	Total Coliforms (cfu /100ml)	Feacal Coliforms (cfu/100 ml)	Total Coliforms (cfu/100ml)	Feacal Coliforms (cfu/100 ml)
	Dry		Wet	
1	TNTC	130 ± 1	TNTC	Nil
2	TNTC	Nil	TNTC	68 ± 5
3	TNTC	1	TNTC	Nil
4	50 ± 8	Nil	TNTC	Nil
5	TNTC	100 ± 1	TNTC	Nil
6	TNTC	45 ± 5	TNTC	58 ± 6
7	TNTC	Nil	78 ± 11	42 ± 5
8	TNTC	4 ± 2	TNTC	Nil
9	TNTC	20 ± 8	TNTC	Nil
10	TNTC	131 ± 15	TNTC	Nil
WHO	100	Nil	100	Nil
KEBS	100	Nil	100	Nil

WHO (2011) KEBS (KS EAS 12: 2014), Too numerous to count (TNTC)

There was a general increase in feacal coliform count from 1 ± 0 cfu / 100 ml and 131 ± 15 cfu /100 ml in Sites 3 and 10 respectively in the dry season while Sites 2, 4 and 7 had no feacal coliform counts. In the wet season feacal coliform counts increased from 42 ± 5 cfu /100 ml to 68 ± 5 cfu /100 ml in Sites 7 and 2 respectively (Table 4.7). This increase could be due to bacteria being introduced through surface runoffs, water seepage through latrines pits, and domestic refuse from cattle sheds and dump sites into the well water. Cases of contaminated buckets used to draw water may also contribute to increase in total and feacal coliform counts (Conant & Fadem, 2008). Sites 1, 2, 3 and 4 wells are located in low-lying areas which are prone to flooding and contaminations. In the dry and wet seasons, seventy per cent and thirty per cent of the well water samples respectively had feacal coliform counts above the WHO and KEBS recommended levels of nil cfu /100 ml (Table 4.7)

4.3   Metal ions levels

4.3.1   Copper levels

Sites 1 and 3 recorded the highest copper levels at 341.3 ± 0.2 µg/L and 437.6 ± 0.3 µg/L respectively with a mean of 269.0 ± 70.0 µg/L in the dry season. The copper levels decreased in all the sites with the onset of the rains from 281.7 ± 0.2 µg/L to 1.1 ± 0.1 µg/L in Sites 1 and 5 respectively with a mean of 178.5 ± 73.5 µg/L. All the water wells had levels higher than the WHO (Potera, 2004) and KEBS (KS EAS 12: 2014) maximum recommended values of 0.1 mg/L and 1.0 mg/L respectively (Table 4.8). Copper levels were lower in the wet season than the dry season (Figure 4.16). These high copper values could cause Wilson's disease to the residents of Nyalenda; a disease which is characterized by diarrhea especially in children (Fernando et *al.,* 2020).
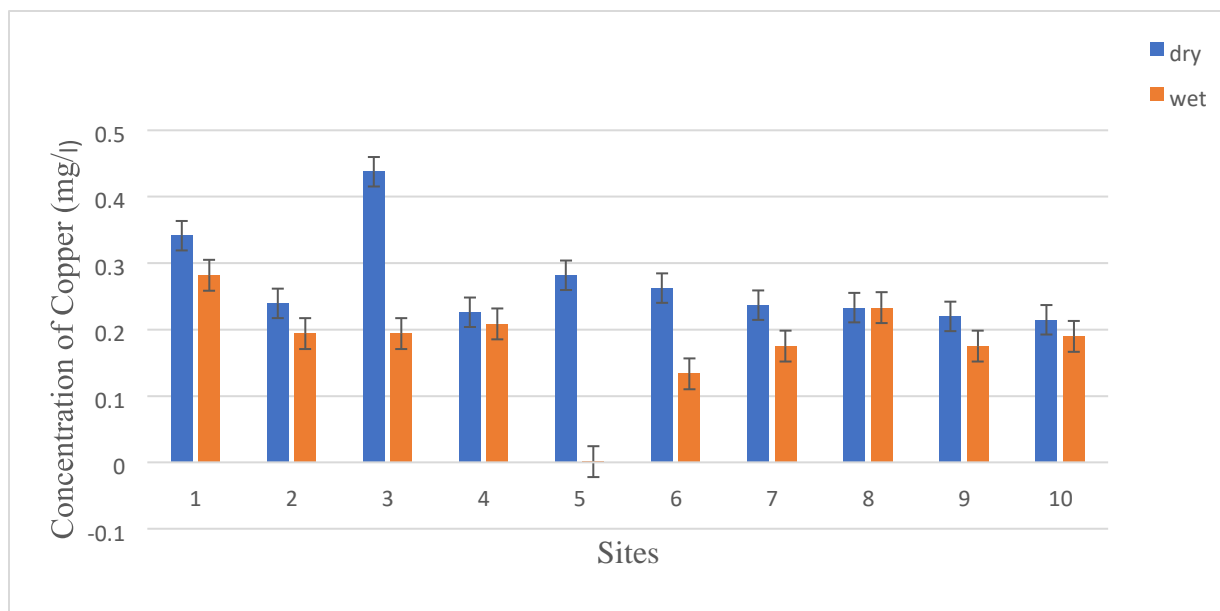
Figure 4.16: Variation of copper levels in shallow wells water

Table 4. 8: Metal ion levels in shallow well water

Site	Cu^{2+} (µg/L)	Pb^{2+} (µg /L)	Zn^{2+} (µg /L)	Fe^{2+} (µg /L)	Fe^{3+} (µg /L)
Dry Season					
1	341.3 ± 0.2	1,382.9 ± 0.1	1,382.5 ± 1.0	20 ± 1.0	1,314.2 ± 0.2
2	239.4 ± 0.2	14.3 ± 0.1	1.438.3 ± 0.4	11 ± 1.0	1,946.9 ± 0.2
3	427.6 ± 0.3	713.0 ± 0.2	1,232.5 ± 0.2	50 ± 2.0	1,781.2 ± 0.4
4	226.0 ± 0.2	121.2 ± 0.2	1,110.4 ± 0.2	10 ± 1.0	121.2 ± 0.2
5	281.7 ± 0.2	< 0.3	1,003.6 ± 1.1	80 ± 10	1,351.4 ± 0.1
6	262.4 ± 0.1	< 0.3	214.2 ± 0.2	160 ± 1.0	1,587.8 ± 0.2
7	236.7 ± 0.1	< 0.3	721.4 ± 0.2	200.0 ± 11	1,287 ± 1.0
8	233.0 ± 0.1	< 0.3	1,078.5 ± 0.3	21 ± 1.0	1,779.9 ± 0.1
9	219.8 ± 0.1	285.0 ± 0.1	0.4 ± 0.1	1 ± 0.1	999.1 ± 0.1
10	214.7 ± 0.2	< 0.0003	1,123.8 ± 0.2	10 ± 0.1	2,720.8 ± 0.2
Mean ± SD	269.0 ± 7.0	251.6 ± 457.5	786.7 ± 472.5	25.4 ± 7	1,488 ± 675.4
Wet Season					
1	281.7 ± 0.2	732.3 ± 0.1	732.3 ± 0.1	170.0 ± 1.0	732.3 ± 0.1
2	193.9 ± 0.1	25.4 ± 0.1	215.6 ± 0.1	20.0 ± 11.0	3,133.7 ± 0.2
3	193.9 ± 0.1	< 0.3	249.7 ± 0.1	30.0 ± 1.0	2,101.6 ± 0.3
4	208.5 ± 0.3	< 0.3	243.4 ± 0.1	41.0 ± 10.0	1,855.6 ± 0.2

5	1.1 ± 0.1	< 0.3	41.2 ± 0.2	90.0 ± 10.0	666.8 ± 0.1
6	133.3 ± 0.0	< 0.3	127.3 ± 0.3	172 ± 10	385.5 ± 0.1
7	175.1 ± 0.1	< 0.3	199.8 ± 0.1	201.0 ± 1.0	472.6 ± 0.2
8	233.0 ± 0.1	< 0.3	204.7 ± 0.2	$310.0 \pm 10.$	373.4 ± 0.1
9	175.1 ± 0.1	199.5 ± 0.1	< 0.3	20.0 ± 1.0	440.2 ± 0.1
10	189.7 ± 0.1	919.5 ± 0.1	$2,052.7 \pm 0.1$	70.0 ± 10.0	672.9 ± 0.01
Mean $\pm$ SD	178.5 ± 73.5	187.7 ± 344.8	406.7 ± 611.3	84 ± 17.2	$1,080 \pm 947.5$
Limits of detection	0.2	0.3	0.3	1.8	1.8
Recommended values in drinking water					
WHO	100	50	500	300	300
KEBS (PTW)	1000	10	500	300	300
KEBS (PNW)	1000	10	500	300	300

KEY: PTW = Potable treated water, PNW = Potable natural water.

WHO (2010), KEBS (2014)

4.3.2   Lead levels

The lead level in Site 1 at $1,382.9 \pm 0.1$ µg/L was exceptionally high during the dry season compared to recommended levels of 50.0 µg/L and 10.0 µg/L (WHO, 2011) and KEBS (KS EAS 12: 2014) respectively. There was a significant decrease in lead level in the wet season in site 1 $(732.3 \pm 0.1$µg/L). The exceptionally   higher level in Site 1 in dry season was due to a metallic cover containing lead which had dropped into the well and was later retrieved before sampling in the wet season. Site 10 recorded less than 0.3 µg/L in the dry season and a high value of 919.5 ± 0.1 µg/L in the wet season (Table 4.8). The lead levels in Sites 2, 5, 6, 7 and 8 were less than 0.3 µg/L in both seasons (Figure 4.17).
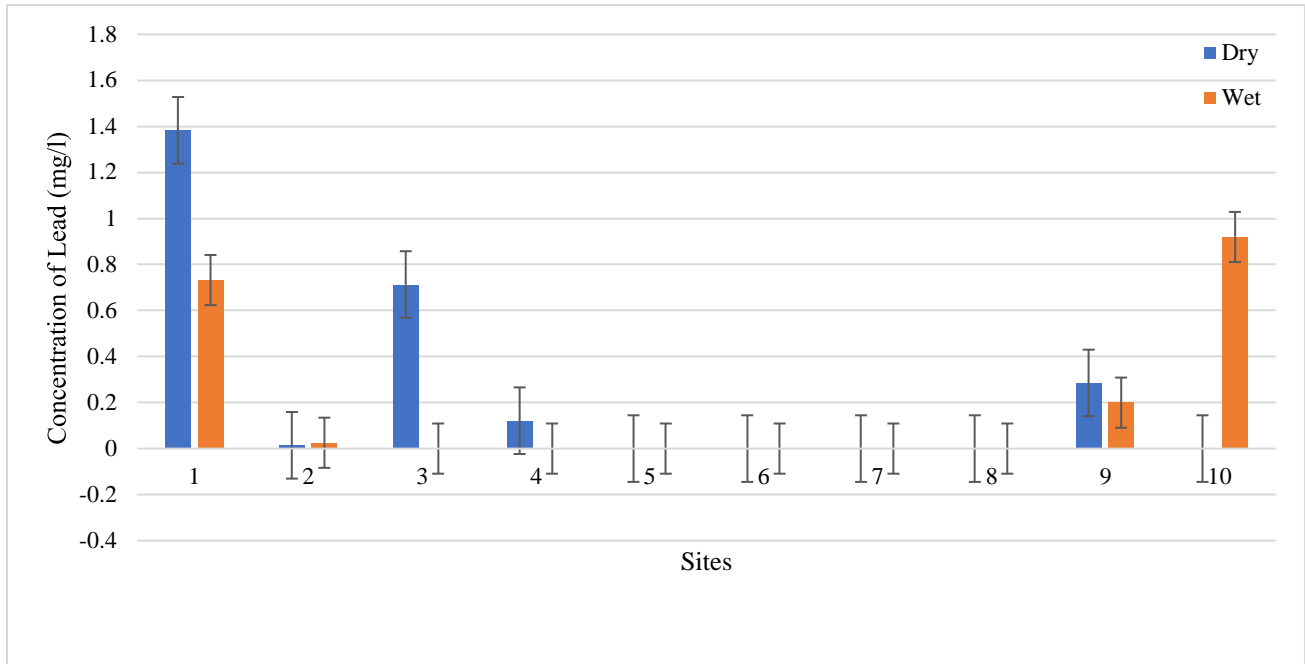
Figure 4. 17: Variation of lead levels in shallow wells water

4.3.3 Zinc levels

The zinc levels obtained were within WHO (2011) and KEBS (KS EAS 12: 2014) acceptable maximum range of 5000µg/L (Table 4.8). There was a general decrease in zinc levels in the from dry season to wet season except for Site 10 (Figure 4.18). The high-water volumes experienced could cause dilution. During the dry season, the maximum level was $1,438.3 \pm 0.4 \mu$ g/L while minimum was $0.4 \pm 0.1 \mu g/L$ in Sites 2 and 9 respectively with the mean of 930.5 ± 479.8 µg/L. In the wet season, maximum level was $249.7 \pm 0.1 \mu g/L$, the minimum value was below 300µg/L in Sites 3 and 9 respectively, with the mean 341.1 ± 607.1 µg/L.
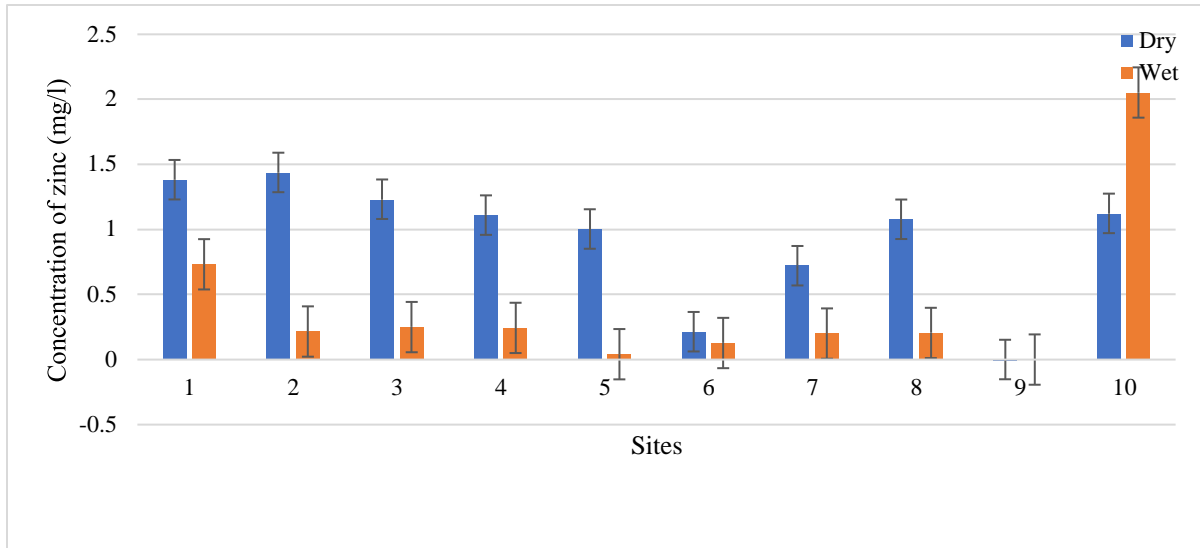
Figure 4.18: Variation of zinc levels in shallow wells water

4.3.4 Ferrous (Fe^{2+}) levels

There was a general increase in ferrous levels from dry to wet season in all the sites (Figure .4.19). During the dry season the maximum ferrous (Fe^{2+}) levels was $160.0 \pm 1.0\,\mu$g/L, with minimum value of $1.0 \pm 0.1\,\mu$g/L in Sites 6 and 2 respectively with a mean of $25.4 \pm 7.0\,\mu$g/L. The wet season maximum level was $172.0 \pm 10.0\,\mu$g/L and a minimum of $20.0 \pm 1.0\,\mu$g/L in Sites 6 and 9 respectively with mean of $84.0 \pm 17.2\,\mu$g/L (Table 4.8).
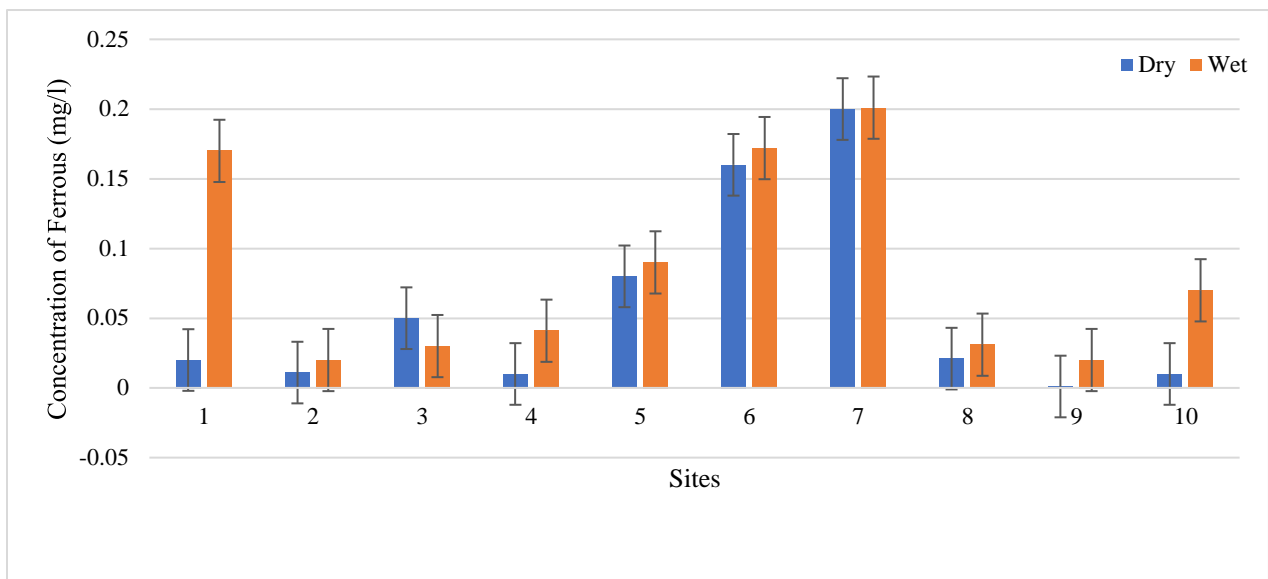
Figure 4.19: Variation of Ferrous levels in shallow wells

4.3.5 Ferric (Fe^{3+}) levels

The ferric levels determined were higher in all the ten sites compared to KEBS (KS EAS 12: 2014) and WHO (APHA, 1992) permissible levels of 300 µg/L (Table 4.8). This could turn the water red causing staining problems in laundry use and could impart bitter sweet or metallic taste in the water (Wanga *et al.*, 2016). The high ferric levels could be due to the underlying rocks with high proportion of ferrous (Fe^{2+}), which dissolved, and was oxidized to iron (Fe^{3+}) state. There was a decrease in ferric levels from dry to wet season (Figure 4.20). The maximum level during the dry season was 2720.8 ± 0.2 µg/L; a minimum of 121.2 ± 0.2µ g/L in Sites 10 and 2 respectively with the mean of 1488 ± 675.4 mg/L. The maximum value determined in the wet season was 3133.7 ± 0.2 µg/L; the minimum was 373.4 ± 0.1µg/L in Sites 2 and 8 mg/L respectively with the mean of 1080 ± 947.5µg/L. (Table 4. 8)

Figure 4.20: Variation of Ferric levels in shallow wells water

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Table 4.9: Correlation coefficients in dry and wet season metal ions values in shallow well water.

Parameter	Copper	Lead	Zinc	Ferrous	Ferric
Correlation Coefficient Sig. (2- tailed) N	-0.470 0.171 10	0.393 0.261 10	0.564 0.090 10	0.673* 0.33 10	0.673* 0.033 10

The correlation coefficient for copper values between the dry and wet season's data was low; at 0.47 (Table 4.9). There was no correlation of lead levels between the dry and wet season data in Site 1 (Table 4.9). There was a moderate correlation of zinc levels between dry and wet season results (Table 4.9). A correlation coefficient of 0.673 at 0.05 level recorded for the dry and wet season's data for ferrous (Table 4.9). There was a moderate correlation of 0.673 for ferric levels between dry and wet season result (Table 4.9).

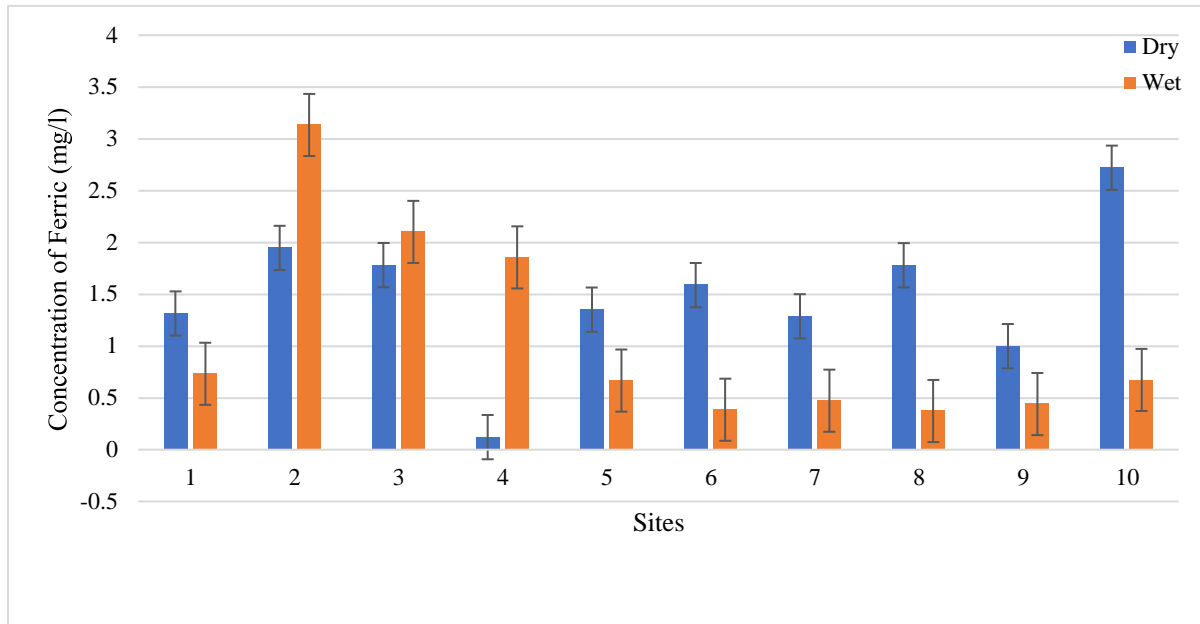Table 4.10: Metals levels in shallow wells water

Site/ parameters	Chromium (µg/L)	Cadmium (µg/L)	Nickel (µg/L)	Manganese (µg/L)
Dry season				
1	341.3 ± 0.2	< 0.2	204.0 ± 2.0	< 0.1
2	239.4 ± 0.2	< 0.2	224.6 ± 0.3	< 0.1
3	437.6 ± 0.3	< 0.2	184.8 ± 0.4	< 0.1
4	226 ± 0.2	< 0.2	694.0 ± 0.1	< 0.1
5	281.7 ± 0.2	< 0.2	240.1 ± 0.1	< 0.1
6	262.4 ± 0.1	< 0.2	136.5 ± 0.4	< 0.1
7	236.7 ± 0.1	< 0.2	74.3 ± 0.1	< 0.1
8	233 ± 0.1	< 0.2	207.3 ± 0.1	< 0.1
9	219.8 ± 0.1	< 0.2	129.6 ± 0.1	< 0.1
10	214.7 ± 0.2	< 0.2	302.3 ± 0.1	< 0.1
Mean ± SD	269.2 ± 70.1	< 0.2	239.7 ± 171.9	< 0.1
Wet season				
1	281.7 ± 0.2	< 0.2	12.0 ± 0.3	< 0.1
2	193.9 ± 0.1	< 0.2	123.7 ± 0.2	< 0.1
3	193.9 ± 0.1	< 0.2	123.6 ± 0.2	5.2 ± 0.2
4	208.5 ± 0.3	< 0.2	254 ± 0.3	440.2 ± 0.2
5	1.1 ± 0.1	< 0.2	104.7 ± 0.5	< 0.1

6	133.3 ± 0.1	< 0.2	92.7 ± 0.2	< 0.1
7	175.1 ± 0.1	< 0.2	139.1 ± 0.1	< 0.1
8	233 ± 0.1	< 0.2	44.2 ± 0.1	< 0.1
9	175.1 ± 0.1	< 0.2	337.7 ± 0.1	< 0.1
10	189.7 ± 0.1	< 0.2	234.1 ± 0.1	246.3 ± 10.0
Mean ± SD	178.5 ± 73.5	< 0.2	146.5 ± 100	69 ± 5.2
Limits of detection	0.8	0.2	0.7	0.1
WHO	100	0.5	1000	100
KEBS (PTW)	50	0.3	20	100
KEBS (PNW)	50	0.3	20	100

KEY: PTW=Potable treated water, PNW= Potable natural water, WHO (2010), KEBS (2014).

4.3.6 Chromium levels

Chromium ions decreased from the dry to wet season (Figure 4.21). The maximum value recorded was $437.6 ± 0.3$ µg/L and minimum at $214.7 ± 0.2$ µg/L with a mean of $269.2 ± 70.1$ µg/L for the dry season. The maximum value in the wet season was $281.7 ± 0.2$ µg/L and the minimum value was $1.1 ± 0.1$ µg/L, with mean of $178.5 ± 73.5$ µg/L (Table 4.10) The chromium levels from all the sites were within the WHO standards (APHA, 1992) and (KS EAS 12: 2014) recommended maximum values of 10 µg/L and 50 µg/L respectively in dry and wet seasons (Table 4.10)
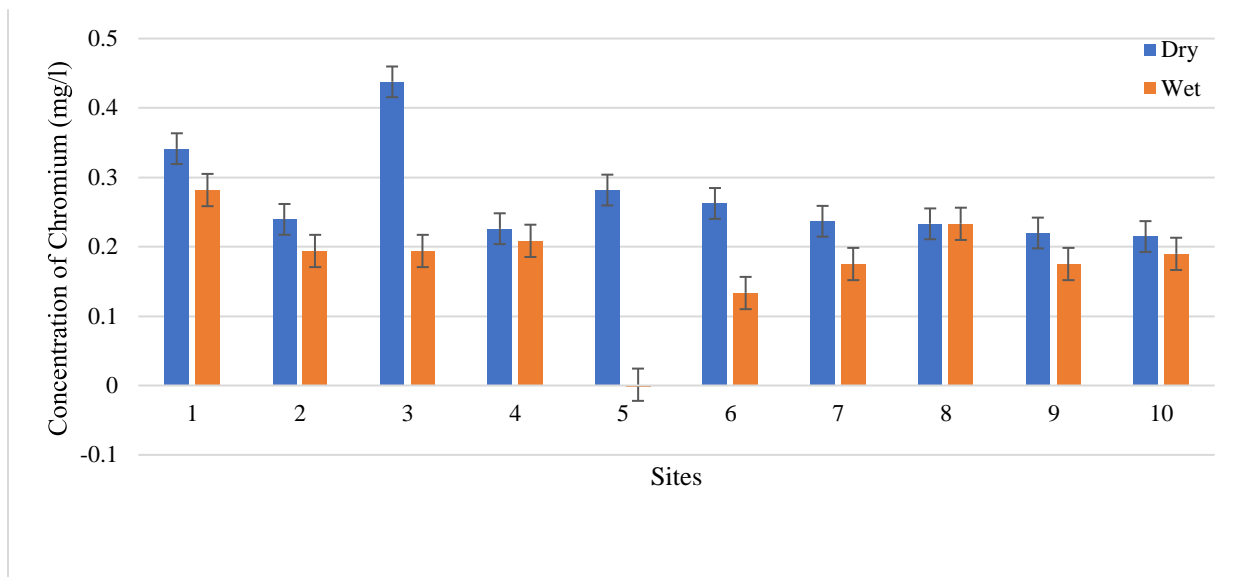
Figure 4. 21: Variation of chromium level in shallow wells water

4.3.7 Cadmium Levels

Cadmium levels were below the detection limits of 0.3 µg/L from all the ten sampling sites. (Table 4.10). The well waters were free from cadmium contamination. The maximum permissible amount in drinking water is 0.5 µg/L (WHO, 2011). Old galvanized plumbing, industrial wastes and fertilizers from farms contributes to Cadmium in water supplies (WHO, 2011).

4.3.8 Nickel levels

The maximum levels of nickel were 302.3 ± 0.1 µg/L and 337.7 ± 0.1 µg/L mg/L in the dry and wet seasons respectively. The nickel levels in all the sampling sites were lower than the maximum permitted limit by WHO (APHA, 1992) of 100 µg/L but higher than the KEBS (KS EAS 12: 2014) levels of 20 µg/L (Table 4.10).

There was a general decrease in nickel levels from dry to wet season. (Figure 4.22). The minimum value recorded during the dry season was 74.3 ± 0.1 µg/L mg/L in Site 7, and a mean value of 239.7 ± 171.9 µg/L. In the wet season a minimum level was 12.0 ± 3.0 µg/L in Site 1 with a mean of 146.5 ± 100 µg/L (Table 4.10). Nickel levels were higher in the dry season than wet (Figure 4.22). Leaching from pipes, fittings and dissolution from nickel ore bearing rocks contributes to nickel in water supplies. (WHO, 2004).
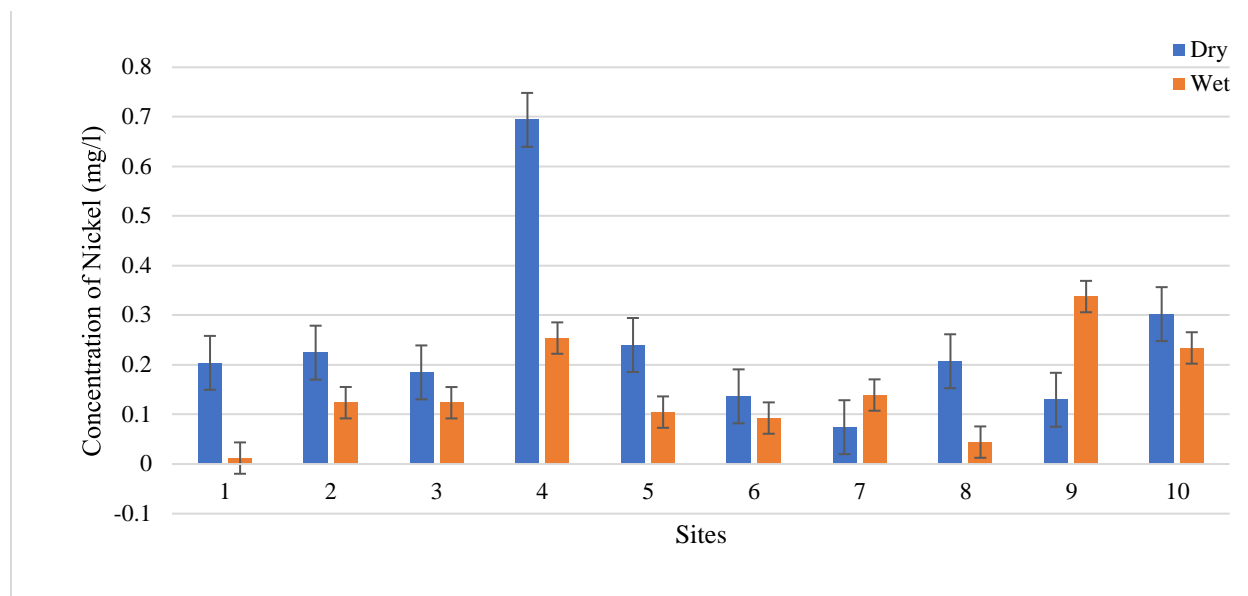
Figure 4.22: Variation of nickel levels in shallow wells water

4.3.9 Manganese levels

Significant levels for manganese were only recorded in Sites 4 (440.2 ± 0.2 µg/L, Site 10 (246.3 ± 100 µg/L) and Site 3 (5.2 ± 0.2 µg/L) respectively. The levels in Sites 4 and 10 were above the WHO (APHA, 1992) and KEBS (KS EAS 12: 2014) recommended value of 0.1 mg/L but lower than that in Site 3 (Table 4.10). The manganese levels detected in Nyalenda A and B are shown in Figure 4.23. During the dry season manganese was not detected in any of the sampling sites (Table 4.10) however, during the wet season the maximum value detected was 440.2 ± 0.2 µg/L, with a mean level of 69.0 ± 5.2 µg/L, these values were above WHO (2010) and KEBS (KS EAS 12: 2014) of 100 µg/L (Table 4.10)
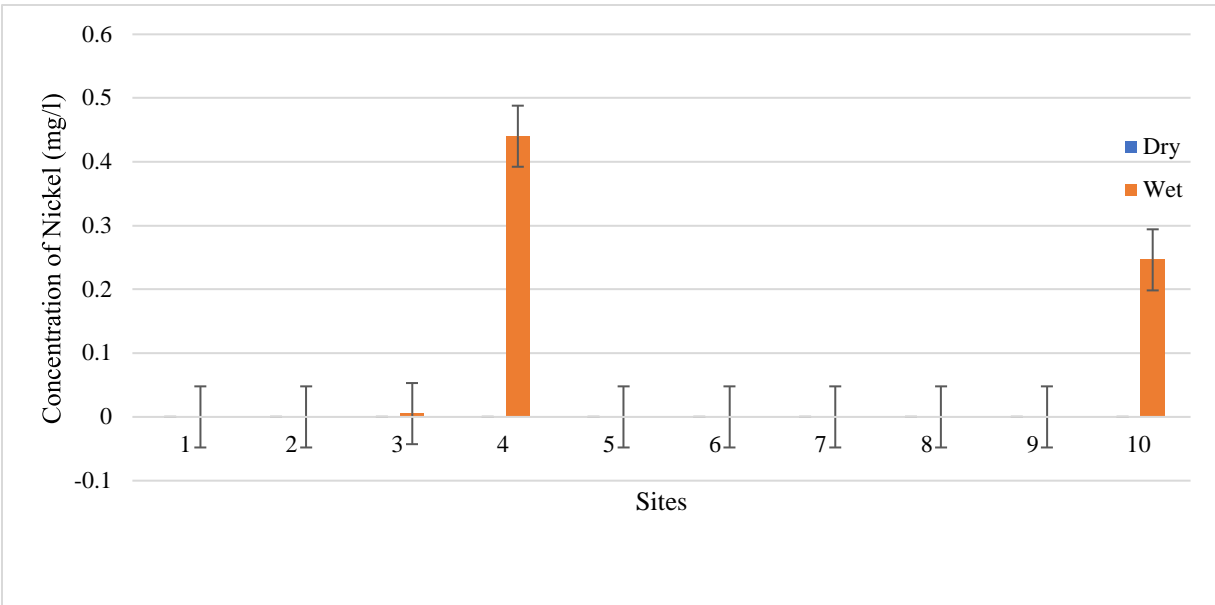
Figure 4.23: Variation manganese levels in shallow wells water

4.3.10 Correlation coefficient in dry and wet season for metal ions in shallow well water.

Table 4.11: Metal ions levels in shallow wells water in dry and wet seasons

Parameter	Chromium	Cadmium	Nickel	Manganese
Correlation Coefficient	.	.	0.079	.
Sig. (2- tailed)	.	.	0.829	.
N	10	10	10	10

There was no correlation between chromium, cadmium, nickel and manganese levels in dry and wet seasons (Table 4.11)

4.4 Response to questionnaire.

Seventy per cent of well owners were educated to high school level while thirty per cent had college level of education. This enabled them to understand the basic information on water and sanitation. Most of wells (80 percent) had been in use for over five years while 20 of them had been in use for 1 year to five years. The well water had been analysed in the last one-year although test results were not communicated to the well owners. Eighty percent of well owners chlorinated their water while twenty percent boiled their water before drinking. For those who

chlorinated their wells, 12.5 per cent of the respondents stated that chlorination was done at household level, 37.5 per cent inside the well only and 50 per cent both in the well and at household level.

Twenty per cent of well owners kept both poultry and cattle while 80 per cent kept only poultry. Disposal of domestic and animal waste at less than 10 m from shallow well was done by 40 per cent of well owners while at below 20 m were 10 per cent. Fifty per cent of well users had no waste disposal sites (Table 3.1). A positive response that a family member had contracted diarrhea disease in the past six months was recorded by 60 per cent. Forty percent of the respondents stated that no member of the family had suffered from diarrhea within the six-month period. As to who educated the respondents on proper care of shallow-well water, public health officers were recorded at 30 per cent and 70 per cent recorded for non-governmental organizations practicing community health including the World Vision, the Red Cross, SANA International, Care Kenya. The challenges to provision of safe well water quality included cost on repairs, lack of chlorine for disinfection, cost of fuel used for water boiling, vandalism of well metal covers and seasonal flooding, poor siting of pit latrines and dumpsites in the adjacent neighborhood. All these contributes to contamination of well water.

4.5   Proximity of pit latrine and domestic solid wastes disposal sites on the wells water quality.

Shallow well sites 1, 6, 7, 8 and 10 were located within 10 to 15 metres and had higher faecal coliform counts compared to Site 2, 3 4, 5 and 9; all which were located within 16 to 20 metres. However, the levels of total coliform counts were too numerous in all the sites.

The colour of the shallow well water in the nine sites were recorded at 0 Hazen units. Indicating proper well water protection from surface runoffs and water seepage from the nearby latrines and the solid waste dump sites (Table 4.1). The pH, turbidity, TDS levels of the well water in all the sites were within the WHO and KEBS limits indicating that the latrines and dump sites contents did not contaminate the well water due to well water protection from surface runoffs and ground seepage (Table 4.1). The electrical conductivity levels recorded in the sites were within WHO and KEBS limit except for site 2, 5 and 7. The exception can be attributed to the metal ions leaching from the solid waste dumpsites (Table 3.1)

Nitrates, nitrites and chlorides were found to be higher in Sites 1, 6, 7, 8 and 10 which were nearer the domestic solid waste sites. Sites 2, 3, 4, 5 and 9 had lower concentration of nitrates, nitrites and chlorides.

Sites 2, and 7 did not record any faecal coliforms count in the dry season while sites 1, 3, 4, 5, 8, 9 and 10 had no faecal coliform count during the rainy season (Table 4.7). This could be attributed to good protection, proper siting of the wells and regular chlorination of water. The domestic solid waste disposal sites were located near water wells in sites 2, 3, 5,7 and 10. This could lead to contamination of the water from the wells.

The levels of nitrates, nitrites and sulphates determined in all the sites 1 to 10 were within WHO and KEBS limits (Table 4.3). However, the chloride levels in sites 1, 2 and 3 were higher than the recommended limits and could be attributed to solid waste dump sites and latrines contents leaching into the water wells (Table 3.1). The phosphate levels were within the KEBS limits (2.2 mg/L) but above the WHO standards (0.1mg/L). Soap and detergent use in domestic cleaning could cause the high phosphate levels (Table 4.3)

The total alkalinity, total hardness, calcium hardness, magnesium hardness and salinity recorded levels in all the sites were within the KEBS and WHO limits except for sites 1 and 2 where the total hardness levels reached 600 mg/L and 760 mg/L respectively. This is above 500 mg/L WHO limit (Table 4.5). The contents of latrines and domestic solid waste sites did not come into contact with the well water to affect the quality.

The copper values recorded in all the sites were above WHO limit of 0.1mg/L but below KEBS limit of 1mg/L while lead levels obtained in sites 1, 3, 4, 9 and 10 were above the WHO and KEBS limits (Table 4.8). The high metal values can be attributed to solid waste dumpsites leaching to the shallow well water (Ignacio *et al.*, 2017; Edwards *et al.,* 2014). Zinc and iron levels were within WHO and KEBS limits (Table 4.8)

The chromium levels were above the WHO and KEBS limit except in site 5 ($1.1\pm0.1\mu$g/L). Cadmium, nickel and manganese levels were within WHO limits (Table 4.10), indicating that contents of the pit latrines and domestic solid waste sites were free of the metals ions or did not come into contact with the well water.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1   Conclusions

The colour, pH, electrical conductivity, turbidity, total dissolved solids of all the water shallow well from Nyalenda A and B Estates were generally lower than the maximum permissible units of WHO and Kenya standards

The phosphates and flourides values analyzed were higher than maximum recommended limits. Total hardness, calcium hardness, magnesium hardness, total Alkalinity and salinity levels were within KEBS and WHO recommended values.

The distance between the wells and the pit latrines were too close; a possible source of contamination. Total coliforms were too numerous to count (TNTC/100 ml) in ninety per cent of the sampling sites in both the dry and wet seasons. Seventy per cent of the wells had feacal coliforms count in the dry season while thirty per cent had feacal coliforms in the wet season. These levels were higher than WHO (APHA 1992) of 100 cfu/100 ml and KEBS (KS EAS 12: 2014) of Nil respectively.

All the shallow wells were protected with concrete slabs, metal plates and secured with padlocks. Buckets attached to ropes were used to draw water from the wells and temporarily placed on concrete floor before emptying into other water container. People stepped on the well pavement with contaminated shoes. Spillover water from drawing- buckets would drain back to the well. Site 6 was not covered, allowing contaminants to get into the well. At Site 7 the cover was rusty and had holes which allowed foreign matter into the well. All the wells required disinfection for safe domestic use.

Copper and lead levels were generally above maximum permissible values for drinking water at 437.6± 0.3 µg/L and lead (1382.9 µg/L) levels were higher than KEBS (2014) and WHO (2010) values (Table 4.8).

The zinc and ferrous, chromium, nickel and cadmium levels were below KEBS and W.H.O maximum permissible limits of 50 µg/L and 100 µg/L respectively. The nickel levels in all the shallow wells were lower than the maximum permitted limit by WHO (APHA, 1992) of 1000 µg/L but higher than the KEBS (KS EAS 12: 2014) levels of 20 µg/L.

Significant manganese levels were analyzed only in Sites 4 and 10 at 440.2 ± 0.2 µg/L and 246.3±10.0 µg/L respectively. The values were above WHO (100 µg/L) .and KEBS (200 µg/L) (Table 4.10)

Based on the findings from this study the water from the shallow wells in Nyalenda A and Nyalenda B Estates are not fit for drinking and domestic purposes.

5.2   Limitations

In this research two water samples were collected from the shallow wells during the dry and wet season leading to duplicate results per parameter analysed. Three samples could increase the accuracy of the results.

The control site for the research work was not established to enable the researcher conclusively determine whether the close proximity of pit latrines and domestic solid waste sites influenced the water quality.

Some homesteads had high perimeter walls and remained locked. This made it not possible to determine whether there were latrine or domestic solid waste sites, factors that could influence the water quality in nearby wells.

5.3   Recommendations

The following recommendations were made from the study:

1. Qualified public health officers as provided for in the WHO guidelines and Kenya Bureau of Standards on water quality should do regular disinfection of wells in all the wells providing water to residents to guard against diarrhea disease outbreaks like including cholera and typhoid.

2. Increased community education on water and sanitation should be conducted by qualified government and non-governmental organizations staff

3. Public health office should intervene and discourage well owners and their neighbours from constructing wells near pit latrines and domestic dumpsite and vice versa. This will guarantee safe water in the current and future wells.

4. The shallow well water chemical and biological quality analysis to be carried out regularly (at least after six months) in certified laboratories and the results of analysis be communicated to the well owners and users.

5. The county government of Kisumu city should develop a long-term plan to provide the Nyalenda A and Nyalenda B residents with safe drinking water and connect the area to the existing sewerage system (Figure 3.1) to reduce bacteriological water contamination.

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7.1   Appendix

Figure 7.1: Fredrick Otieno's well

Figure 7.2: George Otieno's well

Figure 7.3: Wilson Ogello's well

Figure 7.4: Sylvanus Nyamwenga's well

Figure 7.5: St. Edward Catholic's Church well

Figure 7.6: Kuap Nyalenda Catholic's Church well

Figure 7.7: Kojwang John's well

Figure 7.8: Jackton Mando well

Figure 7.9: Tom Nyamanga's well

Figure 7.10: Steven Guya Wasawo's well

7.2 Appendix 2

7.2.1 FAAS Calibration curves for heavy metals

The calibration curves for copper, lead, zinc, iron, chromium, cadmium, nickel, and manganese are shown in Appendix 2. Figures 2A, 2B, 2C, 2D, 2E, 2F, 2G and 2H were prepared using various concentrations of the selected heavy metals standards prepared in section 3.10.3 – 3.10.11 respectively and analysis was done with FAAS using the condition given in Table 3.3.
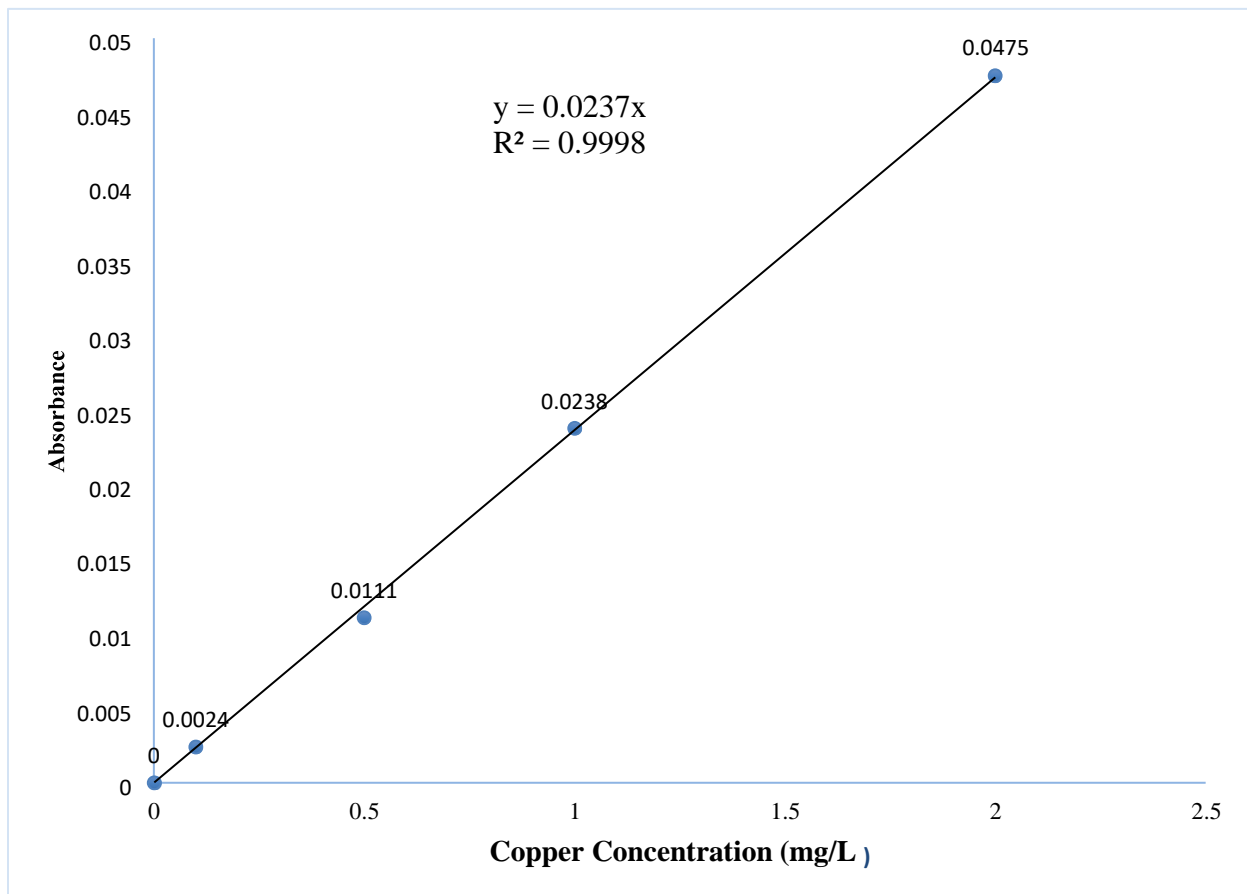
Figure 7.11: Copper metal standard calibration curve.
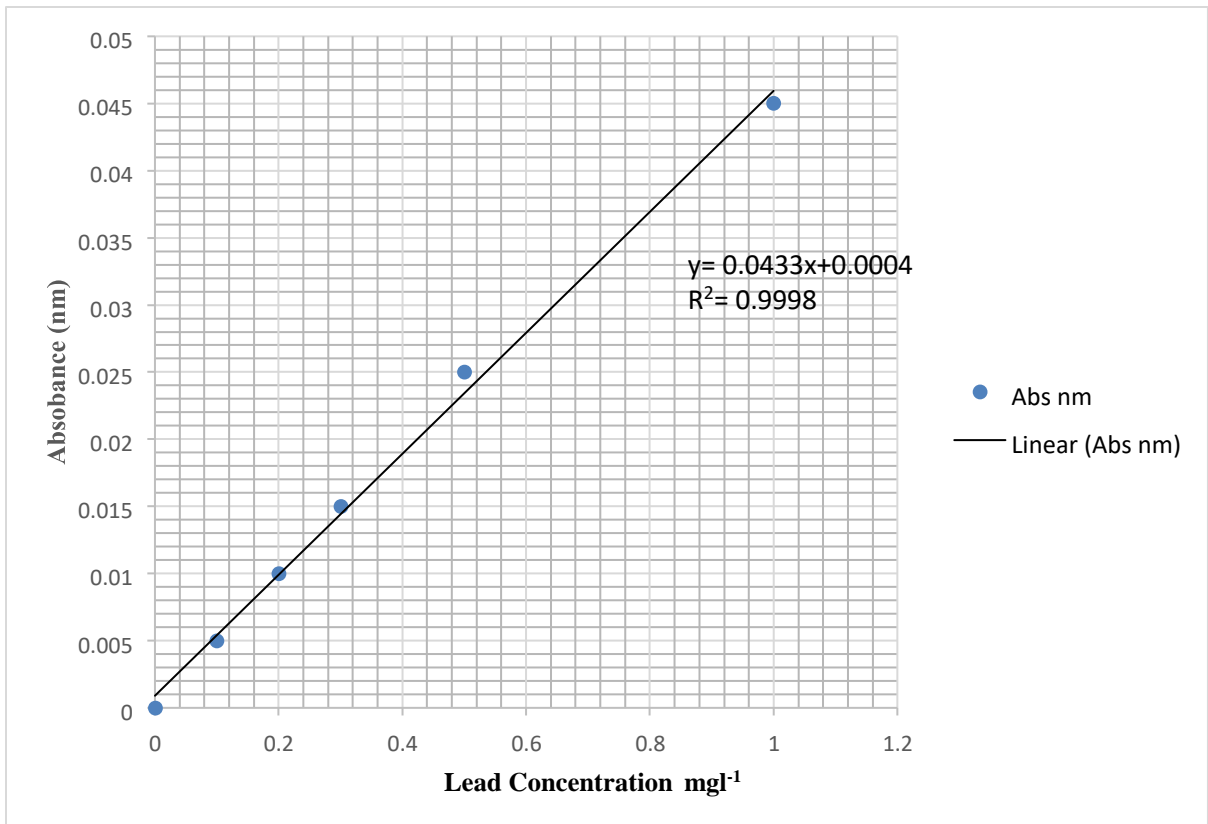
Figure 7.12: Lead metal standard calibration curve.
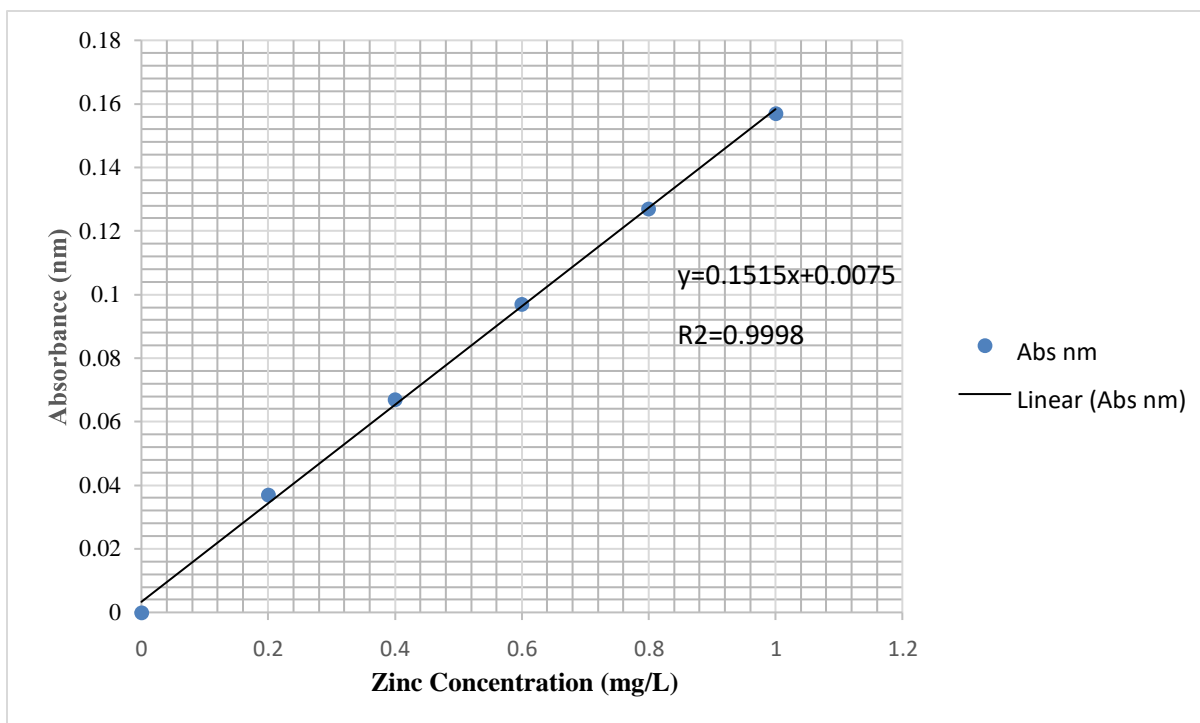
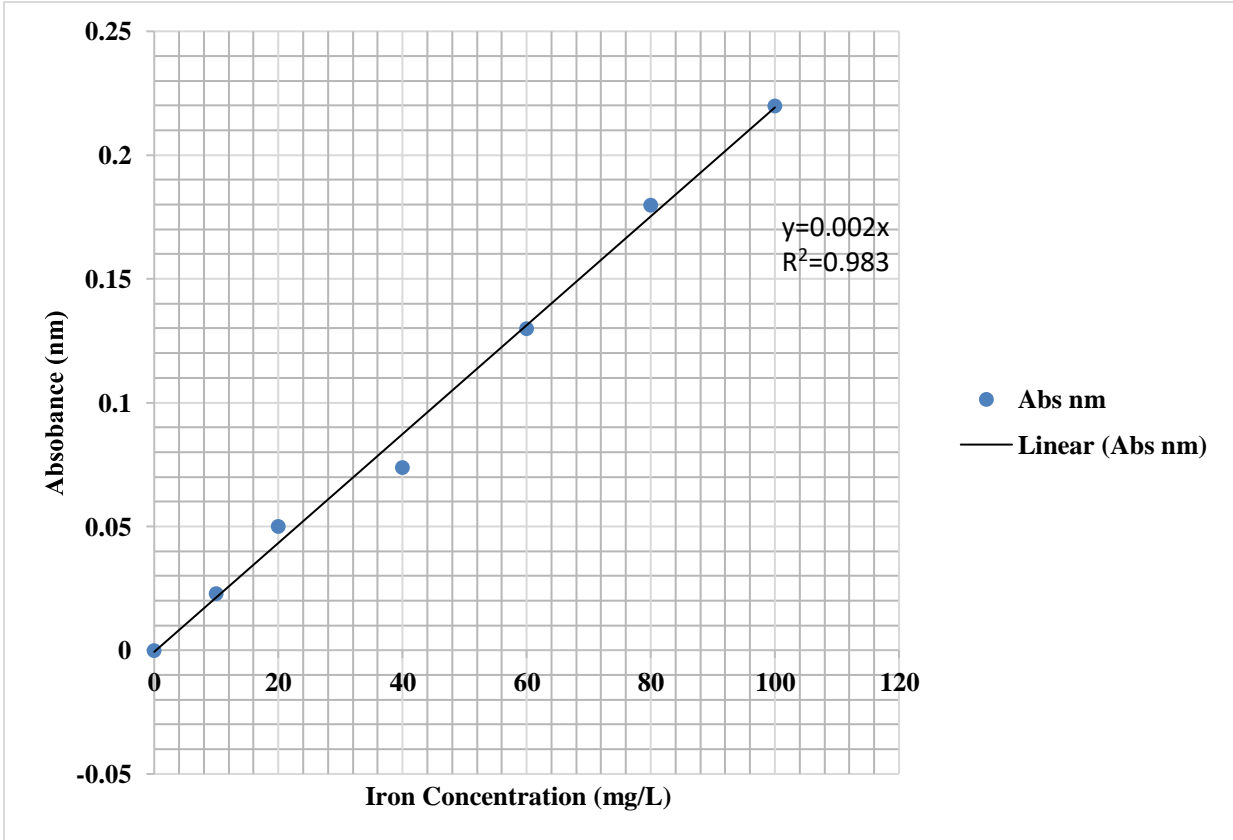Figure 7.13: Zinc metal standard calibration curve.

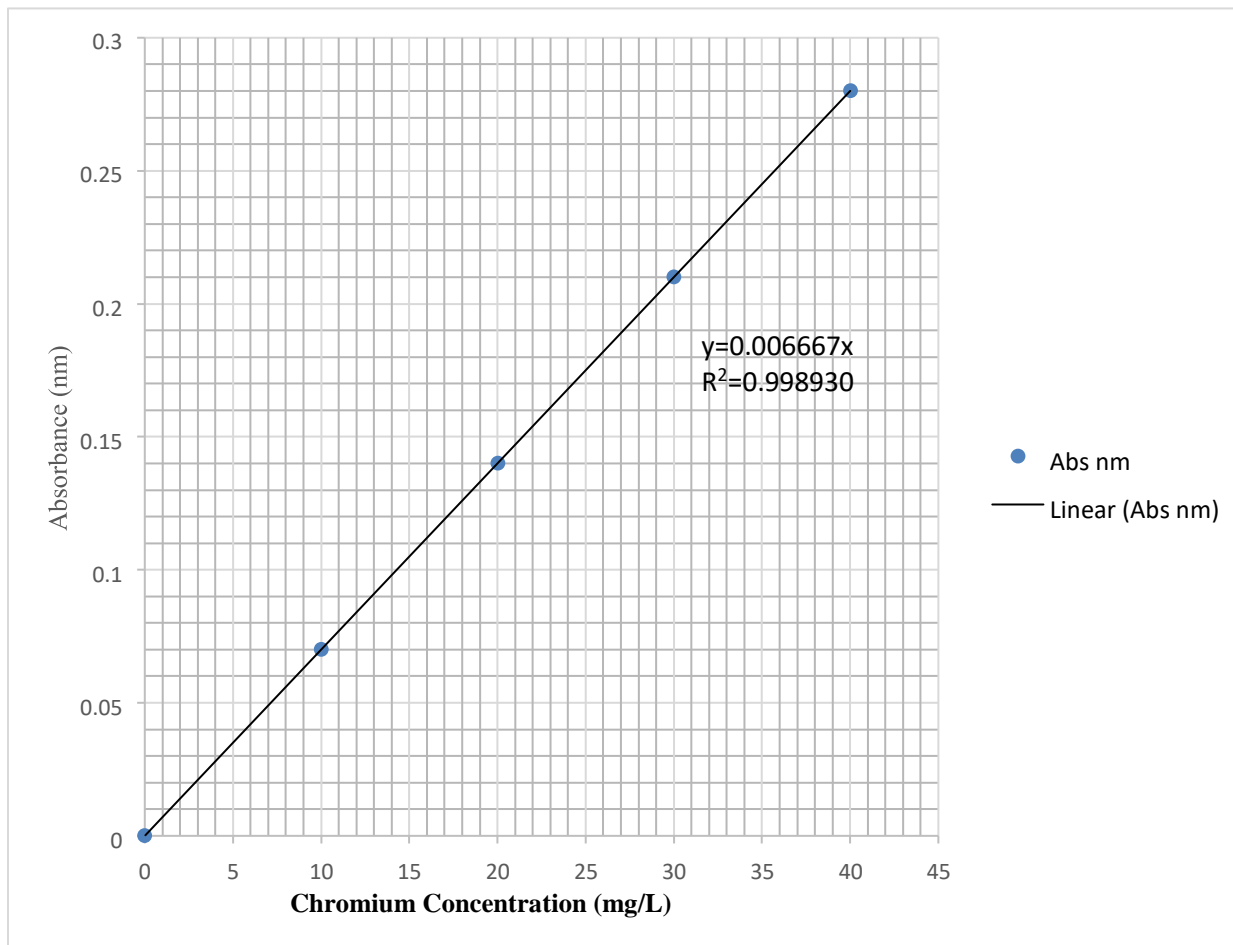Figure 7.14: Iron metal standard calibration curve.

Figure 7.15: Chromium metal standard calibration curve.
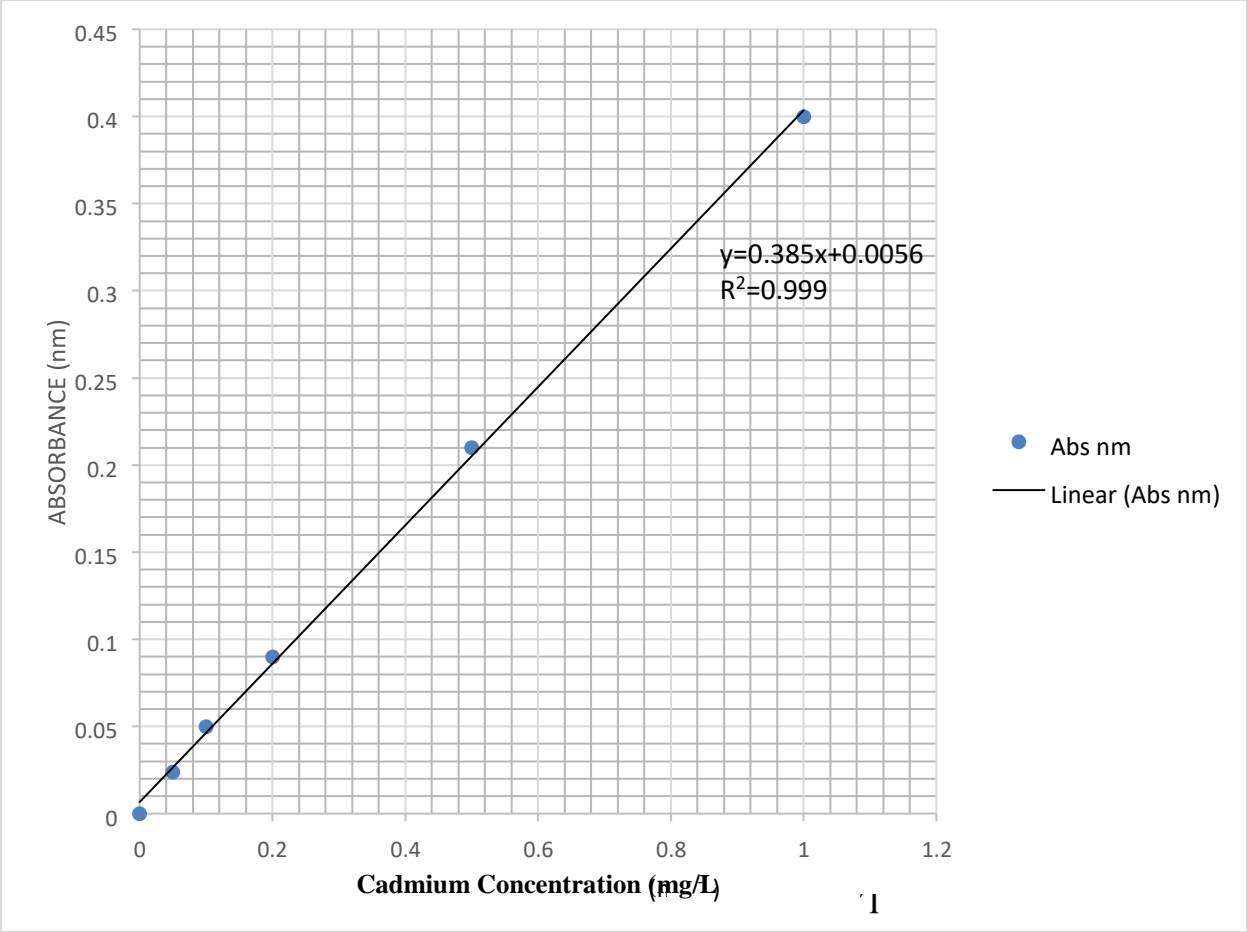
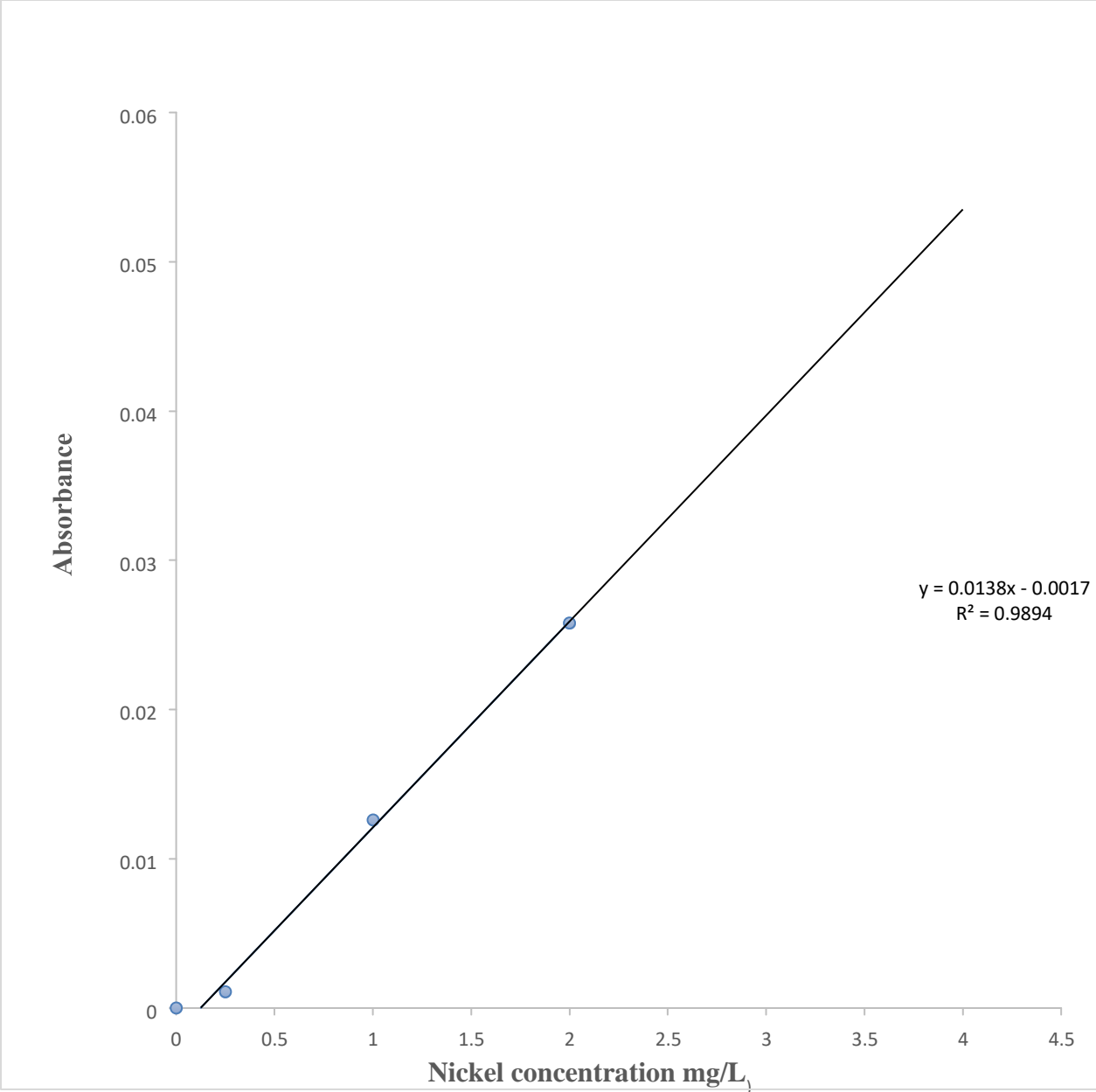Figure 7.16: Cadmium metal ion standard calibration curve

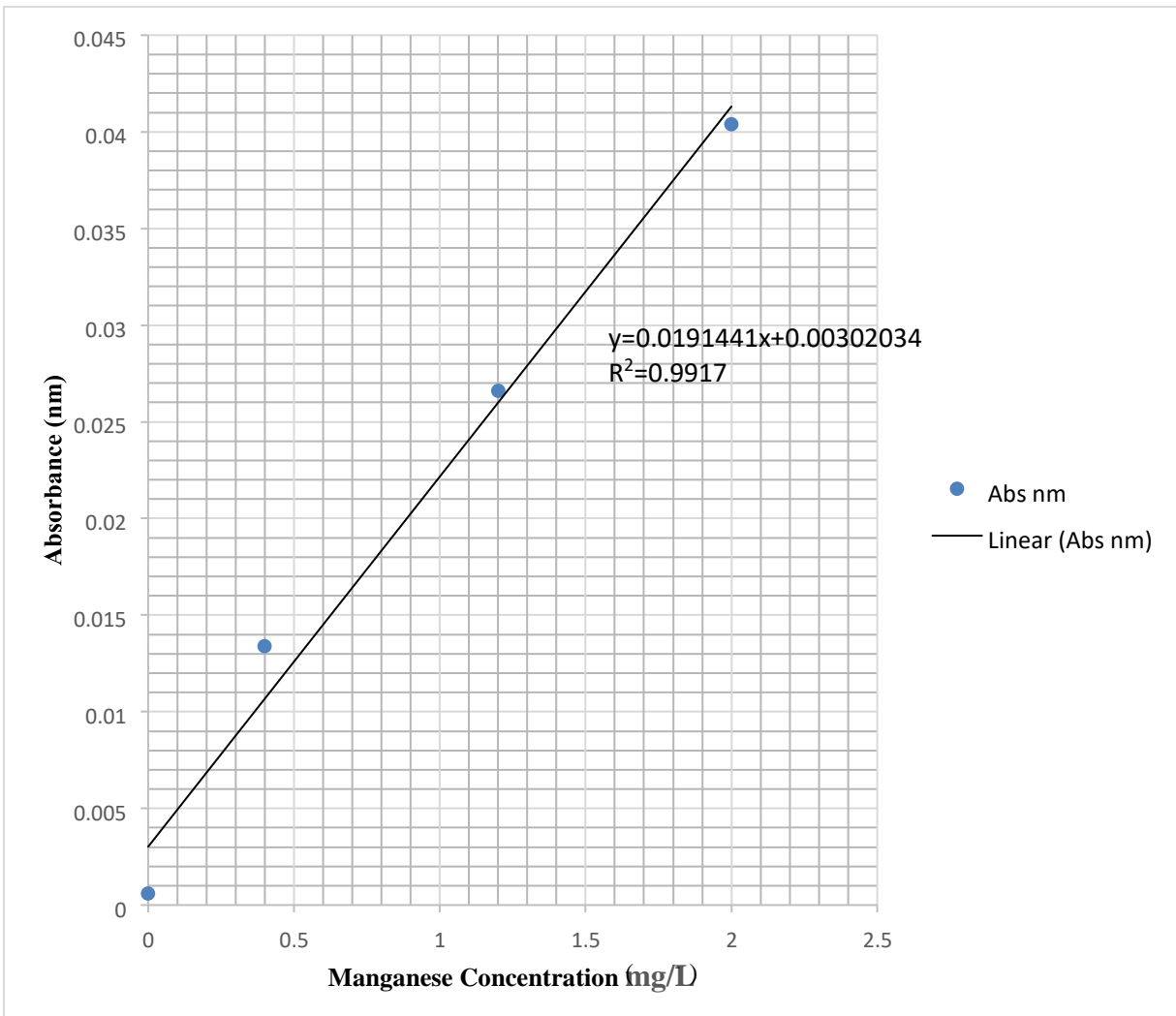Figure 7.17: Nickel metal ion standard calibration curve

Figure 7.18: Manganese metal ion standard calibration curve.

7.3   Appendix 3

QUESTIONAIRE TO NYALENDA WELL OWNERS/USERS [Kindly take some time and answer the questions below to the best of your knowledge by marking an (X) in the appropriate box where applicable]

1. What is the level of your education

[A] Primary school   [B] Secondary school   [C] College/University

2. For how long has your shallow-well been in use?

[A] Less than one year   [B] 1year to 5years   [C] Over 5years

3. When was your shallow- well water tested for quality last? [A]

Below 6 months   [B] Over 6 months to 1year [C] Over 1 year

4. How is your shallow-well water treated before drinking/use?

[A] by chlorination   [B] by boiling   [C] Not at all

5. In case the water is chlorinated, is it at

[A] household level only?   [B] inside the well only?   [C] Household and well?

6. Which animals do you keep?

[A] Poultry   [B] Cattle   [C] Poultry and cattle

7. How far from the shallow-well do you dispose domestic/animal waste [A]

Less than 10 metres [B] Over 10metres to 20 metres [C] Beyond 20metres

8. Has any of your family member had any diarrheal disease in the last six

months?

[A] Yes   [B] No

9. Who educated you on how to take care of your wells?

[A] Public health officers from the government

[B] Self-education from relevant study materials.

[C] Non-governmental organizations

[10] What are the challenges to provision of quality water from your wells?

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