UNIVERSITY OF NAIROBI

ASSESSMENT OF LEVELS OF SELECTED HEAVY METALS IN BOREHOLE WATER IN ONGATA RONGAI, KAJIADO COUNTY, KENYA

BY

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DECLARATION

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

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DEDICATION

This thesis is a dedication to my family and friends for being supportive and understanding when I was taking my study.

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My sincere praise and thanks goes to the Almighty God.

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ABSTRACT

Heavy metal content in groundwater sources is of a growing concern as they are known to be persistent in nature and have been found to bioaccumulate in animals and plants. The heavy metals have been found to cause detrimental health effects to human beings and some of the effects include cancer, nervous system damages, respiratory diseases and even dermatological problems. There'r therefore, need to assess levels of heavy metals in water sources. This study was carried out to evaluate the quality of groundwater sampled from ten selected boreholes in Ongata Rongai town, Kajiado County. Selected heavy metals; zinc, lead, mercury, manganese, cadmium and chromium and associated physicochemical parameters; pH, dissolved oxygen, electrical conductivity, total dissolved solids, turbidity and total suspended solids were determined from the ten borehole sites together with human activities as sources of contaminants. Seasonal variation was considered as an aspect of pollution to the subsurface environment where there was no obvious observable environmental degradation. The heavy metals were determined by use of Flame Atomic Absorption Spectroscopy. Questionnaires were randomly issued to residents in the area to assess their knowledge of water quality and heavy metal knowledge. The physicochemical parameters determined were in the following ranges: pH 6.6±0.1 –8.6±0.1; dissolved oxygen 1.22±0.01-4.83±0.01 (mgl^{-1}), electric conductance 233±1.0-312±1.0 (mscm^{-1}), total dissolved solids 630±1.3 - 980±1.0 (mgl^{-1}); turbidity 0.04±0.01-0.7±0.01 Nephelomteric Turbidity Units (NTU); total suspended solids 0.9±0.1 - 2.6±0.01 (mgl^{-1}), while for heavy metals; zinc Below Detectable Limits (BDL)- 0.73±0.01 (mgl^{-1}); lead 0.21±0.01- 0.42±0.01 (mgl^{-1}), mercury 0.0002±0.0001 - 0.0019±0.0001 (mgl^{-1}); manganese 0.03±0.01- 0.26±0.01 (mgl^{-1}). Cadmium and chromium had levels below limits of detection of 0.001 (mgl^{-1}) and 0.005 (mgl^{-1}) respectively. Statistical analysis of the data using a 1-Way Analysis of Variance (ANOVA) showed 95% confidence ($p<0.05$) interdependence of the distance from the boreholes and contaminant levels. The study concluded that lead and manganese levels were slightly higher in all water samples as compared to World Health Organization (WHO), Kenya Bureau of Standards (KEBS) and National Enrvironment Management Authority (NEMA). Cadmium and Chromium were below detectable limits irrespective of the season and proximity to septic tanks. There was no strong relationship between physical chemical parameters and proximity to septic tanks. The seasonal variation had no statistical significant effect on chemical parameters levels and they were within WHO, KEBS and NEMA. The responses from questionnaire showed that public awareness about water quality and effects of heavy metals should be done. It can also be concluded that the water is fit for consumption, however regular analysis are recommended and proper disposal management should be employed.

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LIST OF ABBREVIATIONS/ACRONYMS AND SYMBOLS

AAS	Atomic Absorption Spectroscopy
APHA	American Public Health Association
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
CBD	Central Business District
DNA	Deoxyribonucleic Acid
EPA	Environmental Protection Agency
FAAS	Flame Atomic Absorption Spectroscopy
FTU	Formazin Turbidity Unit
GIS	Geographic Information system
GOK	Government of Kenya
GPS	Global Positioning System
HCL	Hollow Cathode Lamp
HM	Heavy Metals
KEBS	Kenya Bureau of Standards
MCL	Maximum contaminant level
NEMA	National Environment Management Authority
NTU	Nephelometric Turbidity Units
UNEP	United Nations Environment Programme
USA	United States of America
USEPA	United States Environmental Protection Agency

USGS	United States Geological Survey
WRMA	Water Resource Management Authority
WARSEB	Water Services Regulatory Board
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Groundwater pollution (also referred to as groundwater contamination) happens when impurities are emitted on to the ground and percolate to the groundwater, this may also happen in nature, according to Momodu and Anyakora (2010), and when the pollutant is small, undesirable element, or impurity in the groundwater, is alluded to as a contamination rather than pollution (Momodu *et al*, 2010).

Several trace metals are constituents of certain rock formations and make their way into the environment by weathering of the rocks. Industrial activities like mining, metallurgy, disposal of solid waste, paint and enamel works contribute to increased levels of poisonous metals like lead, cadmium, and chromium. These impurities possess the ability to reach groundwater (Iqbal and Gupta, 2009). The movement of metals and their metalloids into groundwater is dependent on several factors, for instance, chemical reactions that determine the separation of impurities into various phases and species. Therefore, the movement of these metals are dependent on the pH and redox state of groundwater (Kallis, 2006).

According to Khrisat *et al*., (2019), origin of groundwater pollution is grouped based on three factors which include: municipal, industrial and agricultural sources. In their study carried out in Azraq Catchment in Fuhais-Jordan, they advised that in order to accomplish good water quality there is need to continuously monitor water resources hence need for assement of levels of heavy metal in Ongata Rongai. Other sources of groundwater pollution could be categorized as oint and non-point origin. Point sources are particular identifiable sources for instance pipe discharges while non-point sources are diffuse and no specific source can be identified for instance runoff. The concern of heavy metals and metalloid pollution in the surrounding is a growing concern globally. This is due to their persistence in the environment. The metal ions bio accumulate in biota and are removed by excretion into the environment, leading to their toxic nature among other abundant sources, (Bortey-Sam *et al*, 2015) and as such, there is need to assess the concentrations of heavy metal regularly. As indicated by Adumanya *et al*, 2013, heavy metals occur in our environment as particulates, dissolved and colloidal phases.

Cobbina *et al, (2015*) described heavy metals as a metal element that has a comparably high density and are hazardous at little concentrations. However, Jeje *et al* (2014) were more specific and described heavy metals as "Groups or metals or metalloids with an atomic density larger than 4 g/cm^3 or are 5 times denser than water". Jeje *et al* (2014) emphasized that the "Density of heavy metal is of minimal concern but the emphasis should be placed on their chemical properties instead" (Momodu *et al*, 2010).

Mercury, lead, cadmium, and arsenic have been known to cause detrimental health problems (Njar *et al*, 2012). These metals naturally occur in the surrounding but are also released into the environment due to anthropogenic activities that largely contribute to their existence in the environment. Some of the anthropogenic activities that could lead to their release into the environment include mining, industrial waste disposal, transport sector, agricultural activities, and the domestic effluent disposal systems.

Water is an essential resource that is abundantly utilized all over the world in agriculture, transport, industries and for domestic use purpose. There is a need to have quality water for domestic use to promote good human health, (Ramesh and Elingo, 2001). In the urban settlement, groundwater is vulnerable to adulteration from solid waste leaches, untreated sludge and manufacturing emissions that leak into the ground and thereby reaching water-bearing rock formations, (Lapworth *et al*, 2017). Water is not pure as it can dissolve, absorb, adsorb and acquire suspended impurities in it and this is attributed to its polarity and hydrogen bonds and is found in two forms; either as surface water or underground water (Pitt *et al*, 1999).

Other than the physical properties of water, there's a need to assess the chemical parameters of water and the levels of heavy metals. Heavy metal are currently the most persistent water impurities with known detrimental effects on human health. Gautam *et al* (2014) established that these heavy metals transpire in water as an outcome of improper disposal of industrial waste, electronic waste, municipal wastewater, landfill leachates, mining activities and natural geochemical weathering of rocks. Volatile and particulate metal compounds are carried from one place to another by the wind. These heavy metals include; lead, zinc, mercury, manganese, chromium, and cadmium. However, according to World Health Organization (WHO, 2014), the concentration of these metals has greatly increased due to human activities.

Ongata Rongai like any other growing urban area has inadequate access to piped treated water, therefore, the population in the area relies on groundwater obtained from boreholes, hence there is a need to evaluate the quality of water (Abong'o *et al*, 2017). Increasing concentration of these metals in water is an impending health risk to humans, animals, and plants because they are lethal even at little concentrations (Momodu *et al*, 2010). A number of these heavy metals, however, play a vital role in biological cycles especially in trace levels but are quite poisonous at very high concentrations. Examples of known roles include formation of protein structures and pigment, taking part in redox reactions, regulating osmotic pressure, regulation of the ionic balance and disposal systems serving as an enzymatic unit of a cell (Oves *et al*, 2016).

Rapid real estate growth which started in the 1990s, has led to growth of population in Ongata Rongai, a Nairobi suburb located 16 kilometers away. Greater Ongata Rongai as described by Kazungu *et al,* (2011), sits within the Nairobi metropolitan, however, it does not lie in the governance borders of the capital and is demarcated from Nairobi, the capital city of Kenya by the Mbagathi River. It's split into two governance locations, Nkaimurunya and Rongai, which are segregated by the Magadi Road. Kandisi River, a branch of the Mbagathi River is in Ongata Rongai. The area possess two significant industrial activities: Kitengela glass, an artefacts manufacturer hidden in Tuala neighbourhood and Tam feeds, an agro-manufacturing industry at Gataka. The sources of water for domestic use are; Mbagathi River, supplying 15% and private boreholes in the area supplying 46% of water (Directory of Cities, 2019).

1.2: Statement of the problem

The study was designed to investigate the levels of heavy metals in borehole water in Ongata Rongai. Similar to any other urban settlement, Ongata Rongai has its population increasing and exerting pressure on available amenities such as water, as per the Government of Kenya (GOK) population and housing census report (GOK, 2019).

The rapid population increase in the area has created a potential for heavy metal pollution of the domestic water and a recent publication also demonstrated that septic tanks in Ongata Rongai are a source of inorganic constituent contaminants that enter the borehole water (Abong'o *et al*, 2017).

The population in Ongata Rongai relies on groundwater obtained from boreholes and as a result, there is a need to assess the quality of water (Abong'o *et al*, 2017). Jeje *et al, (*2014) pointed out that increasing heavy metal levels in water sources has attracted a lot of concern from researchers about the heavy metals toxicity to biota. The toxic nature of lead, cadmium, and mercury is a threat to human health. These metals are elements of the earth's crust however anthropogenic events such as septic tanks, mining activities, agricultural activities and industries contribute to enhanced levels of heavy metals in borehole waters (Gautam *et al*, 2014).

There is limited literature on heavy metals levels in borehole water used by Ongata Rongai residents and that provides recommendations to avert any heavy metal pollutions detected in borehole water. There is need to put strict regulations in place and public education about heavy metal pollution to safeguard the quality of borehole water and environment of Ongata Rongai.

1.3: Objective

1.3.1: General objective

The general objective was to determine the levels of selected heavy metals and physico-chemical parameter in ten borehole water samples in the dry and wet seasons in Ongata Rongai, Kajiado County.

1.3.2: Specific objectives

The specific objectives were to:

i. Determine the physico-chemical parameters, pH, dissolved oxygen, electrical conductivity, turbidity, total suspended solids (TSS) and total dissolved solids (TDS) in selected ten borehole water samples from Ongata Rongai in the dry and wet seasons
ii. Determine seasonal variation of selected heavy, zinc (Zn), mercury (Hg), lead (Pb), cadmium (Cd), chromium (Cr), and manganese (Mn) levels in ten borehole water sample during the dry and wet seasons.
iii. Assess the effect of proximity of septic tanks to boreholes on the levels of physico-chemical parameters and heavy metals in the ten borehole water samples and compare the levels with WHO and KEBS limits in drinking water during the dry and wet seasons

1.4: Justification and significance of the study

Heavy metals have been known to be among persistent impurities in water (Jeje *et al*, 2014) therefore there is need to evaluate the levels of these metals to show the effect of septic tanks constructed at < 16 m distance from borehole water (Abong'o *et al*, 2017).

Heavy metals can be toxic in very little concentrations and usually accrue in the surroundings and later become a health risk to people (Elinge *et al*, 2011). There is a lack of elaborate water services and hence the load of supplying water closer to users is currently fulfilled by boreholes (Oyem *et al*, 2015). WHO (2014) report shows that anthropogenic activities are the major contributors to increased quantities of heavy metals in water sources.

Ongata Rongai has several quarries in site and the increase in population has contributed to the increase in amounts of domestic effluent which is mostly disposed off by the use of septic tanks (Abong'o *et al*, 2017). Septic tanks, as well as other anthropogenic activities, have been known to contribute to increasing quantities of heavy metals in water (Sawere *et al*, 2016). Therefore, the quality of drinking water and its heavy metal concentration detection are essential in maintaining human health (Dusa *et al* 2017).

The establishment of heavy metal levels in the borehole water in Ongata Rongai, Kajiado County will dispense beneficial information on water quality in terms of the heavy metal content. The data obtained from this study will be used to advise the borehole owners and authorities in Kajiado County on quantities of heavy metals in water from the selected ten boreholes. The results will be used as baseline statistics on the concentrations of heavy metals in the selected borehole water for future reference by other researchers.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1: Groundwater

The precise technical elucidation of the term groundwater is any water that is under the surface of the Earth (Uliana, 2012) and this comprises of;

(a) The precipitation confined in the spaces between soil particles

(b) The fresh to moderately salty water in saturated soil layer at the surface, utilized for domestic and farming needs.

(c) The exceedingly brines analogous to petroleum deposits and deep sedimentary units

(d) The moisture found in the lower interior of the earth.

There are a lot of trace elements that exist naturally in groundwater, in levels of less than 0.1 mgl^{-1}. Among them are heavy metals that are poisonous in low levels. These elements are usually not scheduled for analysis, unless under specific circumstances.

Composition or quality of undergroundwater are dependent on:

- Constituents of the soil (humus, organic and inorganic matter such as (Fe^{2+}, Mn^{2+}, NH_3, H_2S, CH_4, HCO_3^-, SiO_2, and F^-);
- Contaminants from the environment such as sludge, industrial waste;
- Water quality to be infiltrated (rain, surface water)
- pH
- The undergroundwater retention time.

The constitution of undergroundwater is impacted by anthropogenic activities such as agricultural, industrial and house-hold activities. Shallow aquifers are the most affected by these activities, (WARSEB, 2002).

Groundwater flows freely and subtly along the hydrological gradient through tiny pores and cracks in the rock in the aquifers. It is a natural water reservoir that is part of the hydrological cycle, and which has been uncared for by authorities and the developing communities at a moment when concern for the water sector as a whole are crucial (Mumma *et al*, 2001). In their report Mogaka *et al* (2006) highlighted that contamination of groundwater can result to degraded quality of drinking water, diminished water supply, deteriorated surface water systems, and/or potential health problems as such there is need to evaluate the quality of water.

Safe drinking water is a fundamental necessity for a person's growth, good health, and well-being, it is a basic human right (WHO, 2001). Chemical impurities such as heavy metals and pesticides in drinkable water are always overlooked and less prioritized as compared to the microbial contaminants. Detrimental health effects caused by chemical contaminants are usually realized after prolonged subjections, while the impact of microbial pollutants are almost instantaneous. All the same, chemical impurities in water sources could be fatal (WHO, 2007). Adika *et al* (2018), concluded that water in Kakamega county from some of the sampled boreholes was unfit for consumptions as the it contained lead, mercury and arsenic to be slightly above WHO recommended levels. Following this conclusion it is advisable to assess levels of heavy metals in groundwater.

The plentifulness of poisonous substances in drinking water may be carcinogenic as well as cause severe illnesses (Ikem *et al.*, 2002). Epidemiology has found a compelling relationship between the origin of some ailments in human beings, for instance, cardiovascular illnesses, kidney-associated defects, neurocognitive defects and various types of cancer with the availability of some heavy metals for instance cadmium, mercury and lead (Al –Saleh and Al- Doush, 1998). As such, there is need to assess level of heavy metals in drinking water, to ensure that Ongata Rongai residents have acess to safe drinking water. A study done by Muraga *et al* (2017), in Athi River Sub-catchment areas, Kenya revealed that manganese, lead and zinc levels were above WHO recommended levels.Considering the health effects posed by these metals, there is need to assess quality of water.

Research done in Dhampur Region, India by Matta *et al* (2016), about Impact of industrial effluent on ground water and surface water quality showed that the water was was severely polluted by heavy metals and they concluded that people who depended on the polluted water were prone to health hazards of polluted drinking water and further suggested that water quality management was needed. It is therefore important to assess the levels of heavy metals in water.

There are primarily two types of aquifers defined by their formation, confined aquifers, and unconfined aquifers, Nairobi Aquifer System (NAS) is a confined aquifer. The main aquifer beneath Ongata Rongai is the NAS that flows from Naivasha to the Tana Athi basin and being a confined aquifer (Figure 2.1), it means that the chances of pollution are low as stated by the Water Resource Management Authority (WRMA, 2010).

Ongata Rongai town covers an area of about 39.5 km^2 as indicated in 2019 Kenya Population and Housing Census report (GOK 2019) and had 510 boreholes as of 2009 and the number is still rising as demand for the population grows (WRMA, 2010). The vulnerability of the Nairobi aquifer system (NAS) to pollution is low, surface water interaction is significant with a base flow of 35 % to 45 % of the total flow making it susceptible to depletion and a moderate effect on quality because of abstraction (WRMA, 2010). Figure 2.1 shows a schematic diagram of confined and unconfined aquifers.

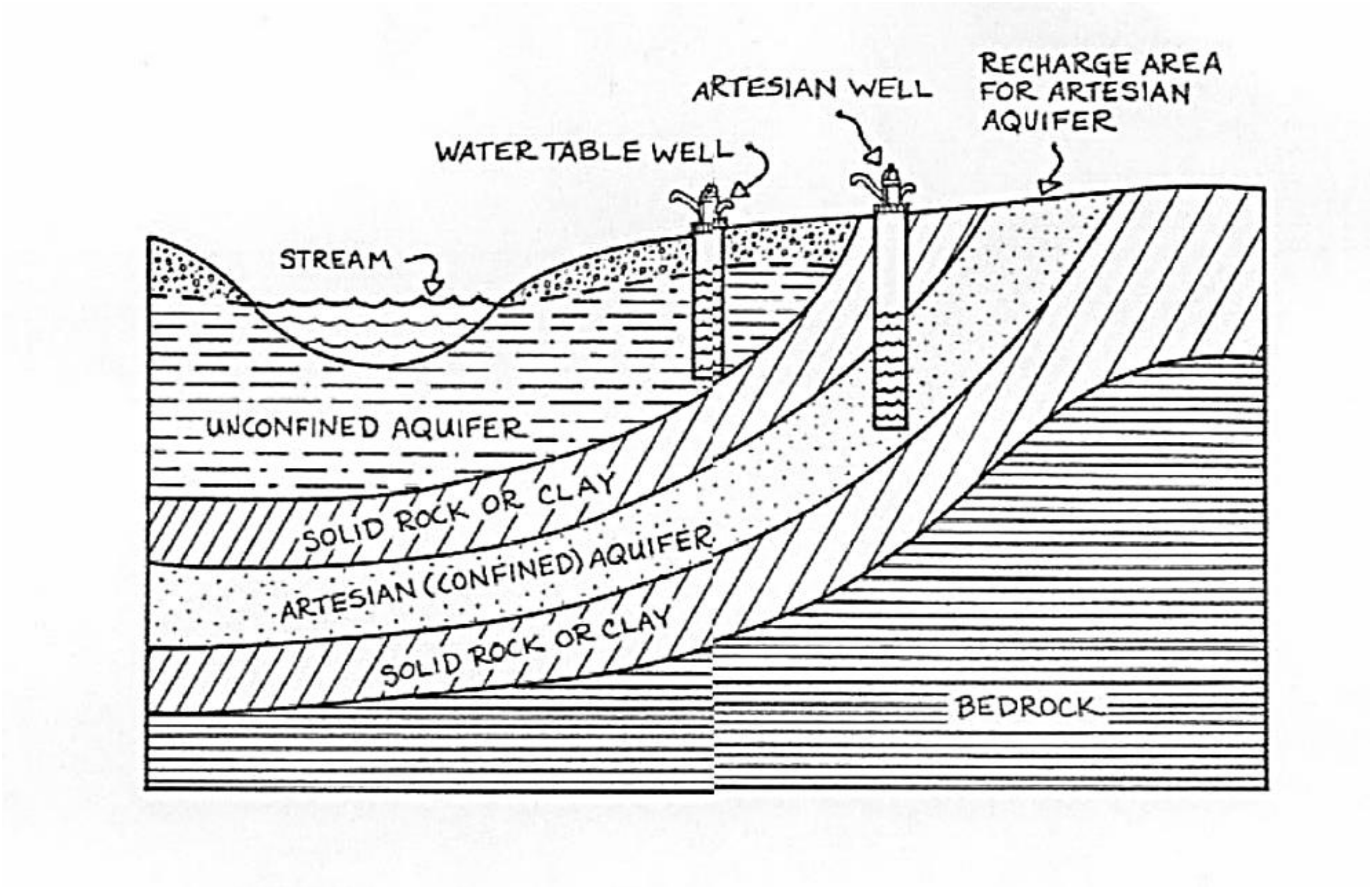

Figure 2.1: Schematic diagram showing confined and unconfined aquifers (Freeze *et al*, 1979)

Groundwater contamination, as an aspect of environmental pollution, occured when a contaminant released into the subsurface environment reaches the aquifer as a plume, where it moves in the same manner as the undergroundwater, depending on the type of contaminant; physical, chemical or biological contaminant, its solubility in water, density of the contaminant, the amount and the velocity of the surrounding groundwater, which is very slow, thus contaminants persist in the aquifer for prolonged periods (USEPA, 2002).

The importance of water in all aspects of life cannot be emphasized enough, (Mohankumar *et al*, 2016) further explained that the quality of water from boreholes determined its domestic use, crop farming or livestock watering. As such, water is said to be polluted when foreign materials or substances are introduced to it hence making it unsuitable, (Haseena *et al*, 2017) added that such substances reduced the quality of water making it deleterious to human health and the surrounding.

Singh *et al* (2017) point out two categories of water contamination; point and non-point pollution. The point sources deliver pollutants directly into water sources, for instance, domestic and industrial effluents (Abong'o *et al*, 2017), usually point sources are known. On the contrary, non-point sources are indirect and unmanageable. They included runoffs from disused mines, leaks from landfills and mostly non-points sources that were not easily identifiable as they camr from a wide area.

Mohankumar *et al* (2016) explained that pollution of groundwater was a major problem as it was very difficult to eliminate the pollutants in groundwater. The pollution of groundwater was either by natural sources or anthropogenic activities (Freeze *et al,* 1979). Water pollutants could be broadly classified as; industrial, agricultural, sewage effluent, thermal and radioactive.

Water is an invaluable and vastly utilized asset (Ramesh and Elango, 2014). It's among the most plentiful compound on earth and envelops about 71% of the earth's surface (Ramesh and Elango, 2014). Bresline *et al*. (2007) and the National Academy of Science (NAS) (2009), reported that more than a billion people have limited access to clean drinkable water. The obtainable drinkable water to the population is about 0.3 - 0.5% of the water found on the earth and its cautious utilization is vital (Ganesh and Hedge, 1995). The bulk of the population who reside in the countryside are poverty-stricken; most prone to lack of drinkable water (MacDonald and Calow, 2009). Ahaneku (2014) reported that governments all over the world were facing challenges in providing clean, dependable and transportable water to the people in rural areas as well as urban slums. Lack of clean water makes people susceptible to bad health and impoverished livelihoods (Ahaneku, 2014).

A load of bringing water proximal to the users is lessened by wells that draw from the undergroundwater. These wells are usually of great depth (more than 100m), constrict, drilled mechanically and are fitted with electric pumps to obtain water from undergroundwater repositories. (Tularam and Krishna, 2009) Groundwater is an invaluable tucked-away natural asset (Lashkaripour and Ghafoori 2011) that is available in most surroundings and needs no pre-treatment and is always closer to the areas of need at minimum cost (MacDonald and Calow 2009). Groundwater is customarily believed to be of good natural quality since it comes from its geological surrounding (Tularam and Krishna, 2009), however, MacDonald and Calow (2009) contradicts that by stating that natural undergroundwater is sometimes of poor quality.

The report from WHO (1984) indicated that water as a universal solvent, dissolves several chemicals and thus have impurities that could be detrimental to human health if it is above allowable limits. The groundwater as a resource is vulnerable considering its potential to provide large volumes of water and as a result, pump out tenacious pollutants (MacDonald and Calow 2009). The quality of groundwater in nature varies depending on the rock type within the aquifers along its flow channels. The likelihood for chemical interaction between the water and rock material where it passes is dependent on the direction of its flow (Lashkaripour and Ghafoori 2011), chiefly because the undergroundwater moves slowly (MacDonald and Calow 2009). Adulteration of quality of groundwater could be through pollution of the local undergroundwater, or immediate adulteration of the water source itself (MacDonald and Calow 2009). Pollutants possess the ability to move perpendicularly towards the aquifer and then to the borehole, or more hazardously, straight by seeping through soils around badly built wells (MacDonald and Calow 2009).

Undergroundwater can be polluted by natural means and human activities (Idoko, 2010). Heavy metals are categorized as chemical pollutants of groundwater and drinking undergroundwater and surface water tainted by heavy metal ions is harmful to the well-being of people (Ohwoghere, 2012). Metal pollutants are of great concern in a lot of water sources around the globe as reported by United Nations Environmental Programme, 2007. Most calamitous illnesses related to the undergroundwater usage have been attributed to heavy metal pollutants.

Water is vital for life but it is capable of transmitting diseases all over the world amongst all walks of people (WHO, 2010). That said, WHO (2010) many people are susceptible to perilous concentrations of pollutants in their drinking water. It’s imperative to monitor metal levels in surface or groundwater supplies to provide the baseline data required to evaluate the aptness of water resources for human use (United Nations Environmental Programme, 2007).

In Ongata Rongai, Kajiado County, groundwater is the greatest source of water for the population (Abong’o *et al*, 2017). This resource is widely utilized without assessing its quality yet it is crucial to be conscious of the undergroundwater resources to ascertain that it is good for human consumption and to conserve the water sources from pollution (MacDonald and Calow 2009). The compelling demand for water gives priority to the development of boreholes disregarding quality of groundwater research. The persistent use of untreated and perhaps polluted groundwater poses short or long term (or even both) health risk to the population.

Many studies have been done to establish the manifestation and regulation of heavy metals in undergroundwater and drinking water. Momodu *et al*, (2010) had evaluated the undergroundwater pollution by heavy metals Pb, and Cd and Aluminum in Nigeria, and found that 98% of the boreholes water analyzed had high levels of Lead and Cadmium that were of health hazard to the consumers. Momot and Synzynys (2005) studied hazardous aluminum and heavy metals in undergroundwater of middle Russia and the findings revealed heavy metals (Hg, Cr, and As) in the samples tested. Batayneh (2010) researched on heavy metal levels in water springs of the Yarmouk Basin (Jordan) and findings of the research revealed that Yarmouk Basin in North Jordan is polluted by heavy metals that might negatively impact on the health of the ecosystem. In other related studies Hassan *et al* (2017) researched on Seasonal Variations in Water Quality Parameters of River Yamuna, India and concluded that the water quality was degraded and it was a potential health risk hence there is need to assess quality of water used.

Iqbal and Gupta (2009) and Rajappa *et al,* (2010) analyzed the heavy metal pollution of undergroundwater in India and reported the presence of some heavy metals in undergroundwater samples. Since 97% of all freshwater is groundwater it should be well managed and quality monitored regularly. As part of the hydrological cycle, vapor from the surface water including oceans precipitates to the earth's surface in a pure state and percolates into the earth beneath the ground through soil pores and rock fissures and is accumulated within the aquifers (Fischer *et al*, 2003). It is from the aquifer that the resource is harnessed by boring a hole deep enough to reach the aquifer and pumping out the water. This shows that the quality of surface water should be as good as the groundwater, however because of human activities, the possibility of pollution or contamination of water in the subsurface environment is of great concern throughout the world.

2.2 Sources of groundwater pollution

2.2.1: Improper disposal of hazardous wastes

Dangerous waste should be handled by licensed or authorized persons and disposed of properly. There are household products that are not supposed to be discharged into septic systems, e.g. oils (e.g., for cooking, motor), lawn and gardening chemicals, petrochemical solvents, disinfectants, some pharmaceutical formulations, heavy metal formulations like photographic and swimming pool chemicals high in chlorides. Comparably, several substances utilized in industrial effluents should not be discharged into drainages at the workplace due to the ability to pollute groundwater as a source of drinkingwater (Elbeshbichy and Okoye, 2019).

2.2.2: Emissions and spills from reserved chemicals and petroleum products

Underneath storage tank may develop a leak, which usually is the case as the tank gets old and degrades, its content like leaded fuel, can seep through the soil and get to the undergroundwater. Some unused underground tanks are a serious risk since their site may be undisclosed. Overhead storage tanks are equally a danger to groundwater if they leak or spill and sufficient measures are not employed at the site of the spill, the substances often percolate into the soil, heightening the probability of undergroundwater pollution (Elbeshbichy and Okoye, 2019).

2.2.3: Landfills

Solid waste emitted in municipal and industrial landfills countrywide may contain substances that should be thrown away into hazard waste landfills or by incineration may find their way in municipal landfills (Tsuma *et. al*, 2016*)*. Regulation of disposal of house-hold waste has not been done. Once in the landfill, toxic substances percolate into the undergroundwater through rainwater and runoffs. Ideally, landfills should possess clay or fabricated liners and leachate (fluids from a landfill having pollutants) collection systems to guard the undergroundwater, but many of these landfills lack these safeguards, to stop the percolation of pollutants by precipitation (Tsuma *et. al*, 2016*)*.

2.2.4: Surface impoundments

These are shallow depressions employed by industrial entities as well as municipal councils to hold, treat, and release waste containing free liquids posing a risk to the subsurface water (Tsuma *et. al*, 2016)

2.2.5: Septic tanks, sewers and other pipelines

Septic tanks and sewer pipes ferrying waste may leak liquids into the environment. Sewage constitutes of organic matter, inorganic salts, heavy metals, bacteria, viruses, and nitrogen. Corrosive substances from industries being transported by pipelines have been found to leak after corroding the pipes and seep into the surrounding environment (Njar *et al*, 2012)

2.2.6: Pesticide and fertilizer use in agriculture

A lot of fertilizers and pesticides are utilized every year. A number of them ingress and pollute undergroundwater, even when properly applied, others accumulate in soil and water for long periods of time (Abu Zeid and Biswas, 1990). Another prospective origin of undergroundwater pollution is wastes from animals that seep underground from farm feeding areas or as manure (Abu Zeid and Biswas, 1990).

2.2.7: Improperly constructed wells

Improperly constructed boreholes (Figure 2.2) can lead to groundwater pollution when adulterated surface or groundwater is introduced into the borehole (Canter and Knox, 1985).

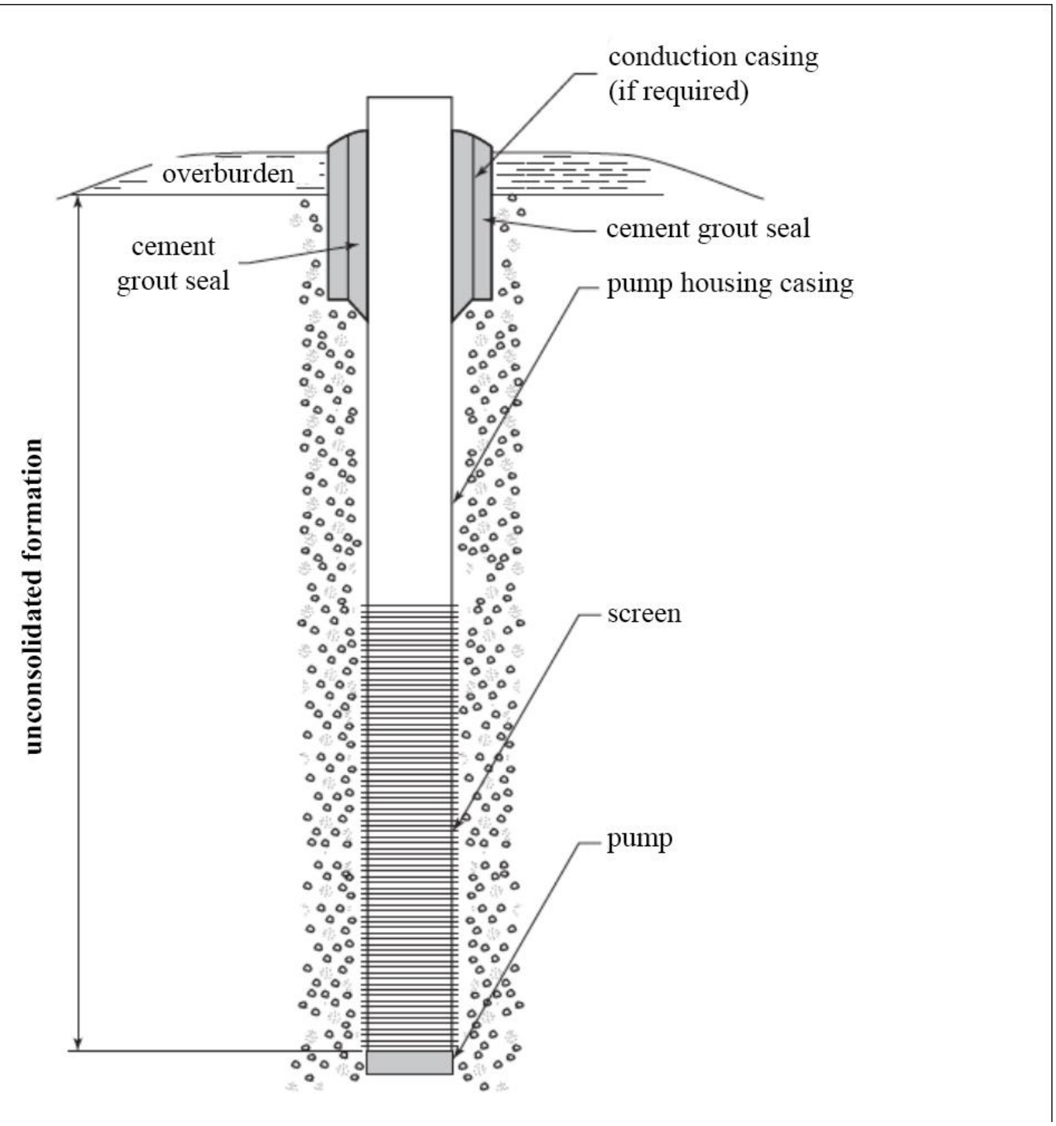

Figure 2.2: Borehole construction design (Akudago et al, 2009).

Poorly constructed wells and also poorly left wells may serve as a means by which pollutants can get to an aquifer if the case of the well has been done away with, as usual, or if it is worn out. Besides, others utilize disused boreholes as disposal points of wastes for instance old engine oil. These boreholes may stretch to an aquifer that replenishes drinking water wells and lead to groundwater pollution. Construction challenges, for instance damaged cases, inadequate covers, or absence of concrete pads, permits runoff water and any pollutants therein to enter into the borehole (CDC, 2009 https://www.cdc.gov/healthywater/drinking/private/wells/location.html**)**

Wastes from farm animals and septic tanks may constitute pollutants in surface runoffs. Water quality may be degenerated by contaminated fill packed around a borehole.

2.2.8: Mining activity

Active and abandoned open-pit mines (for instance stone quarries), and artisanal mines can promote groundwater pollution. Disused mines may be utilized as wells and waste pits, sometimes simultaneously. Mining or quarrying process is complicated as it leads to environmental degradation as it damages the vegetation cover and also influences the quality of surface and groundwater. The mining waste; gaseous, particulates, liquids, as well as a number of compounds having trace hazardous substances contaminate the surrounding. (Hine *et al.*, 2002)

2.2.9: Boreholes sites

The borehole's safety and effectiveness depend greatly on its site. It is vital to maintain safe distances between private groundwater wells and possible sources of contamination (EPA, 2000).

2.2.10: Septic tanks as a source of groundwater contamination

Human excreta contains traces of heavy metals, in feces and in urine, which have a characteristic of accumulation in the soil, sediment, and would eventually reach the groundwater, from within 3 days to months and therefore the recommended distances of septic tanks from boreholes is 50 feet or approximately 15 m according to WHO (2006).

The maintenance, design and improper use of the septic tank-soil absorption systems in a densely populated place with a high rate of sewer generation pose a risk to the groundwater quality. The government regulations for sizing and design of septic tank requires that for a 20 block apartment with 2 occupants per unit, the capacity should be 2400 L per day which would mean about 3m deep by 1.5 meters which make it easier to maintain when inspecting to check and repair cracks in the impermeable concrete lining or wall, which would cause sludge to leak, or even the efficiency of sludge suction pumps due to high head or depth (Canter and Knox, 1985). Unfortunately, some private developers dig too deep due to space constraints, within the flat and also to cut down on the cost of regular pumping of sludge. If sludge builds up then it overflows into the soak pit (soil absorption field) polluting the soil and consequently the groundwater, especially where the water table is high (<100 m), shallow aquifers are most vulnerable (Figure 2.3). Improper use of the septic tanks by disposing of hazardous wastes containing heavy metals or highly acidic wastes lowering the pH, making the free ions mobile in solution, combined with poor design and poor maintenance makes the use of septic tanks risky to the groundwater. There is a need to educate property owners on the importance of groundwater protection and also regular borehole water quality monitoring because the residents depend on the same boreholes for domestic water uses, (Eze and Eze 2015).

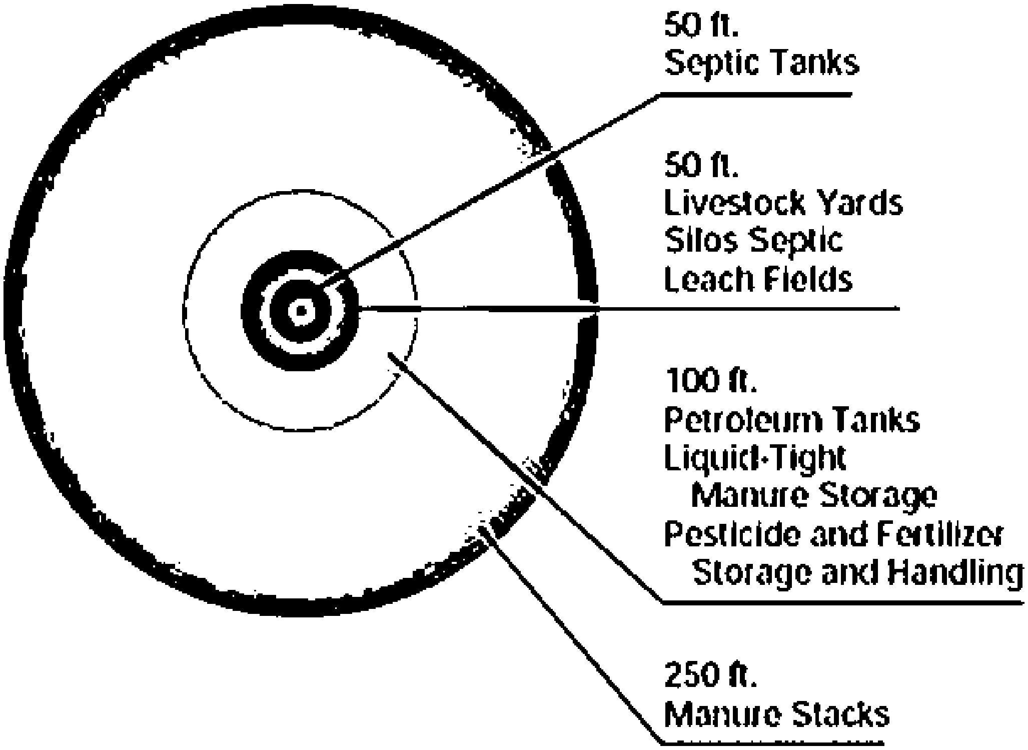

Figure 2.3: Recommended distances of boreholes from possible sources of contamination (CDC, 2000)

Groundwater contamination is mostly due to anthropogenic activities. In densely populated areas where land is intensively used, groundwater is susceptible to pollution. Nearly, any event where substances or waste may be emitted to the surrounding, either deliberately or fortuitously, has the ability to contaminate groundwater, including toxic heavy metals (Momodu *et al*, 2010). Heavy metals comprise of a poorly elucidated categories of inorganic poisonous compound, and abundantly found at polluted areas are Pb, Cr, As, Zn, Cd, Cu, Hg, and Ni (Evanko and Dzombak, 1997).

Human practices such as mining, agriculture, solid waste in landfills, domestic wastewater; sewer, sewerage sludge, open stormwater drainage, seawater infiltration due to over-abstraction or climate change. In most cases groundwater pollution depend on activities on the surface that pollute the soil or the strata above the water table, and as a result gain access to the aquifer (Figure 2.4).

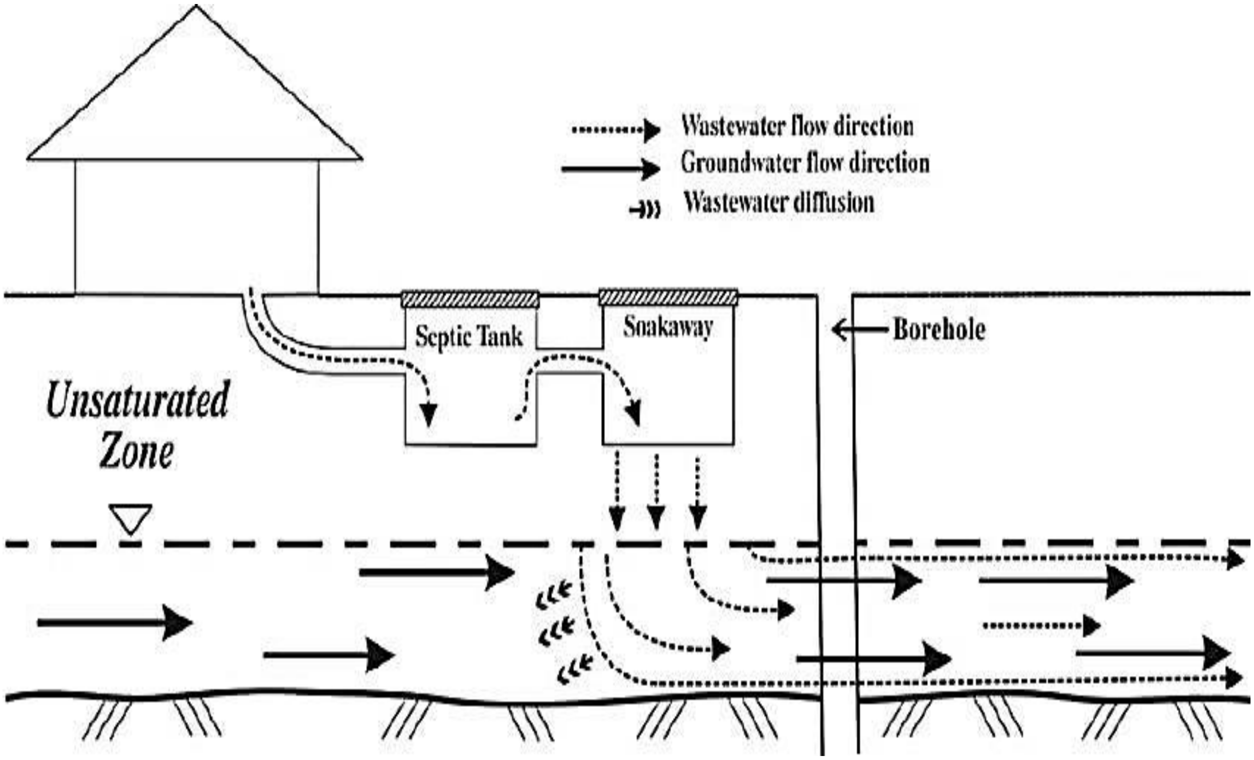

Figure 2.4: Septic tank soakway system, wastewater flowing into a borehole (Tilley et al, 2014)

Domestic water uses can be a source of pollution in groundwater (Figure 2.5). Domestic effluent from indoor and or outdoor use can avail contaminants when wrongly disposed into the environment (Hassan, 1974). Most domestic or household products contain harmful substances including chemicals, for example, heavy metals, high or low pH wastes, particulates, and colloids whose fate could either be in the surface streams, surface run-off, in septic tanks, landfills and ultimately in groundwater or the ocean as a sink for the contaminants, thus affecting the levels of normal chemicals and Physico-chemical aspects of drinking water quality from the wells (Figure 2.5).

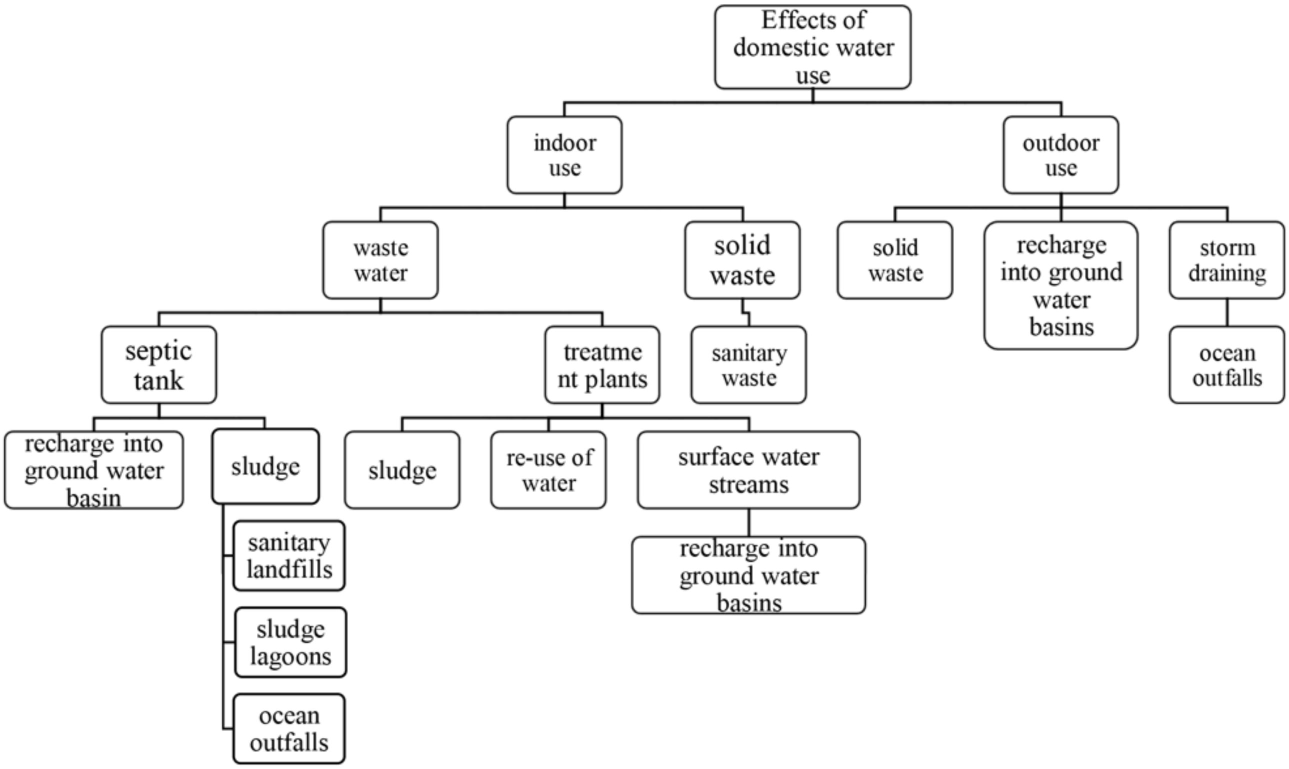

Figure 2.5: A flow diagram showing effects and fate of domestic water use (Hassan, 1974)

2.3: Heavy metal pollution

Heavy metals occur naturally in the soil surrounding during pedogenisis at trace levels (<1000 mg/ kg) and are rarely poisonous (Pendias and Pendias, 2001). Heavy metals are scarce and their levels in natural, non-reduced undergroundwater are mostly less than 1ppm hence, categorized as trace elements. Iron and manganese are most abundant and higher in concentrations. In comparison, the other elements are naturally low in concentration usually below 50 ppm. Assessment of any of these elements to determine whether the levels are higher or any probable anthropogenic influences, analytical methods using low detection limits are employed (Fresenius, 1994).

Heavy metals are injurious due to their bio-accumulation nature. Substances amass in biota every time they are ingested and reserved quickly than they are assimilated then released into the surrounding. Heavy metals infiltrate into the water sources through the discharge of industrial and domestic effluent, or even as a result of emitted heavy metals due to acidic rain breaking down soils.

Their bioavailability is dependent on physical parameters for instance; pH, oxygen content, temperature, phase association, adsorption and sequestration (Hamelink, 1994). As concluded by Wang (2001), metal ions interrelate with cell constituents for instance DNA and nuclear proteins resulting into DNA changes and conformational transformations that could lead to cell modification, cancer or cell death.

Leachate from landfills that contain a particulate form of heavy metals and in low pH conditions, percolate to the groundwater in an ionic state, especially during the rainy season, as borehole recharge. The historical use of land, for example, application of natural manure and artificial fertilizers, over time contaminates the topsoil as the trace metals accumulate in the soils and eventually percolate to shallow water tables. Mining and quarrying activities would damage the integrity of the rock structure during blasts to extract minerals and building material, causing cracks that allow direct pollution from the surface. Disposal of leaded fuel, use of leaded paint and wastewaters from industries, onsite wastewater disposal systems like septic tanks, pit latrines and cesspools have been pointed out as a major origin of undergroundwater pollution in the current age, since the population density is increasing faster than the development of sewerage infrastructure (Fugusson, 1990), as is the case in Ongata Rongai town.

In his thesis, Kalis (2006), showed that the whole metal content of the soil or level of total metal in the soil solution or surface waters is not the best measure of metal availability to organisms; the free metal ion content is the determinant in heavy metal intake and is the one that binds at an organism's surface.

The levels of these metals in soil relies on their relation with soil the component (clay minerals, organic matter, and oxyhydroxides of Fe and Al), pH, and redox potentials e.t.c. The metals can be adsorbed on soil colloids (silicates, organic matter, oxyhydroxides of Fe and Al), then eroded and leached to the surface and groundwater, respectively, or be absorbed by plants growing on the polluted areas. Buildup of these heavy metals in the soils, surface, and groundwater, as well as plants, present a huge danger to animal and people's health. Toxic and mobile heavy metals depend on their species and other soil properties (Mdlambuzi, 2014). Trace elements, like copper and zinc are important in maintaining the metabolism of the human processes. Nevertheless, at elevated levels, they can result to detrimental effects on human health.

2.4: Physico-chemical parameter

2.4.1: pH

The pH is said to be a measure of hydrogen ion concentration (APHA, 1989) is calculated as logarithm of the reciprocal of hydrogen ion as shown in equation (2.1)

$$pH = -\log (H^+) \qquad (2.1)$$

The activity of the hydrogen ion in diluted solutions is almost equivalent to its concentration. The acid-base equilibrium is used to estimate the pH of water in nature, it is taken care of by the carbon dioxide–bicarbonate–carbonate equilibrium system. Carbon dioxide levels are indirectly proportional to pH values. The temperature has been known to impact on the equilibria and the pH. A reduction in pH of about 0.45 is observed when temperature of pure water is increased by 25°C. The effect of temperature is amplified in water with a buffering capacity conferred by bicarbonate, carbonate and hydroxyl ions, (APHA, 1989). Water mostly used for drinking has the pH recorded to be within the range of 6.5–8.5. Lower pH has been found in natural waters and this is due to acidic rain or may be higher in areas with limestone.

The pH is a vital property in water quality checks and has no identified consequence on users. Failure to minimize corrosion may lead to poisoning of drinking water and have deleterious impact on its flavour and outlook. The recommended pH values varies in various sources as per the constituent of the water and the type of the medium employed in the construction of the distribution system, however, it ranges from 6.5–8.5, (WHO 2006).

The pH of an aqueous sample is determined by an electrometric technique using a glass electrode. The temperature possesses an important effect on pH determination (ASTM, 1976; APHA, 1989). The pH is crucial in the assessment of the corrosivity of water, however, the association with many other properties is complex. The extent of corrosion is determined by the constituents of natural waters namely, gaseous matter, colloids and different types of electrolytic and non-electrolytic substances, and the pH. There is a high possibility of corrosion when the pH is lower. (Langelier, 1946)

2.4.2: Electrical conductivity

Conductivity is a determination of the capability of a material to pass electrical current (USEPA, 1986) and it depends on the availability of inorganic dissolved solids such as chloride, nitrate, sulphate, and phosphate anions (that is; negative ions) or sodium, magnesium, calcium, iron, and aluminum cations (that is; positive ions). Organic substances for instance oil, phenol, alcohol, and sugar are poor conductors of electric charge and hence have a poor conductivity when in water. Conductivity is a non-specific measurement of the ionic species available in the water sample, which can be used as a screening tool for brewery waters. The temperature affects conductivity: for instance, it increases with increase in temperature as a result, conductivity is recorded at 25 ^{0}C (USEPA, 1986).

Conductivity is determined using a conductivity probe and a meter. The principle of operation of the conductivity meter is that the voltage is exerted between two electrodes in a probe dipped in the water sample. The resulting reduction in voltage as a result of the resistance of the water gives the conductivity per centimeter. The probe measurement is converted to microsiemens per centimeter (or micro-omhs per centimeter) and shows the result for the analyst to record. The recommended levels by WHO are 500 µscm^{-1} (WHO, 2008), while KEBs limits are 1000 µscm^{-1}.

2.4. 3: Total dissolved solids

Generally, WHO (2003) describes total dissolved solids (TDS) as inorganic salts and small amounts of organic matter present in solution in water. TDS level below 600 mgl^{-1} is acceptable; drinking water is more unsavory at TDS levels larger than 1000 mgl^{-1}. Increased levels of TDS may be not agreeable to the users, as a result of increasing scaling in water pipes, heaters, boilers, and household appliances. There's no proposed health-based guideline value for TDS (WHO, 2001)

2.4.4: Total suspended solids

Total Suspended Solids (TSS) and Turbidity are unique evaluations that give the same findings of the quality of water. TSS is the determination of the mass of solids found in a volume of water and describes particulates of varied sources, including soils, metals, organic materials and debris that are suspended in water (WHO, 2008). There is no guideline provided by Kenya Bureau of Standards (KEBS) Standards however WHO sets it at 500 as obtained from WHO (2006). The presence of TSS in water makes it less appealing to the eye.

2.4.5: Dissolved Oxygen

Induced infiltration of stormwater in urban areas into the earth is popularly utilized as a substitute to its direct release to rivers (Pitt *et al*., 1999; Dechesne, 2002; Fischer *et al*., 2003). Rainwater percolation ponds are required to make up for decreased undergroundwater refueling due to covering of the urban terrain and are made to improve the holding and degeneration of pollutants in the soil and unsaturated zone (Chocat, 1997; Fujita, 1997; Mason *et al*., 1999). Moreover, refill of undergroundwater with toxic rainwater may elevate the flux of dissolved oxygen (DO), thereby re-oxygenation of shallow water-table aquifers that often have reduced DO levels (Starr and Gillham, 1993; Malard and Hervant, 1999; Chapelle, 2000).

The content of dissolved oxygen in water is dependent on the origin, raw water temperature, treatment and chemical or biological processes occurring in the distribution system. No health-based guideline value has been suggested. Nevertheless, very high levels of dissolved oxygen may worsen the degradation of metallic pipes. Oxygen's limited solubility, as described by Henry's law, is directly proportional to atmospheric pressure and inverse to water temperature and salinity. In dilute solutions at sea level, the solubility of oxygen ranges between 10.0 ppm and 7.0 ppm at temperatures ranging between 15 °C to 31 °C (APHA 1981). The most important chemical characteristic is its ability to accept electrons from (oxidize) other species in water. Dissolved oxygen concentration should be considered a crucial parameter in any investigation of contamination of groundwater, especially those which involve the movement of landfill leachate or wastes from minefields (Wilson and McNabb 1983).

Dissolved oxygen is commonly measured by the modified Winkler titration method and /or with a dissolved oxygen electrode according to APHA (1981). In the field conditions, both the accuracy and detection limit are approximately 0.2 mgl^{-1} (Winograd and Robertson (1982). The solubility of oxygen is directly proportional to the hydrostatic pressure. In dilute solutions, dissolved oxygen has relatively little or no significance for other water uses (APHA, 1981). Forms of water use give cursory consideration include drinking water, recreation, aesthetics, and industry. The concentration of oxygen in water affects the availability of metals in solution. (APHA 1981).

2.4.6 Turbidity

WHO (2017) defines turbidity as describes the cloudiness of water as a result of suspended particles such as clay and silts, chemical precipitates such as manganese and iron, and organic particles such as plant debris and organisms. The degree of turbidity of water is often taken to be an approximate measure of the extent of pollution. However, it is not the only measure when determining the presence or absence of pollution. This is because water may be clear but is contaminated by acids, toxic metals or other substances that do not cause turbidity. Following rainfall, variation in color of the water may indicate contamination due to surface runoff and may lead to the need for treatment before use especially for public supplies (Spellman, 2003).

The Kenya Standard (KS) (2007) and WHO (2008) guidelines value for turbidity is 5 (Nephelometric Turbidity Unit) NTU and above this value, water can be objected for aesthetic value. Turbidity above 5 NTU may be discernible to consumers. Suspended or colloidal particles impede the transmission of light through water hence causing turbidity. Inorganic or organic matter or both may cause turbidity. Microorganisms, (bacteria, viruses, and protozoa) are found to adhere to particles, and reducing of turbidity by filtering greatly lessen microbial pollution in water that has been treated. Inert clay or chalk dust or the precipitates of insoluble reduced iron and other oxides may reduce turbidity in some groundwater drawn from anaerobiotic waters, while in surface waters it may be due to particles of different types and mostly may have microorganisms attached to them that are detrimental to health. Turbidity in distribution systems may occur as a consequence of perturbation of sediments and biofilms as well as from the entry of dirty water from the exterior systems.

Besides, the efficiency of disinfecting water may be influenced by turbidity which protects the organisms, as water treatment processes are geared towards the extrusion of the particles before sanitization. This will elevate the efficiency of sanitization by chemicals such as chlorine and ozone but also is a vital process in ascertaining the efficiency of physical purification processes like ultraviolet treatment since the particles block the transmission of light through water.

Turbidity may interfere with the consumer's judgement of how suitable the water is for consumption as visible cloudiness is unattractive. Turbidity itself (for instance from undergroundwater minerals or post-precipitation of calcium carbonate from lime treatment) presents no health risk, it is an imperative indication of availability of impurities that would be of worry to health, particularly from insufficiently treated or un-filtered surface water. Statistics showing an increased danger of gastrointestinal infections that are consistent with high turbidity and turbidity occurrences in the distribution. Turbidity is recorded in NTU and can be at first observed by the naked eye when above 4.0 NTU. However, to ascertain that disinfection was efficient, the turbidity should be under 1 NTU and as recommended by (WHO, 2001) it should be much lower.

2.5 Heavy metals and their health effects

2.5.1: Zinc

Zinc (Zn) is usually found in 0 and +2 oxidation states. Anions, amino, and organic acids readily complexes with Zn. Zn is bioavailable usually at high pH and it is easily hydrolyzed at pH from 7.0 to7.5, to form $Zn(OH)_2$. Zn easily forms precipitates under reducing conditions and may co-precipitate with hydrous oxides of iron or manganese" (Hashim *et al*, 2011). Zinc adds an unpleasant flavour to drinking water at a minimum level of about 4 mgl^{-1} (as zinc sulphate). Water with zinc at concentrations over 3–5 mgl^{-1} may appear prismatic and an oily film may be formed on boiling (Jeje and Oladepo, 2014). Although drinkable water rarely has zinc at levels over 0.1 mgl^{-1}, however, in tap water it may be significantly higher due to the zinc contained galvanized pipes; Zn contamination is a precursor of increased cadmium levels from much older material.

Zinc is a vital trace mineral that we obtain from our diet. Other than iron, zinc is in abundant trace chemical in the body and is a constituent of every cell and an essential food element and a coenzyme in cells, required in small amounts, for example, in men, 15 –20 mg/day (WHO, 2008). Zinc curbs the poisonous nature of cadmium from happening in the body, as a result, expends the level of zinc. Cadmium utilizes zinc in high amounts if it's present in the body. The need for zinc tends to grow if the diet has elevated levels of Cadmium.

In large quantities, Zn may cause nausea and vomiting in children. As well as cause anemia and cholesterol problems in human beings. "Major sources of Zn include; mining and metallurgical processing of zinc ores and its manufacturing applications. (Gautam *et al*, 2014) also found out that Zn may be found in our environment from the burning of coal". Currently, no proposal of value set as a base guideline for zinc in drinking water. Zinc levels in natural surface water is often lower than 10 µg/litre, while in undergroundwaters, 10–40 µg/litre.

Zinc deficiency has far-reaching implications, ranging from damaged neuropsychological functions, retarded or stunted development, hindered reproduction, immune diseases, dermatitis, poor wound healing, fatigue, anorexia and baldness (FAO, 1998). Lack of zinc in farming soils is a global concern, impacting both farm produce and quality. Expectant women of all ages in low income areas are most affected by Zn deficiency than it does the rest of the population and the outcome of pregnancy in this demography can be enhanced by taking zinc supplements 25 to 30 mg daily (Osendarp, 2001). Groundwater has been found to have zinc radioactive isotopes, the origin is erosion and decomposition of natural deposits having other radioactive elements (Oves *et al*., 2016). However, it is not scheduled as a toxic contaminant by the WHO criteria for toxic heavy metals.

2.5.2: Mercury

The hazardous nature of mercury has been studied widely and in our environment, mercury (Hg) is found in three oxidation states; 0, +1 and +2. Mercury can be found in the alkylated species (methyl/ethyl mercury) depending on alkalinity of the system. Hg^{2+} and Hg_2^{2+} are stable under oxidizing conditions.

Levels of mercury in rainwater may vary from 5–100 µg/liter, however, quantities as little as 1 µg/litre have been recorded (IPCS, 1990). In nature, the occurrence of mercury in undergroundwater and surface water is less than 0.5 µg/litre, nonetheless, mineral elements may lead to elevated concentrations in groundwater. Occasionally, mercury may be at higher concentrations in groundwater but usually the levels of mercury in drinkable water normally less than 0.5µg/litre.

Flame Atomic Absorption Spectroscopy (FAAS) used by Japan Water Works Association, 2001, recorded that for organic mercury limit of detection are 5 µg/litre while 0.6 µg/litre by ICP. The catastrophic impact of inorganic mercurial substances are largely found in the kidney. Ulcers in the proximal tubular cells were observed following a single intraperitoneal injection of 1µmol of mercuric (II)-chloride per kg of body mass (0.2 mg/kg of body mass as mercury) in male rats. Building up of mercury in the kidneys, nonetheless, confirmed that the taking up level was greater than that anticipated from the digestive system (Gautam *et al* 2014).

Mercury has been used in the manufacture of light bulbs, batteries, electrical switches and relays, barometers, and thermometers, bulk of which is disposed of in municipal landfills. As characterized by most metals, mercury dissolves readily in acidic leachate and gradually filtrates into the soil and groundwater. Studies have reported that mercury in groundwater may be beyond the acceptable drinking water standards originating from unlined landfills, however, it is least likely to seep into groundwater from landfills which are lined and use leachate collection systems. Despite that, liners and leachate collection systems are not very efficient. Many scientists have reported that liners leak with time (Line and Miklas, 1989; Bonaparte and Gross, 1990). Mercury gets to the body by ingesting, breathing in and absorbing through the skin. Catastrophic effects of its toxicity and acute exposure indications include central nervous system and kidney impairment. Subjection to mercury, causes nausea, unclear sight, laboured breathing, over-salivation, and pneumonitis, while continued longer-term exposure affected parties may exhibit memory problems, high blood pressure, sight impairment, hallucinations, tremors, and mood swings. Mercury affects brain development as it has been found to cross the brain-barrier, its effects are greatly unsettling in expectant, breastfeeding women and young children. Emphasis is put for these groups of people due to worry over growth impairments in babies from mercury exposure (LeBeau, 2008). Studies have shown catastrophic effects of its toxicity for instance mothers who had consumed mercury-contaminated fish were said to have given birth to physically deformed babies (Gautam *et al*, 2014).

2.5.3 Lead

Lead (Pb) largely occurs in two major oxidations states that is; 0 and +1, however, Pb +2 is the most abundant and very reactive form. When Pb complexes with inorganic compounds such as (Cl^-, CO_3^{2-}, SO_4^{2-}, PO_4^{3-}), compounds of low solubility are formed (Hashim *et al*. 2011). The virulence of lead is owed to its ions potential to displace other divalent cations like Ca^{2+}, Mg^{2+}, Fe^{2+} and monovalent cations like Na^+, hence ultimately tampering with the biological activities of a cell (Hashim *et al*, 2011).

Lead is a bio-accumulating hazard, with children under 6 years old, fetuses and expectant women are highly vulnerable to catastrophic health effects. Lead is highly poisonous and its toxicity affects the central nervous system (US EPA, 1986). Visible indications of acute poisoning, consist of dullness, restlessness, bad temperament, lack of concentration, head pains, muscle spasms, stomach pains, kidney impairment, hallucinations, amnesia and encephalopathy, intoxication takes place at blood lead levels of 100–120 μg/dl in adults and 80–100 μg/dl in children. Indications of acute lead poisoning, are: fatigue, insomnia, temperamental, head pains, joint aches, and stomach pains, may manifest in grownups at blood lead levels of 50–80 μg/dl (US EPA, 1986).

In nature, lead occurs in the groundwater as a result of ancient geologic processes that took place very many years ago. The leading lead pollution in drinking water currently is, lead solder and flux commonly used to piece together the copper pipes that replaced lead pipes. Lead is abundant in the environment; air, food, water, soil. The most common cause is corrosion. Dissolved oxygen, reduced pH (acidity) and little mineral content in water are factors may speed up corrosion. Short-term subjection to high quantities of lead result into nausea, loose stool, convulsions, coma or even demise. Initial signs of plumbism in grownups are not specific and include dysthymia, anorexia, intermittent abdominal cramps, nausea, loose stool, difficulties in bowel movement, and muscle cramps (Gautam *et al*, 2014). Other onset symptoms in grown ups are restlessness, tiredness, reduced sex drive, and insomnia. Exposure to reduced levels of lead over a prolonged period has been reported to have devastating effects. High levels of lead results to impairment of the human brain, kidneys, nervous system and rapture of erythrocytes. Lead toxicity may result in loss of blood and hemoglobin in the urine (Foster *et al*., 2002). Lead is carcinogenic (Foster *et al*., 2002).

2.5.4: Cadmium

This metal is mostly found in two stable oxidation states that is; 0 and +2. Its hydroxide and carbonate have been known to have a high pH while Cd^{2+} and aqueous sulphate species have been reported to have decreased pH (<8). However, availability of arsenate, chromate, phosphate and sulphide Cd may precipitate and show mobility at pH ranging from 4.5 to 5.5 (Hashim *et al*, 2011). Cadmium pollution is major as a result of fertilizers made from phosphate ores constituents. It dissolves in water depending on the acidity of water; suspended cadmium may dissolve due to elevations in acidic conditions (Ros and Slooff, 1987). Naturally, in water, cadmium is observed at the lower sediments and suspended particles (Friberg *et al*, 1986). The determination of cadmium is by Atomic Absorption Spectroscopy using either direct aspiration into a flame or a furnace spectrometric technique. The detection limit is 5 µg/l and 0.1 µg/l respectively with the flame method and furnace procedure (ISO, 1985, 1986; Ware, 1989). It is carcinogenic and it enters the body by both breathing in and parenteral ways of subjection (Krajnc *et al*, 1987; Oldiges *et al*, 1989).

Cadmium may be found in water because of industrial waste disposal or the corrosion of galvanized pipes. People may have flu-like symptoms when exposed to cadmium fumes. The signs consist of chills, fever and muscle ache also referred to as "the cadmium blues." The signs may go away after 7 days if there is no destruction to the respiratory tract. Acute exposures may lead to tracheobronchitis, pneumonitis, and pulmonary edema. Taking in of any notable quantities of cadmium may cause instant poisoning and harm the liver and the kidneys. Cadmium also causes anemia and hepatic disorder (Elkins and Pagnotto, 1980).

2.5.5: Chromium

Chromium (Cr) is found in three oxidation states for instance "0, +6 and +3 yet Chromium (+6) is the most dominant and poisonous form of Cr. Most abundant Cr (+6) compounds are chromate CrO_4^{2}- and dichromate $Cr_2O_7^{2-}$. At low pH, Cr (+3) is the most dominant species. Studies have shown that Cr (+6) can be reduced to Cr (+3) by soil organic matter, Sulphide and Fe(+2) ions under anaerobic circumstances this explains the leaching of Cr (+6) as the pH of the soil increases" (Hashim *et al*, 2011).

The danger of chromium relies on its oxidation state once absorbed, Cr (+6) easily invades cell membranes while Cr (+3) does not. Once it penetrates the cell membrane, Cr (+6) is rapidly reduced to Cr (+3) and thereafter adheres to macromolecules. In animal research, Cr was observed to amass mainly in liver, kidneys, spleen, and bone marrow after ingestion and parenteral uptake of different compounds, its spread depends on the chromium species. In humans, elevated levels are observed in hilar lymph nodes and lungs, then in the spleen, liver, and kidneys (Janus., 1999).

Cr is emitted to the surrounding through leakage, bad storage or inappropriate waste disposal ways (Khopkar, 2006). Tannery waste has been found to contaminate water (Khopkar, 2006). Great sources of Cr (+6) and Cr (0) in drinking water are effluents from steel and pulp factories as well as degradation of natural deposits of Cr (+3). There is an increased likelihood of the building up of Cr in aquatic life. Chromium is commonly used in metallurgical processes; magnetic tapes; and paint manufacturing, cement, paper, rubber, a constituent of floor covering and among others. It's also used in making of wood preservatives. EPA reported that chromium has capability to cause many health effects when people are subjected to levels above the maximum contaminant level (MCL) for relatively short periods: dermatitis or ulceration. At levels above the MCL, chromium can result to lifetime defects for instance damage to the liver, kidney circulatory, and nerve tissues. The hexavalent state has been reported to be carcinogenic (Khopkar, 2006). All minerals will cause toxicosis in animals, once consumed in massive quantities (Punitha, *et al*, 2018).

2.5.6 Manganese

At a concentration above 0.1 mgl^{-1}, manganese (Mn) may result in an undesirable taste in drinks and discoloration of laundry, it forms a black precipitate coat on pipes and sanitary ware resulting in a collection of deposits in the plumbing system. Levels below 0.1 mgl^{-1} are often admissible to the users, (WHO 2010).

Surface water and groundwater sources naturally contain Mn. It is also found in soils as well as in various diet sources, such as leafy, cereals and animal products (IOM, 2002). Human activities are to be blamed for most of the manganese pollution in water. Generally, people become exposed to manganese by eating Mn contaminated food (ATSDR, 2000; USEPA, 2002). Avid tea drinkers' intake more manganese than the rest of population. Averagely, a cup of tea has 0.4–1.3 mg of manganese (ATSDR, 2000). Other than food sources, Mn supplements as reported by (Moss *et al.*, 1989) showed that 12% of the grownups in the USA take them.

High Mn levels in undergroundwater, some lakes and dams are favored by reducing conditions found in that environment; (ATSDR, 2000) found levels up to 1300 µg/l in neutral groundwater and 9600 µg/l in acidic groundwater. Anaerobic groundwater has been found to possess high levels of manganese in solution. The divalent species (Mn^{2+}) is abundantly found in water at pH 4–7, however highly oxidized species are found at higher pH values or as an outcome of aerobiotic (ATSDR, 2000). Manganese adheres onto soil particles and the extent of adsorption depends on the organic matter and cation exchange ability of the soil. Mn has been found to build up in simple organisms (for instance phytoplankton, algae, mollusks, and some fish) as opposed to complex organisms; biological magnification in food chains is insignificant (ATSDR, 2000).

In general, 99% level of Mn in undergroundwater (5600 µg/l) exceeds that of surface waters, this has been reported by The National Water-Quality Assessment Program and still the median level in undergroundwater (5 µg/l) is lower than that in water at the surface.

2.6 Atomic Absorption Spectrometry

Atomic Absorption Spectrometry (AAS) is an analytical technique that's used to establish the concentration of elements in a sample. The principle behind it is that the sample solution is evaporated and then metal ions contained are converted to free atoms (Beaty and Kerber, 1993). The atoms then absorb the emitted radiation from the lamp cathode which is the source of light and contains the elements to be determined. Atoms of various elements absorb the characteristic wavelength of lights (The Perkin-Elmer Corporation, 1996).

The intensity of light absorbed is proportional to the number of atoms in the sample. An AAS has three basic components; light source, atomizer, and detector. (*Atomic absorption* spectrometry, The Perkin-Elmer Corporation, 1996). The Hollow Cathode Lamp (HCL) has a tungsten anode and a cylindrical hollow cathode made with the element under study. They are enclosed in an inert medium with a glass tube. When a potential is exerted between the anode and cathode some gaseous atoms are ionized and the ions bombard the cathode hence producing some metal atoms. Some of the scattered atoms become excited state and emit characteristic radiation of the metal which is then concentrated into a beam of light and passes through a quartz window. The atomization of the sample occurs when the sample is aspirated into an acetylene flame. Here the sample is transformed into atoms at ground state in the vapor phase. The vaporized sample absorbs the radiation from HCL. A monochromator selects the absorbed characteristic light and directs it to a detector (made of a photomultiplier tube) that emits an electric signal proportional to the intensity of light. Figure 2.6 shows the schematic diagram of FAAS.

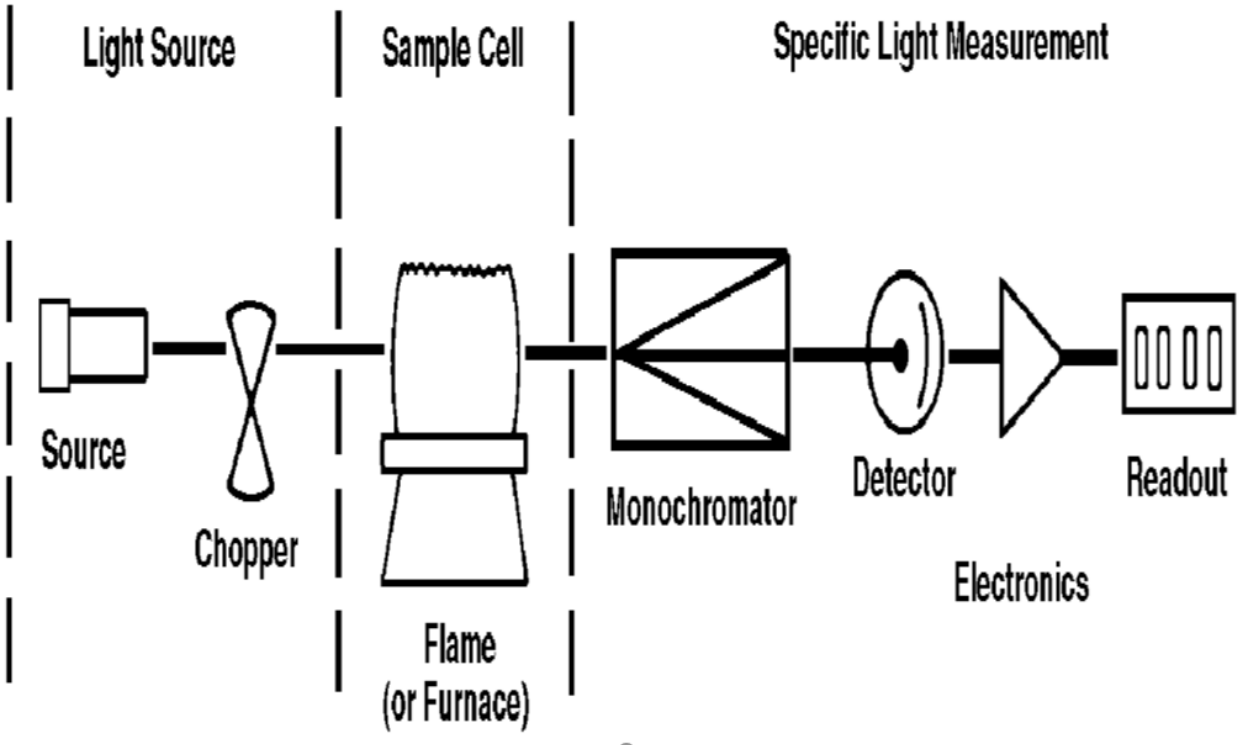

Figure 2.6: Schematic diagram of Atomic Absorption Spectroscopy, (Vadivel, 2020).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1: The study area

The study area, Ongata Rongai, (Figure 3.1), sits on an area of 16.5 km^2 and has 60,184 households with a total of 178,795 people (GOK, 2019). It is found at 50 km from Kajiado County headquarters and 20 km from Nairobi County Central Business District (CBD) along the Langata-Magadi road. It lies approximately at latitude (0° 53' 60" S) and longitude (36° 25' 60" E) (Table 3.1).

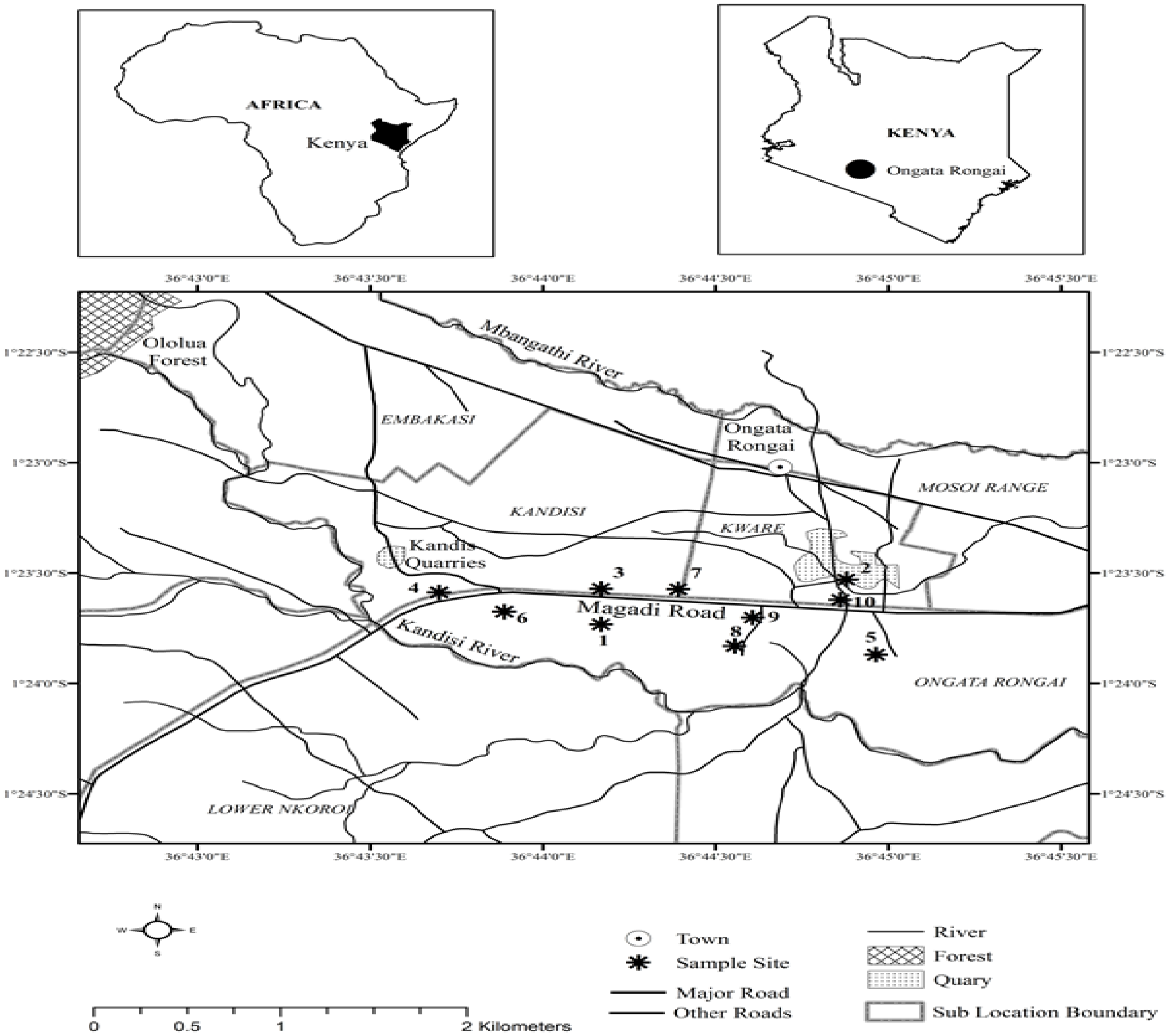

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Figure 3.1: Map showing selected borehole sampling sites in Ongata Rongai

Table 3.1: Sampling sites GIS location and a description of the surrounding area

Site No.	**Altitude (m)**	Coordinates	**Description of sampling sites surroundings**
1	1788	01^{0} 23’ 42” S 36^{0} 45’ 49” E	Muslim mosque with borehole. The very densely populated area near a slaughterhouse. Surrounded by flats. One Septic tank at 30 m and an abandoned horticulture farm nearby.
2	1794	01^{0} 23’ 45” S 36^{0} 43’ 40” E	New life mission. Borehole at the slope. Densely populated shopping centre. Septic tanks at about 33 m
3	1793	01^{0} 28’ 45” S 36^{0} 45’ 49” E	Near the shopping centre. Heavy water abstraction for sale. Medium population
4	1780	01^{0} 25’ 40” S 36^{0} 23’ 36” E	Mbathi’s house. The borehole has been in use for 15 years. Homestead at a higher side of property’s slope, Septic tank at about 31m
5	1788	02^{0} 00’ 06” S 37^{0} 26’ 18” E	Borehole along at the chief’s camp. Densely populated, septic tanks at about 15 m
6	1781	02^{0} 03’ 00” S 37^{0} 23’ 00” E	Three flats with fifty houses each. The borehole is within the compound of the flat. Septic tanks at about 120 m
7	1791	01^{0} 38’ 56” S 36^{0} 44’ 34” E	Muslim mosque and a slaughterhouse nearby in a densely populated area. River 70 m at the bottom of the slope. Mean septic tanks at about 16 m
8	1790	01^{0} 28’ 24” S 36^{0} 31’ 23” E	Gather's house, with borehole. In a low-density area with bigger plot size homesteads. On flat ground, Septic tank at about 33m
9	1781	02^{0} 08’ 21” S 37^{0} 00’ 06” E	Albanus apartments, Borehole next to a flat of 60 houses. One big capacity Septic tank at about 32 m
10	1776	01^{0} 18’ 30” E 36^{0} 41’ 22” S	Ndungu Ole kapara borehole in a remote area. Septic tanks at about 146 m

3.1 Baseline information on the water borehole sites

The baseline information that guided in selecting the study sites is given in Table 3.2.

Table 3.2 Baseline data on water boreholes and their distance from the septic tanks

Borehole serial number	6231	9262	9262	13435	10663	13850	13732	19870	19653	20944
Borehole Site	1	2	3	4	5	6	7	8	9	10
Water rest level (m)	30	20.3	48	51	27	67	43	116	23	50
Borehole depth (m)	210	80	178	234	94	296	162	286	130	160
Yield (m^3hr^{-1})	6	12	13	10.6	12.6	9.8	12	10.3	10	9
Septic tank number	The distance of the septic tank from the borehole's sampling sites (m)									
A	30	25	24	6	9	30	15	15	15	60
B	40	20	50	7	12	110	15	30	15	120
C	50	20	70	9	15	110	15	30	30	150
D	50	40	70	25	15	150	15	40	40	190
E	140	60	90	110	30	200	20	50	60	210
Mean distance (m)	63	33	60.8	31.4	16.2	120	16	33	32	146

Source: Abong'o *et al.* 2017

The borehole serial numbers were from the previous study (Abong'o *et.al*, 2017) which was retrieved and recorded from national data of registered boreholes, from the Ministry of Water and Irrigation in the year 2012. These serial numbers were coded by single digits as borehole site numbers as described in Table 3.2 and for convenience of data handling. The water rest level was the measured height of how high the groundwater rises and rests in the borehole, based on groundwater hydrostatic pressure mainly used to determine the size and depth of pump installations. This data was also retrieved from the ministry of water and irrigation.

The borehole depth, in meters, was the actual drilled/ dug depth, from top to bottom of the well. The data was retrieved from the ministry of water and irrigation. The yield, in cubic meters per hour, was the quantity of water that could be abstracted from the borehole as a function of time, until the well ran dry, before the next recharge. This was done using a standard, calibrated submersible pump after drilling. The yield was dynamic depending on the number of boreholes pumped within the same aquifer and also affected the water rest level. The data was retrieved from the ministry of water and irrigation. The letters A, B, C, D, and E represented the five nearest septic tanks within minimum radial distances from the borehole sites under investigation. The mean borehole-septic tanks spatial distances were used (Table 3.2)

3.2 Site selection

The coordinates for the sampling sites (Table 3.1) of the selected boreholes following a cadastral map of Ongata Rongai town, along Magadi road, which was based on the socio-economic classification and population density, was recorded by a hand-held Global Positioning System (GPS) receiver (Map 410 Magellan). A total of 10 boreholes in the catchment area (Figure 3.1) located next to the septic tanks sewage disposal systems ($\leq$ 200 m) were selected for water sampling in dry (March) and wet (May) seasons in 2019. The baseline data (Table 3.2) from Abong'o *et al*., (2017) provided useful information on depth, water rest levels and yield at the time of drilling the boreholes before water sampling was done. The determination and recording of the distance between each well and the septic tanks was done. Previous study done by Abong'o *et al* (2017), influenced the site selection as the study did not cover assessment of heavy metals.

3.3: Chemicals and reagents

Stock solutions of each of 1000 ppm of zinc, lead, cadmium, chromium, and manganese standards were prepared from heating metal reagents (99.9%) while mercury was obtained from $HgCl_2$, salt. Analytical quality chemicals and reagents were used; they were obtained from BDH laboratory reagents, (Ltd Poole England). Cleaning of glassware and plasticware was done thrice with deionized water and then immersed in 20% nitric acid overnight. The apparatus were then rinsed thrice with deionized water and a Mermert oven was used to dry them.

3.4 Instrumental procedures

A hand-held GPS receiver (Map 410 Magellan) was used to obtain the coordinates of the sampling sites. Hot plate (Gallonkamp 180 model). pH (Hanna Instruments 4321-01 model), conductivity and TDS meter (Hanna Instruments 4321-01 model). Analytical balance (Sartorius 1213 MP model), turbidity meter (Hach 2100Q model), water deionizer (Ionizer Mk 8), Mermat Oven, desiccators, Flame Atomic Absorption Spectrophotometer (Perkin Elmer 2380) and sampling plastic containers were used. The apparatus used include; sampling 2.0 L plastic containers, 50 ml, 250 ml beakers, measuring cylinder 10 ml and 100 ml, volumetric flask 50 ml, 100 ml, and 1000 ml and watch glass.

3.5 Administration of the questionnaire

A questionnaire (appendix 1) was prepared and distributed to 124 respondances to find out more about the common indicators or effects of the parameters under investigation; for example taste and smell from high levels of manganese and zinc (WHO 2008), discoloration and stains on sanitary ware and clothes due high manganese levels, reported cases of symptoms of heavy metal poisoning as a results of high levels of mercury, lead, cadmium and chromium (Tchounwou *et al.*, 2014); signs of corrosion to plumbing fittings as a result of low D.O and pH levels.

3.6 Sample collection

Surveys and familiarization with sampling sites were done (Figure 3.1) in January 2019, by visiting various borehole owners to seek their consent. Sampling was done in March and May, 2019 representing the dry and wet seasons respectively. Samples were collected in May and March to take into account the seasonal variations; May is the wet season while March being the dry season. Water samples were obtained from the selected ten borehole sites (Figure 3.1) a representative of the Ongata Rongai area for the dry and wet seasons.

Water sampling was done using the APHA method (1998) which covers the standard methods for the examination of waters and wastewaters as well as water quality sampling by opening the tap at each sampling site, draining out the water for 1 minute.

Samples from ten boreholes sites in Ongata Rongai area were taken in pre-cleaned 2.0 L plastic containers for physico-chemical parameters and heavy metal analysis, each sample was labeled and kept in polyurethane cool boxes then transported to the Cropnut Laboratory, Nairobi, for analysis. On-site data and observation and the description of surroundings of the sampling sites were documented (Table 3.1) to include: the exact water resource location, weather conditions at the time of sampling. It was observed that galvanized zinc pipes were used for water piping. Laboratory tests were done according to the APHA method (1998). Caution was employed to ascertain that the samples were truly representing the existing conditions in the study area.

3.7: Determination of Physicochemical parameters

The following properties were investigated for each water borehole.

3.7.1: pH

pH was tested by a pH meter (Hanna Instruments 4321-01 model) that gives a reading within +/- 0.1 pH unit. It is determined by immersing glass electrode in the solution and exerting varying potential linearly. 50 ml of each sample was placed in a 100 ml beaker and placed in a water bath at 25 ^{o}C. The calibration of the pH meter was done by two standard buffer solutions of pH 4.0 and 10.0 before measurement. The stable reading displayed was recorded. The sample measurements were done in triplicate.

3.7.2: Dissolved Oxygen (DO)

The reagents used were 2 ml Manganese sulphate, 2 ml alkali-iodide-azide, 2 ml concentrated sulphuric acid, 2 ml starch solution, Sodium thiosulphate. The reagents used were in a ' dissolved oxygen kit by the 'Hach Company'. 500 ml sampling bottle was filled (no headspace) with a water sample and immediately 2 ml of manganese sulphate was added below the surface of the liquid by inserting the calibrated pipette, and squeezed gradually to prevent the introduction of bubbles. Similarly, 2 ml of alkali-iodide-azide reagent was added and the bottle immediately closed, the mixture was inverted several time to ensure that no air entered the sample

Brownish-Orange color flocculation persisted, which indicated the presence of oxygen. Then 2 ml of concentrate sulphuric acid was added using a pipette held slightly over the surface of the sample and again, cautiously closed and inverted many times until the flocculation dissolved. The sample was said to have been "fixed" and could be kept up to 8 hours in a cool, dark place.

201 ml of the sample was titrated with sodium thiosulphate to a pale straw color in a glass 500 ml glass flask, and continuously swirling the sample water added 2 ml, 10 % starch indicator solution so blue color forms and titrated to a clear endpoint. The volume of titrant used corresponded to the level of dissolved oxygen in the water sample. Each milliliter of sodium thiosulphate added in the titration stage equals 1 mgl^{-1} dissolved oxygen.

The sample in the vial was then de-gassed gently by rolling over, evenly and allowing to settle for one minute. The sample vial was used to analyze the samples, the water sample was analyzed in triplicates for best accuracy and to minimize errors. The results were recorded as a readout on the digital display unit.

3.7.3: Electrical conductivity

The specific conductivity for each sample from the ten boreholes was measured using the Jenway conductivity meter (4510 model) with a dip-type cell. Specific conductance was calculated for each sample using Equation 3.1

$$K = 1/R * A/L \tag{3.1}$$

A: Area

K: Conductivity

R: Resistance

L: Length

50 ml of water samples were fetched from the sample container and added into 100 ml beaker and put in a water bath at 25 ^{o} C. The instrument and cell were calibrated using 0.005 N KCl solutions (conductivity = 654 µmho cm^{-1}) before measurements and results recorded. The sample measurements were done in triplicates.

3.7.4: Total dissolved solids

25 ml of each sample was filtered using 'Whatman filter paper number 1' in pre-weighed labeled ceramic dishes to remove the suspended substances. The dishes were then put in an oven for 5 hours at 103 ^{o}C to 105 ^{o}C. The dishes were removed and placed in desiccators until the samples cooled. The dishes were then weighed and total dissolved solids for each sample were determined by finding the differences in the weights of the ceramic dish before and after drying. The sample measurements were done in triplicate.

3.7.5: Turbidity

A standard solution was provided and used to calibrate the Turbidity Meter ('Hach' TN100). For normal use, it is necessary to calibrate the meter monthly or weekly, however in our case, it was not necessary to re-calibrate the meter. The calibration standards for the TN100 turbidity meter adopted US EPA (2002), certified Reagecon high-molecular polymer turbidity standard solution as compared with the traditional Formazin standard solution. The glass vial for the sample was washed in the interior and exterior using a detergent solution and repeatedly washed out with clean purified water then rinsed with the sample solution twice. The vial was filled with a 10 ml sample and capped properly.

3.7.6: Total Suspended Solids

100 ml of each water sample were taken in triplicate and filtered through dried and pre-weighed filter papers (glass-fiber filter, Whatman GF/C grade) using Buchner funnel fitted to vacuum pumps. An oven was used to dry the filter papers for 5 hours at 105 °C, cooled in a desiccator and reweighed. The process of drying, cooling and reweighing was repeatedly done until a stable weight was achieved (Mackereth *et. al*., 1989).

3.8 Acid digestion for the analysis of heavy metals

The water samples obtained from the sites (Table 3.1) for the selected ten boreholes were acid-digested as recommended by the standard procedure (USEPA, 2002)

To each 100 ml triplicate water sample in a pre-cleaned 250 ml beaker, 25 ml of 10 % hydrochloric (2.5 ml concentrated hydrochloric acid + 22.5 ml distilled deionized water) was added to the beaker and heated on a hot plate. The solution was boiled until 10 -15 ml was left. 10 ml of perchloric acid was added and the solution was heated until perchloric fumes evolved. The remaining sample was put in a 100 ml volumetric flask and topped to the mark. The solution was then shook well, transferred into a clean sampling bottle and awaited analysis by Flame Atomic Absorption Spectroscopy. The samples were prepared in triplicates from every site.

3.8.1: Preparation of heavy metal standard stock solutions

The following standard stock solutions were prepared in readiness for the heavy metal analysis.

3.8.1.1: Zinc (Zn) stock solution

A thousand (1000) mgl^{-1} of zinc ion standard stock solution was prepared by heating 1.0g of zinc II Chloride ($ZnCl_2$) (99.9%) and dissolving it in 30 ml (1:1 v/v) of water: nitric acid solution then transferring the solution to 1000 ml volumetric flask and diluting to the mark.

3.8.1.2: Cadmium (Cd) stock solution

A thousand (1000) mgl^{-1}of Cd ion standard stock solution was prepared by heating 1.0 g of cadmium Oxide (CdO) (99.9%) and dissolving it in 30ml (1:1 v/v) of water: nitric acid solution cooled then transferring the solution to 1000 ml volumetric flask and diluting to the mark.

3.8.1.3: Chromium (Cr) stock solution

A thousand (1000) mgl^{-1} of Cr ion standard stock solution was prepared by heating 1.0g of chromium trioxide (CrO_3) (99.9%) and dissolving it in 20ml of aqua regia and then cooled and then diluted to 1 litre.

3.8.1.4: Lead (Pb) stock solution

A thousand (1000) mgl^{-1} of lead (Pb) ion standard stock solution was prepared by heating 1.0g of lead nitrate $Pb(NO_3)_2$ (99.9%) and dissolving it in 30ml (1:1 v/v) of water: nitric acid solution then transferring the solution to 1000 ml volumetric flask and diluting to the mark.

3.8.1.5: Mercury (Hg) stock solution

A thousand (1000) mgl^{-1} of mercury (Hg) standard stock solution was prepared by dissolving 1.354g of analytical grade salt of mercuric chloride ($HgCl_2$) (99.9%) in distilled deionized water and diluting to the mark.

3.8.1.6: Manganese (Mn) stock solution

A thousand (1000) mgl^{-1} of Mn ion standard stock solution was prepared by heating 1.0g of manganese sulphate (Mn_2SO_4) (99.9%) and dissolved in 20ml of aqua regia and diluted to 1 litre.

3.9: Quality assurance

Quality assurance was ascertained by analysis of blank solutions. Quality control was carried out as recommended by USEPA method, (2002); analysis of laboratory reagent and fortified blanks, as well as samples as an ongoing measurement of performance. Rinsed blanks and calibration of six standard solutions of all monitored analytes were prepared at parts per million (ppm) or parts per billion (ppb) concentration ranges for the various analytes.

3.10: Analysis of the heavy metals with Atomic Absorption Spectrometry (AAS)

Samples were analyzed by direct absorption, except for mercury which was done by cold vapor generation in a special accessory. The samples were analyzed in triplicates to minimize errors. The Flame Atomic Absorption Spectroscopy (FAAS) was warmed up and the recommended wavelengths and flame/gas types set for the various heavy metals as shown in Table 3.3 below.

Table 3.3 Atomic Absorption Spectrometry wavelengths and flame gas used for heavy metal analysis

Element	Wavelength (nm)	Flame/ gases
Zinc	213.9	air/acetylene
Cadmium	228.8	air/acetylene
Chromium	357.9	air/acetylene
Lead	217.0/ 283.3	air/acetylene
Mercury	253.7	Cold vapour generation
Manganese	279.5	air/acetylene

3.11: Heavy metals analysis

The heavy metals: zinc (Zn), cadmium (Cd), chromium (Cr), lead (Pb); mercury (Hg) and manganese (Mn); were determined by Perkin Elmer 2380 Flame Atomic Absorption Spectrophotometer. APHA method, (1992) was followed during preparation of samples to be analyzed. The operating manual was used to give guidance setting up and optimization of the instrument and air- acetylene mixture was used as source of flame. However, for the determination of Hg, hydride generation method was used. The wavelengths for the determination of each metal were as indicated in Table 3.3. Sections 3.8.1.1-3.8.1.6 show the preparation of working standard solutions by suitable diluting of the stock solution. Every analysis was done in triplicate and the average of the three readings was recorded, to calculate the standard deviation for each element analyzed.

3.12: Data analysis

Analysis of data was done using a statistical program for social scientists (SPSS 22) to determine the association between physico-chemical and heavy metal levels in water from various sampling sites and different seasons. Bivariate correlation coefficient using Pearson product moments correlation coefficient, R, a dimension index, whose value is in the range $-1.0 \leq R \leq 1.0$, was used. Statistical tests of significance were done using 1- Way ANOVA ($p < 0.05$) for interpretation of the results.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Response from the questionnaire

One hundred and twenty-four (124) questionnaires were given out to respondents in Ongata Rongai however one hundred and twenty-one (121) had positive response while three (3) questionnaires had nothing captured that could aid the study as represented in Figure 4.1.

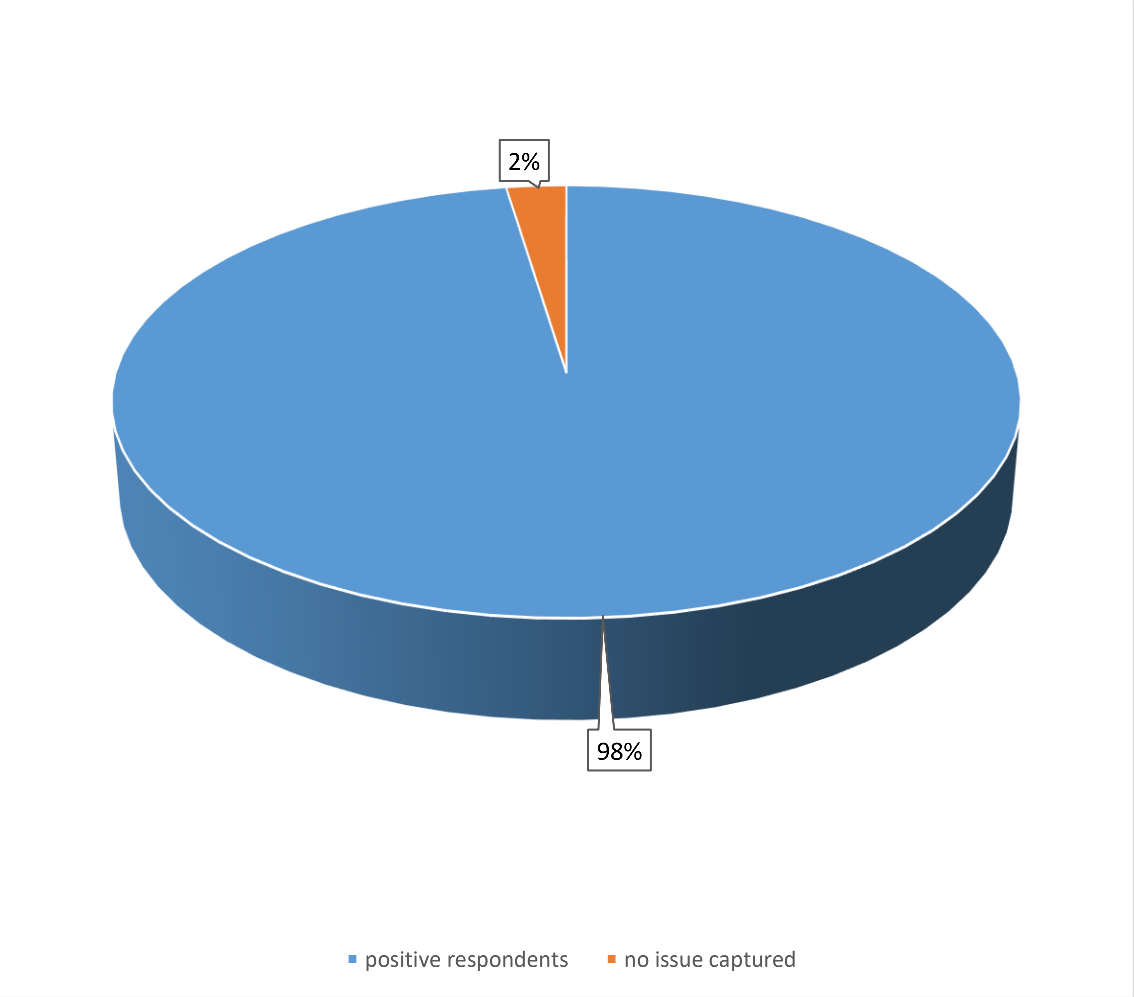

Figure 4.1: Total number of respondents in percentage

4.1.1 Percentage number of respondents interviewed

The questionnaire was prepared to capture any aspects that would favour the selection criteria during site selection to direct our study and methodology. The following respondents were given the questionnaires: domestic workers, local dispensaries, borehole owners, water vendors and direct consumers. The respondents were asked if they had any information on heavy metal levels, water quality and to establish if there were clinical manifestations of heavy metal poisoning reported by local dispensaries. The responses were to help find out if there was public health awareness about heavy metals effects in drinking water and ground water quality (Table 4.1). The responses aided in determining perceived water quality by the users, to assess awareness about effects of heavy metals as well as awareness about water analysis tests as shown in both Table 4.1.

The findings revealed that the 2 % of the population had no issues to highlight, while the 98 % of the total positive responses or the expected responses favoured the study (Figure 4.1). The 5 groups were interviewed and their responses analysed and expressed as percentages of respondents in Table 4.1.

Table 4.1: Total number of respondents and percentage of their responses

Water quality /% Respondents	Domestic workers	local dispensaries	Borehole owners	Water vendors	Direct Consumers
Number of respondents in each group	40	32	24	8	17
Related public health isusse from water	35 87.5%	24 75%	20 83.3%	8 100%	15 88.2%
Treating water before use	36 90%	28 87.5%	18 75%	8 100%	11 64.7%
Known water quality	20 50%	20 62.5%	10 41.6%	6 75%	9 52.9%
Presence of colour, oduor, taste	38 95%	28 87.5%	23 95.8%	6 75%	14 82.3%
Awareness of heavy metals	28 70%	30 93.7%	19 79.1%	7 87.5%	10 58.8%

4.1.2 Related public health issues from water quality

The study revealed that 87.5% of domestic workers were not aware of any public health issues resulting from deteriorated water quality, (Figure 4.2). 75% local dispensaries workers responded and confirmed that they had the knowledge about public health issues. However, they were more informed about water-borne diseases and not heavy metal related health complications. The heavy metal health impacts on the residents of Ongata Rongai was not observed as this required a different study design. The local dispensary workers added that their facilities were under equipped limiting their ability to diagnose heavy metal related illnesses. 83.3% of the borehole owners responded by stating that they were not aware of the heavy metal health problems. 100% of water vendors responded that they had inadequate information about public health issues arising from water quality. 88.2% of direct consumers expressed their views and unanimously stated that there was lack of sufficient information on public health issues arising from the water quality. Some respondents failed to respond to this question hence represented as "No response" as indicated in Figure 4.2.

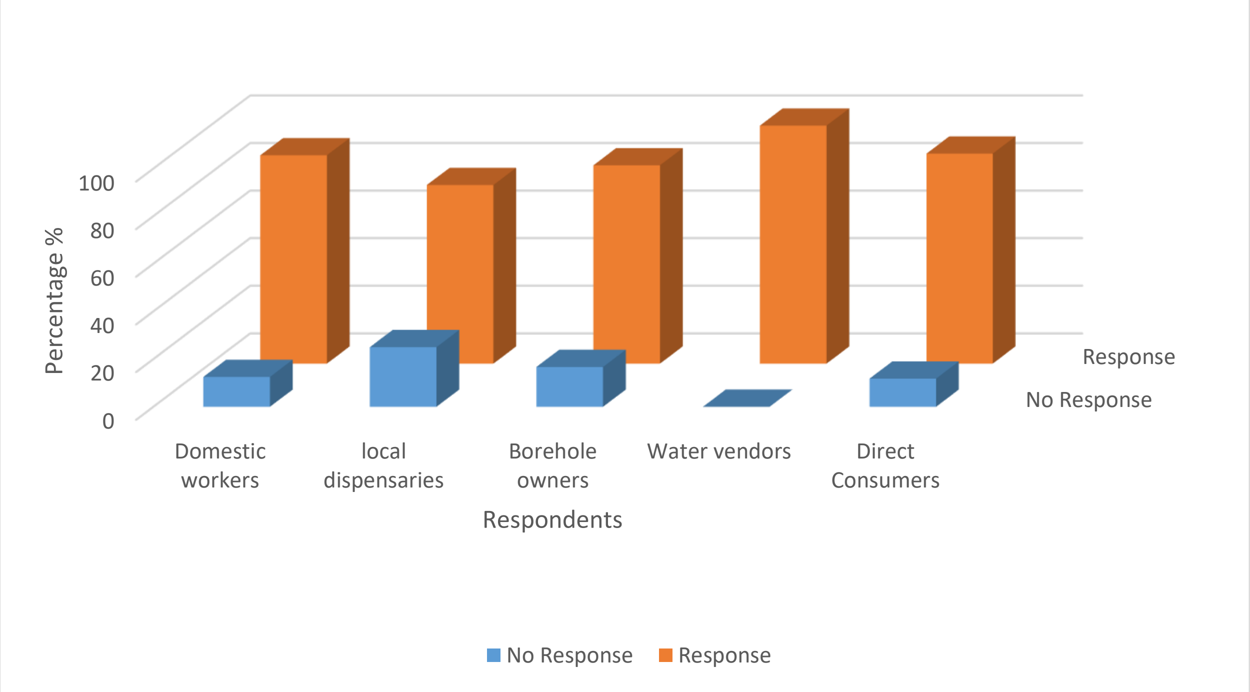

Figure 4.2: Percentage number of respondents on related public health issues from water

4.1.3: Treatment of water before use

Of the 40 interviewed domestic workers (Table 4.1), 90% responded and a majority reported that they were instructed by their employers to boil drinking water to help kill germs in the water used for drinking. 64.7% of direct consumers who responded reported the use of chlorine based chemicals to purify their drinking water only while there was no form of treatment for water used for other purposes (Table 4.1). 75% of the borehole owners responded, are shown in Figure 4.3. Some of them had set up simple water treatment plan that involved filtering and use of chlorine based chemicals before the water was pumped to storage tanks. 100% of water vendors responded, however most of them were indifferent about water treatment since they believed it is the end users burden, their concern was profit and most of them obtained untreated water cheaply. 87.5% of the 32 local dispensary workers (Table 4.1) interviewed reported illness caused by drinking unsafe water quality.

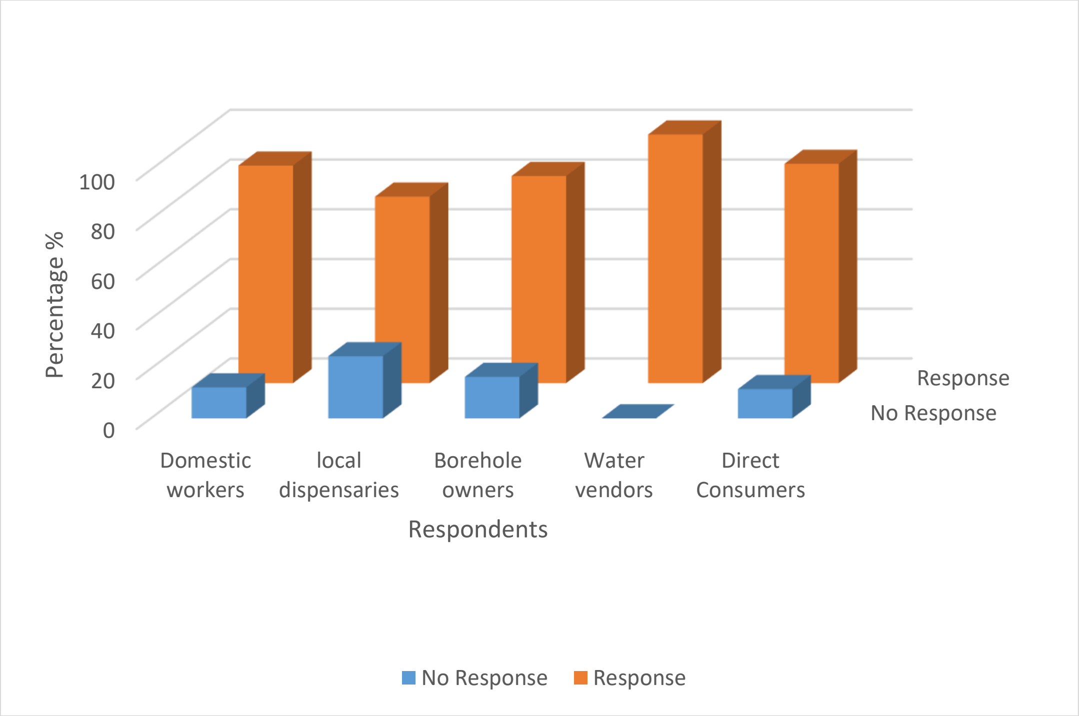

Figure 4.3 Percentage number of respondents who treated water

4.1.4 Number of people who are aware of their water quality

As shown in Figure 4.4, most respondents seemed not to have been confident about responding to this question. 50%, 58.4% and 47.1% of domestic workers, borehole owners and direct consumers respectively did not respond well to this question, (Figure 4.4). Most of the respondents from all those interviewed groups reported that they were not aware of their water quality. 75% of the water vendors, stated that they had no information on the quality of the water they were selling. 62.5% of the local dispensary workers reported that some of the water used by Ongata Rongai residents was unsafe as they had various cases of illnesses caused by unsafe water. Some respondents complained of high costs for water testing, making water analysis tests inaccessible. Some respondents did not know that there are agencies that can help carry out the water analysis. People in the community should be educated on importance of accessing safe drinking water, importance of water analysis tests and the tests should be made affordable.

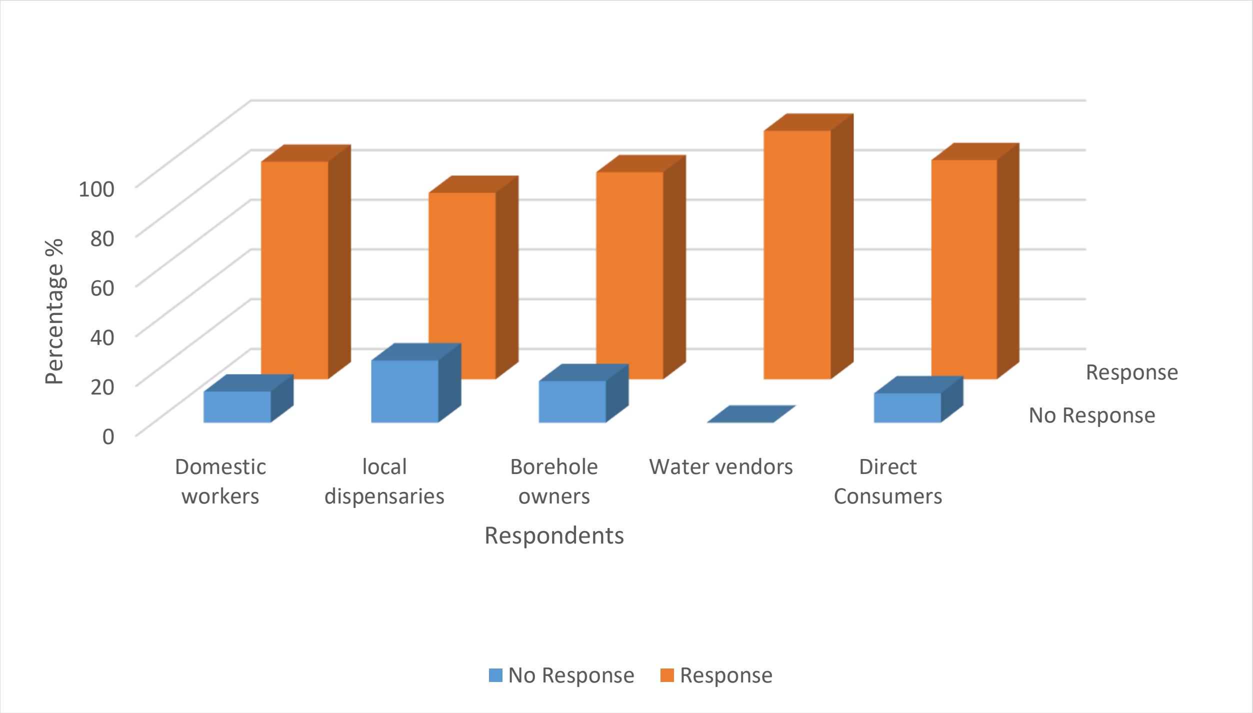

Figure 4.4 Percentage number of people who are aware of their water quality

4.1.5 Knowledge of presence of colour, oduor and water taste

Most respondents emphasized that this was more expressed during wet seasons. This could be attributed to surface run offs and leaches that may introduce dirt and other impurities in their water. 95% of domestic workers responded to this question (Figure 4.5) and complained of disclouréd water, bad smell and a characteristic taste. 87.5% of local dispensaries who responded, confirmed deteriorated water quality especially during wet seasons. 95.8% of borehole water owners responded and also reported to have noticed cloudiness of water mostly during wet seasons. 75% of water vendors also responded and they stated that some times during the dry seasons they obtained water from boreholes/wells that were over-exploited and mostly the water was dirty. Some of them explained that they were leaving water drawn to settle and then decant of clean water. 82.3% of direct consumers confirmed instances when they obtained unclean water and have been forced to purchase bottled water which is an extra expense.

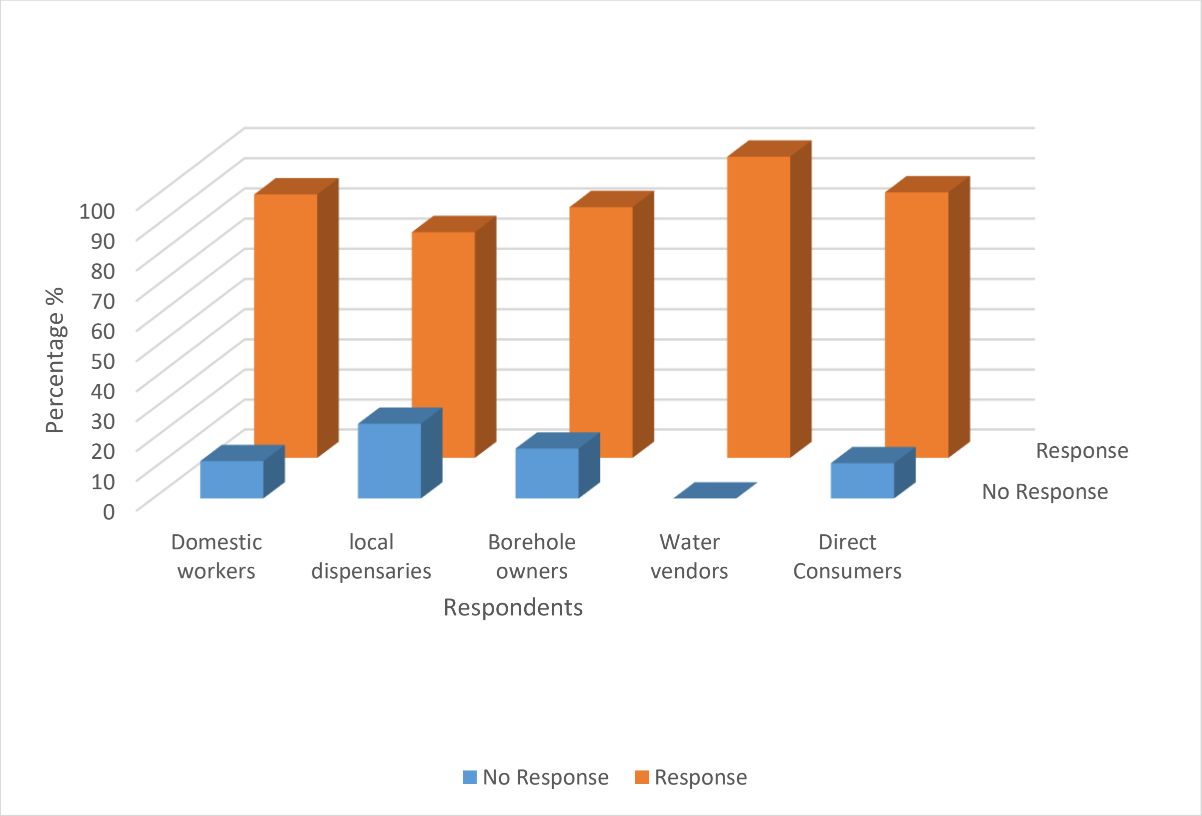

Figure 4.5: Percentage number of people who were aware of colour, odour and water taste

4.1.6 The number of people aware of heavy metals

93.7% of local dispensary workers who responded (Figure 4.6) reported that they were aware of delirious effects of heavy metals on human health. However, they were not able to confirm if there had been illnesses associated to heavy metal poisoning. This could be attributed to lack of health workers capable of diagonising health effects arising from heavy metals. Domestic workers and water vendors had no information on heavy metals and their effects. 70% and 87.5% responded respectively. 79.1% of borehole owner responded and majority of them had insufficient information about heavy metals and their effects on human health. Almost half of direct consumers did not respond to this question (Figure 4.6), however of the 58.8% who responded emphasized on need for education on heavy metals and their health effects.

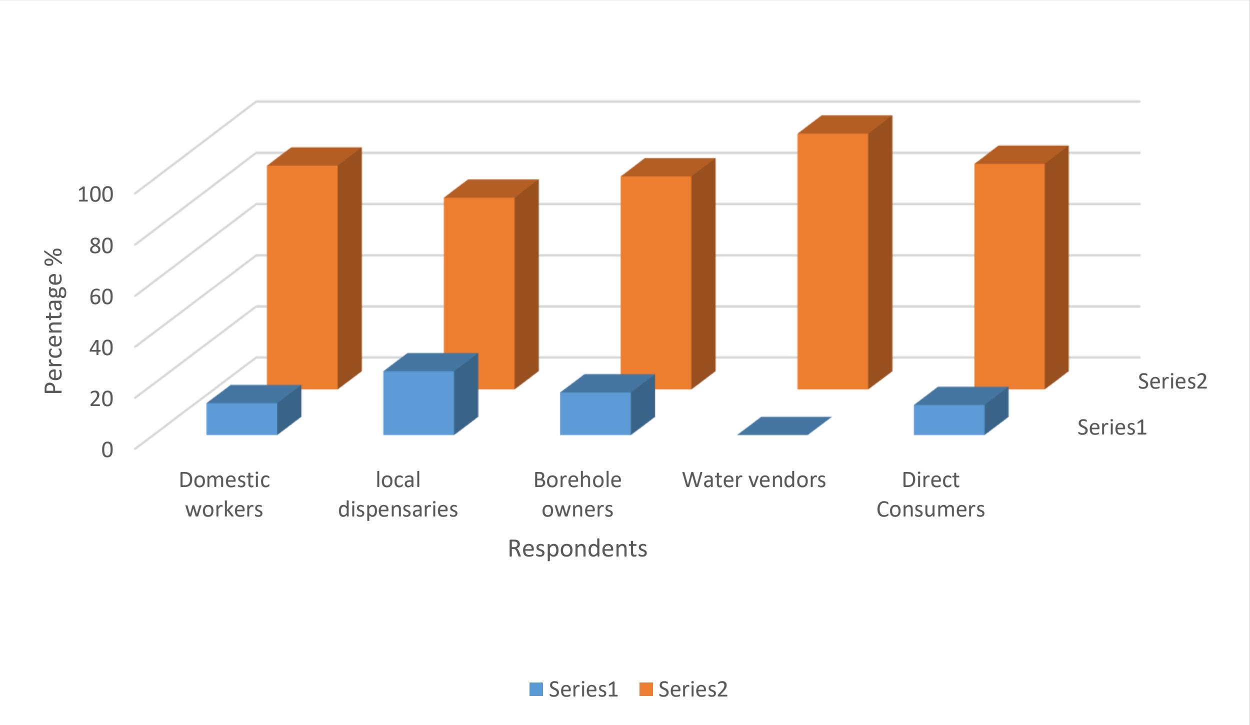

Figure 4.6: Percentage number of people aware of heavy metals

4.2. Levels of physical-chemical parameters in ten borehole water samples, in dry and wet seasons

The results of the physico-chemical parameters measured and analyzed with the variance of the triplicate data were recorded for each borehole water sample as shown in Table 4.2

Table 4.2 Physico-chemical parameters for the dry and wet seasons

Physicochemical parameters						
Dry Season						
Site	pH	DO mgl^{-1}	Electrical Conductivity μscm^{-1}	TDS mgl^{-1}	Turbidity (NTU)	TSS mgl^{-1}
1	7.4±0.01	2.24±0.01	266±1.00	723±2	0.08±0.01	2.4±0.2
2	7.6±0.1	1.22±0.01	289±0.90	844±1	0.06±0.01	1.4±0.1
3	6.8±0.1	2.38±0.01	301±2.00	970±1	0.05±0.01	1.3±0.1
4	7.8±0.1	2.40±0.01	276±1.03	765±2	0.08±0.01	1.2±0.2
5	8.6±0.1	2.20±0.01	254±1.0	639±1.05	0.09±0.01	1.8±0.1
6	6.9±0.2	1.33±0.01	298±2.01	897±2	0.04±0.01	0.9±0.1
7	7.6±0.1	2.42±0.01	264±1.01	701±2	0.07±0.01	1.6±0.1
8	7.8±0.1	3.28±0.01	289±1.02	834±1	0.07±0.01	1.5±0.2
9	8.4±0.1	2.41±0.01	278±2.00	882±2	0.08±0.01	1.4±0.1
10	8.1±0.1	1.37±0.01	312±1.00	980±1.00	0.04±0.01	1.1±0.1
Wet season						
1	7.1±0.1	4.04±0.0	254±0.1	712±1	0.12±0.01	2.6±0.01
2	7.2±0.0	3.79±0.00	233±1.00	824±0.90	0.09±0.01	1.7±0.1
3	6.6±0.1	4.8±0.01	289±1	966±1	0.06±0.01	1.9±0.1
4	7.6±0.1	4.1±0.01	273±1	723±2	0.11±0.01	1.3±0.1
5	8.5±0.1	4.5±0.00	250±1	630±1.3	0.18±0.02	1.9±0.1
6	7±0.1	3.6±0.01	280±1	872±1	0.06±0.01	1.3±0.2
7	7.6±0.1	4.83±0.00	262±2	681±1	0.17±0.01	1.9±0.1
8	7.5±0.1	4.66±0.01	287±1	810±2	0.08±0.01	1.8±0.0
9	7.9±0.0	4.29±0.00	243±1	845±1	0.09±0.01	1.5±0.1
10	7.7±0.01	3.75±0.00	301±0.90	966±0.70	0.09±0.01	1.3±0.1
Recommended values in drinking water						
WHO	6.5-8.92	6	500	600	5	500
KEBS	6.5-8.85	6	1000	1500	5	NIL
NEMA	6.5-8.85	Nil	1000	1200	5	30

The recommended Physicochecmical parameters values were obtained from KEBS: KS 05-459: Part 1: 1996, NEMA: Environmental Management and co-ordination (water quality) regulations, 2006 and WHO (2008) and KS EAS 153: 2014. One Way ANOVA (Analysis of Variance) showed the p values were less than 0.05 as shown in Appendix 2. It could be suggested that there was statistical significance on the effects of seasonal variations on physico-chemical parameters as well as the proximity of the septic tanks to the selected borehole sites.

4.2.1 The pH in ten borehole water samples in dry and wet seasons

The pH level of water is a reflection of its acidity. It is noticed from Table 4.2 that the pH in the dry season was higher than the wet one and it ranged from 7.4 ± 0.1 to 8.1. ±0.1 while in the wet season it varied between 7.1 ± 0.1 to 7.7 ± 0.1 in the ten boreholes the dry season had higher pH values than wet one (Figure 4.7). The table shows that the pH was within the alkalinity range in both the wet and the dry season as recommended by WHO (6.5 – 8.92) and KEBS (6.5 – 8.85) as shown in Table 4.2. The EPA (2001) suggests that public water systems should have a pH between 6.5 and 8.5, which is an approved guide for private well owners. A similar range of 6.5 to 8.5 has been reported by KEBS for packaged drinking water (KS EAS 153: 2014). Acidic water is said to have a low pH, naturally soft and corrosive. Problems with acidic water include leaching of metals and effect on metal water pipes. Alkaline water does not have health problems but has aesthetic problems such as alkali flavour (WHO, 2008). pH values for the water samples in the dry and wet seasons are shown in Figure 4.7.

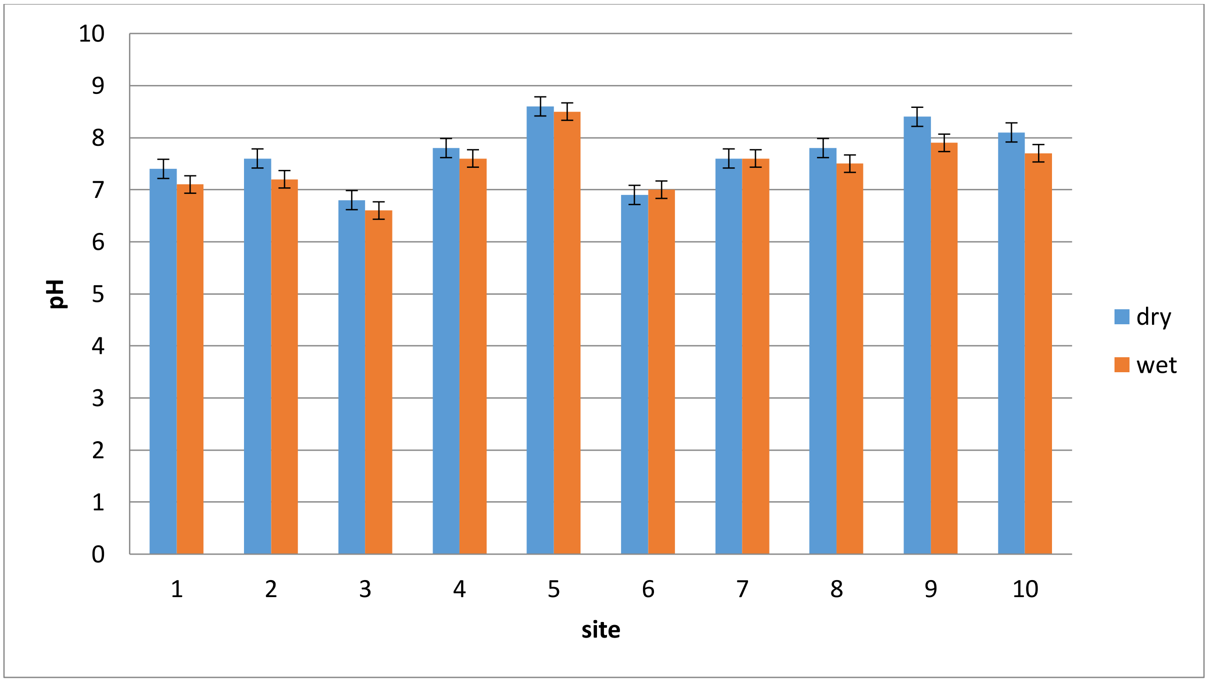

Figure 4.7: pH levels in water samples in the dry and wet seasons.

4.2.2 The dissolved oxygen in the ten borehole water samples in dry and wet seasons

The dissolved oxygen (DO) was greatest in the wet season than in the dry season (Figure 4.8) as a result of increased current flow which enabled the diffusion and mixing of atmospheric oxygen in the water (Chapelle, 2000) The DO in water samples were at the minimum of 1.22± 0.01 mgl^{-1} to a maximum of 3.28±0.01 mgl^{-1} during the dry season at Sites 2 and 8 respectively while during the wet season the minimum was 3.6 ±0.01 mgl^{-1} at site 6 and the maximum was 4.83± 0.01 mgl^{-1} at 7 (Tables 4.2). Sites 2 and 6 had lowest DO values in dry and wet seasons because they are areas which are densely populated. Sites 8 and 7 had high DO values in dry and wet seasons respectively (Table 3.1). Sites 8 is at Gather's house, with borehole in a low-density area with bigger plot size homesteads, while site 7 is at Muslim Mosque and a slaughterhouse nearby in a densely populated area, there is a river at 70 m at the bottom of the slope may be receiving seepage from the borehole. The DO values are insignificant when it comes to quality of drinking water as WHO and NEMA has no recommended guideline for DO while KEBs recommends that the value should not be above 6 mgl^{-1} (Table 4.2).

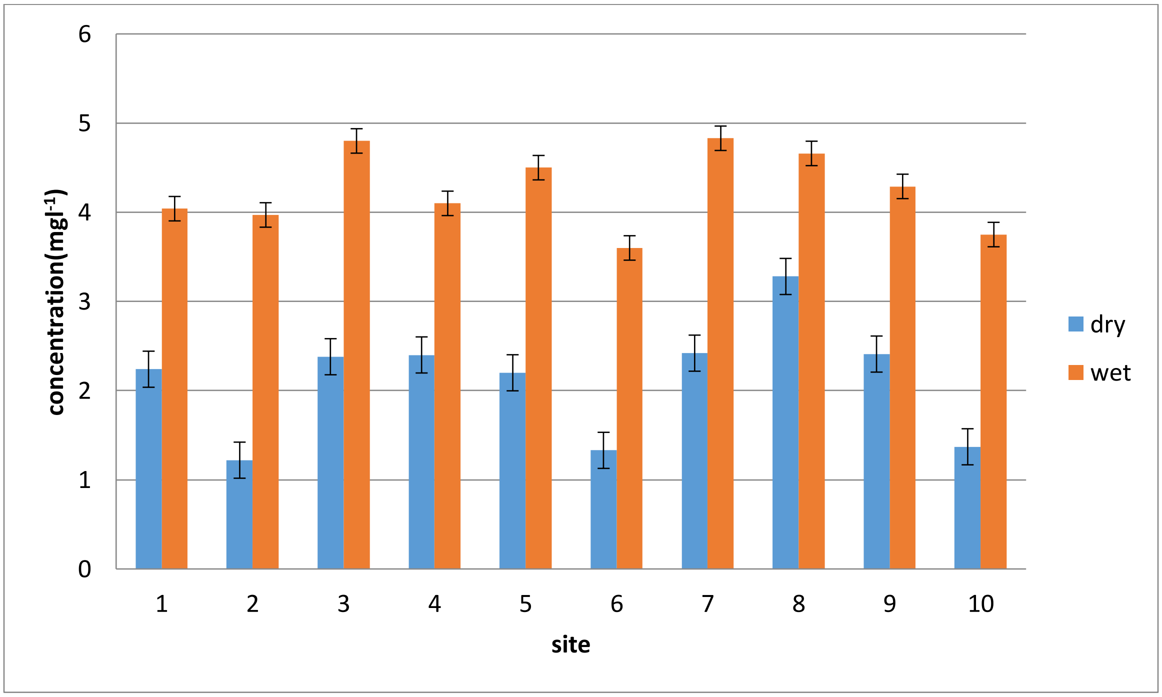

Figure 4.8: Dissolved oxygen levels in water samples in the dry and wet seasons

4.2.3: The Electrical conductivity in ten borehole water samples in dry and wet seasons

Electrical Conductivity (EC) was highest in the dry season than the wet season (Figure 4.9). The EC in water samples were in the minimum range of 254± 1.00 µscm^{-1} to a maximum of 312±1.00 µscm^{-1} during the dry season with a minimum range of 233 ± 1.00 µscm^{-1} to a maximum of 301± 0.90 µscm^{-1} in the wet season (Tables 4.2).The lowest EC in both the dry and wet seasons was obtained from Sites 5 and 2 respectively while the highest in the dry and wet seasons were obtained from Site 10 (Figure 4.9).

The values obtained were below recommended values for WHO, KEBS and NEMA. The values are 500 µscm^{-1}, 1000 µscm^{-1}, and 1000 µscm^{-1} respectively (Table 4.2).

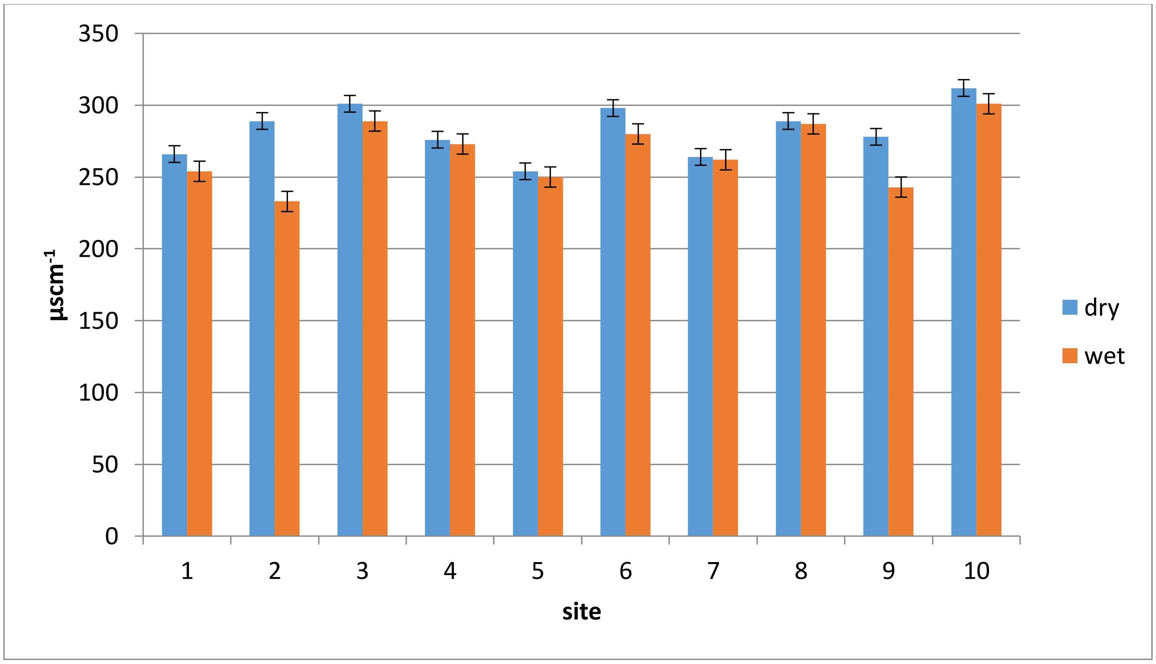

Figure 4.9 Electrical Conductivity levels of water samples in the dry and wet seasons

4.2.4 The total dissolved solids levels in water samples in dry and wet seasons

Total dissolved solids (TDS) were greater in the dry than the wet season (Figure 4.10). The TDS in water samples were in the minimum range of 639 ± 1.05 mgl^{-1} to a maximum of 980±1.00 mgl^{-1} during the dry season with a minimum range of 639± 1.3 mgl^{-1} to a maximum of 966± 0.7 mgl^{-1} in the wet season (Tables 4.2). The values were slightly above recommended WHO value of 600 mgl^{-1} but within KEBS and NEMA within acceptatble range. The KEBS limits are 1200 mgl^{-1} while NEMA standards are 1500 mgl^{-1} (Table 4.2).

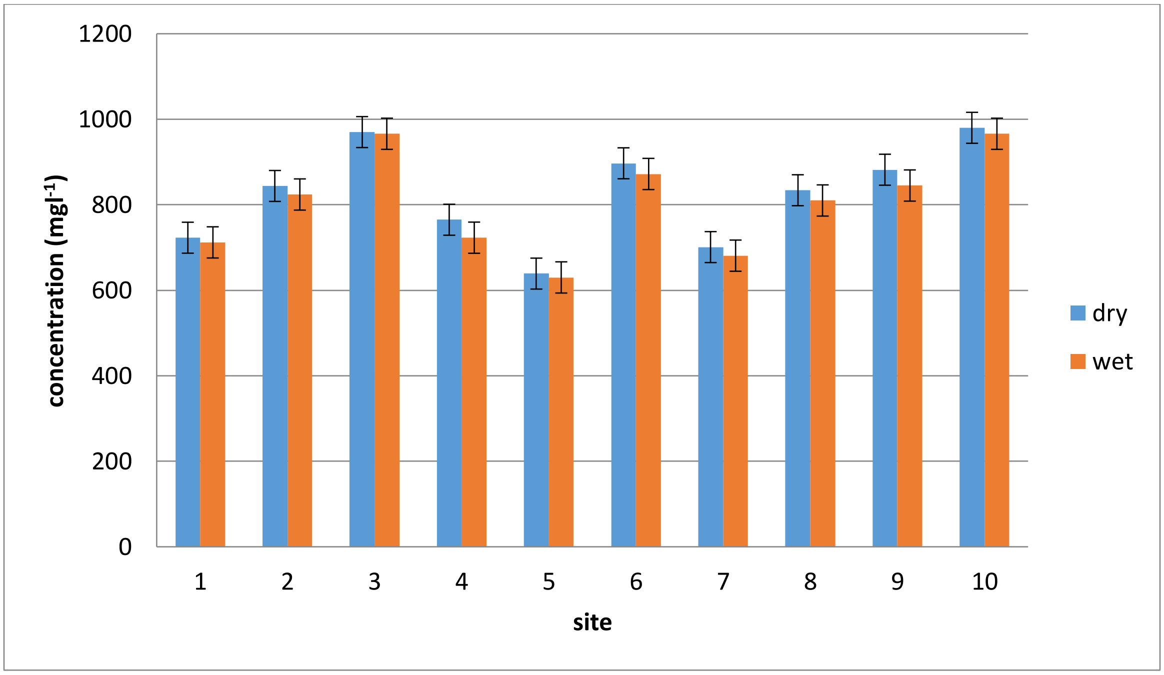

Figure 4.10: Total Dissolved Solids levels in water samples in the dry and wet seasons

The level of total dissolved solids (TDS) values was highest in the dry and wet seasons in site 10 while the lowest was obtained in site 5 in both seasons. Site 10 is in remote area and within a mean distance of 146 m from the septic tanks while site 5 is in a densely populated area and septic tanks are within 15 m of septic tanks. This could be attributed to human activities around. Wet season had lowest TDS than the dry season due to dilution.

4.2.5: The turbidity levels in ten borehole water samples in dry and wet seasons

Turbidity was higher in the wet than the dry season (Figure 4.11). Turbidity in water samples was in the minimum range of 0.04 ± 0.01 NTU to a maximum of 0.09±0.01 NTU during the dry season (Table 4.2) with a minimum range of 0.06± 0.02 NTU to a maximum of 0.18± 0.01 NTU in the wet season (Tables 4.2). The lowest turbidity in both the dry and wet seasons was obtained from Site 6 while the highest in the dry and wet seasons were obtained from Site 5 (Figure 4.11).

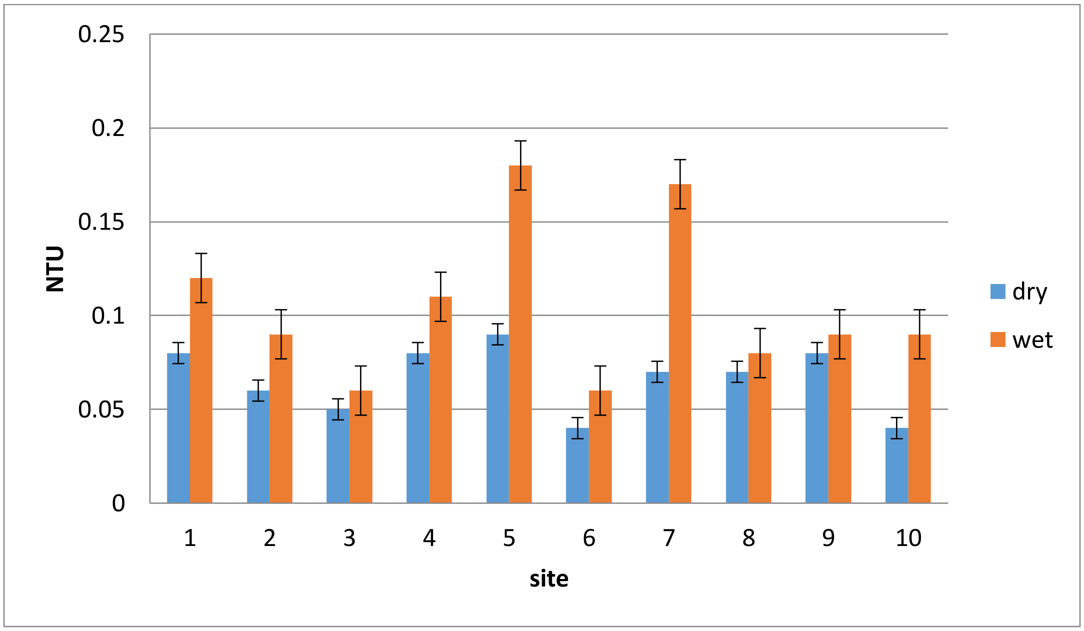

Figure 4.11: Turbidity of the borehole water samples in the dry and wet seasons

In general, turbidity was greatest during wet season. Site 5 was observed to have large values in both seasons and the lowest value was obtained at Site 6. The obtained values are below recommended values as per guidelines from WHO, KEBS and NEMA. The guideline is 5NTU (Table 4.2)

4.2.6: The total suspended solids levels in ten borehole water samples in dry and wet seasons

The total suspended solids (TSS) were greater in the wet than the dry season (Figure 4.12). TSS in water samples were in the minimum range of 0.9 ± 0.1mgl^{-1} to a maximum of 2.400±0.02 mgl^{-1} during the dry with a minimum range of 1.300± 0.01 mgl^{-1} to a maximum of 2.600± 0.01 mgl^{-1} in the wet season (Table 4.2). The lowest and highest TSS in both the dry and wet seasons were obtained from Site 1 while the highest in the dry and wet seasons were obtained from Site 6 (Figure 4.12). The obtained values were within the set guidelines by WHO and NEMA of 600 mgl^{-1} and 30 mgl^{-1} respectively. No guideline has been set by KEBS (Table 4.2).

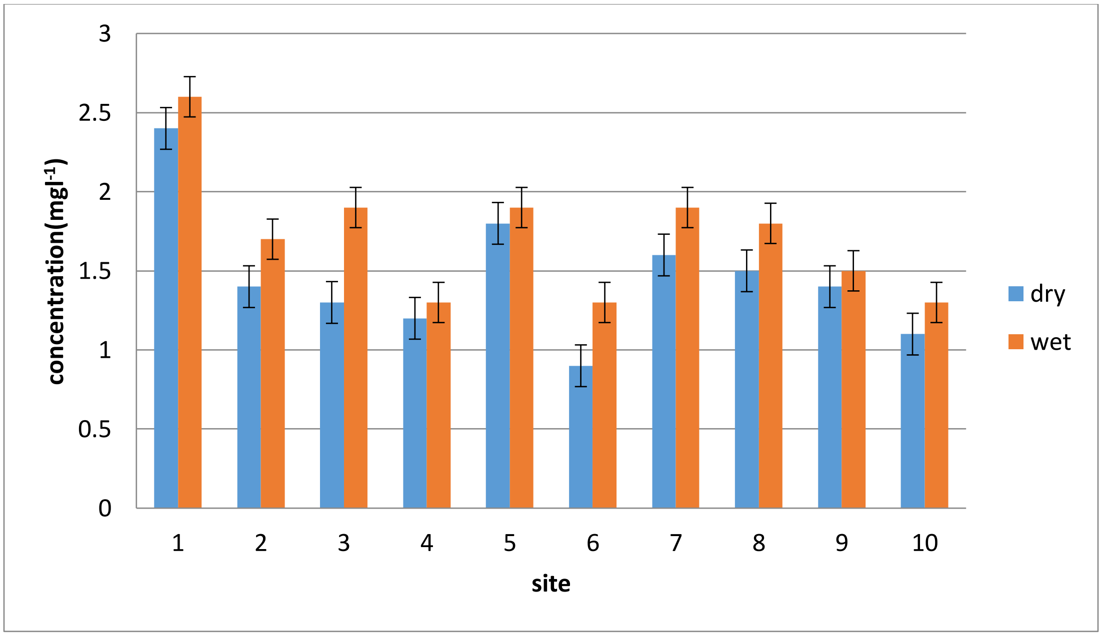

Figure 4.12: Total Suspended Solids levels in water samples in the dry and wet seasons

4.3: Levels of heavy metals in the ten borehole water samples in dry and wet seasons

4.3.1 Preparation of heavy metals calibration curves

The calculation of concentrations of heavy metals was done through the calibration curves (Appendix 4) determined by plotting concentrations of the standard solutions against the corresponding peak heights. The calibration curves for Zn, Pb, Hg, Mn, Cd, Cr are shown in appendix 4 in Figures 4A, 4B, 4C, 4D, 4E and 4F respectively.

Table 4.3: The levels of heavy metals in ten borehole water samples in the dry and wet seasons and WHO KEBS, and NEMA recommended value in drinking water

Heavy metal level						
Dry Season						
Site	**Zinc** (mgl^{-1})	**Lead** (mgl^{-1})	**Mercury** (mgl^{-1})	**Manganese** (mgl^{-1})	**Cadmium** (mgl^{-1})	**Chromium** (mgl^{-1})
1	0.16±0.01	0.22±0.02	0.0017±0.0002	0.12±0.01	BDL	BDL
2	0.73±0.01	0.33±0.01	0.0017±0.0001	0.09±0.01	BDL	BDL
3	0.16±0.02	0.22±0.01	0.0018±0.0003	0.22±0.01	BDL	BDL
4	0.32±0.01	0.30±0.02	0.0019±0.0001	0.19±0.01	BDL	BDL
5	0.51±0.01	0.42±0.011	0.0017±0.0001	0.26±0.001	BDL	BDL
6	0.21±0.01	0.24±0.01	0.0016±0.0001	0.18±0.01	BDL	BDL
7	0.11±0.02	0.22±0.00	0.0013±0.0002	0.05±0.01	BDL	BDL
8	0.68±0.01	0.24±0.01	0.0010±0.0001	0.13±0.00	BDL	BDL
9	0.14±0.01	0.25±0.02	0.0017±0.0001	0.07±0.01	BDL	BDL
10	0.12±0.00	0.23±0.02	0.0002±0.0001	0.03±0.01	BDL	BDL
Wet season						
1	0.03±0.01	0.21±0.01	0.0017±0.0002	0.17±0.01	BDL	BDL
2	BDL	0.25±0.01	0.0016±0.0002	0.11±0.01	BDL	BDL
3	0.18±0.01	0.27±0.01	0.0018±0.0001	0.20±0.01	BDL	BDL
4	BDL	0.26±0.01	0.0016±0.0001	0.19±0.02	BDL	BDL
5	BDL	0.29±0.01	0.0010±0.0002	0.26±0.001	BDL	BDL
6	BDL	0.25±0.01	0.0006±0.0002	0.18±0.01	BDL	BDL
7	BDL	0.28±0.02	0.0006±0.0001	0.04±0.01	BDL	BDL
8	BDL	0.29±0.01	0.0005±0.0002	0.12±0.01	BDL	BDL
9	0.05±0.01	0.26±0.01	0.0019±0.0001	0.07±0.02	BDL	BDL
10	0.03±0.01	0.25±0.01	0.0004±0.0001	0.04±0.01	BDL	BDL
LOD	0.01	0.001	0.001	0.0001	0.001	0.005
Recommended values in drinking water						

WHO	3.0	0.01	0.006	0.01	0.003	0.05
KEBS	5.0	0.05	0.001	0.01	0.005	0.05
NEMA	5.0	0.01	0.001	0.01	0.003	0.05

The values were obtained from KEBS: KS 05-459: Part 1: 1996, NEMA (2006) and WHO (2008).

The One Way ANOVA showed that p values were below 0.05, suggesting that seasonal variation and proximity of septic tanks to borehole waters had significant statistical effect on the levels on heavy metals in the water samples.

The study showed that Cd and Cr were below detection limits of 0.001 mgl^{-1} and 0.005 mgl^{-1} respectively in all the sites in the dry or the wet seasons (Table 4.3). Zinc was not detected during the wet season in the sites 2, 4, 5, 6, 7, and 8. The levels in these sites were below the detection limit of 0.01 mgl^{-1}. In the dry season the level of zinc ranged between 0.16±0.01 and 0.12±0.00 mgl^{-1} while the ranges for the other metals were as follows: Pb 0.42±0.011 (highest) to 0.22±0.02 mgl^{-1} (lowest); Hg 0.0019±0.0001 (highest) to 0.0002±0.0001mgl^{-1} (lowest); Mn 0.26±0.001 (highest) to 0.04±0.00 mgl^{-1} (lowest). For the wet season the range in the level of metals were: Pb 0.29±0.01 to 0.21±0.01 mgl^{-1}; Hg 0.0018±0.0001 to 0.0004±0.0001 mgl^{-1} ; Mn 0.26±0.001 to 0.07±0.02 mgl^{-1} (Table 4.3).

4.4 Variation of heavy metals levels in the selected ten borehole water in dry and wet seasons

4.4.1: Seasonal variation of zinc levels in the selected ten borehole water samples

The zinc (Zn) levels were greater in the dry than the wet season (Figure 4.13). Zinc in water samples was in the minimum range of 0.110± 0. 020 mgl^{-1} to a maximum of 0.23 ±0.07 mgl^{-1} during the dry season with a minimum range of below detection limits (BDL) to a maximum of 0.18 ± 0.01 mgl^{-1} in the wet season (Table 4.3). The lowest and highest zinc levels in the dry season were obtained from Sites 7 and 2 while the lowest and highest in the wet season were obtained from Sites 7 and 3 respectively (Figure 4.13). Site 2 is on a slope and in a densely populated area with septic tanks at a mean distance of 33 m. Zinc is found in humans diet and it may be found in feacal waste. Also surface run offs down the slope could be contributing towards elevated zinc concentration in water sample. Site 7 is at the bottom of the slope with septic tank at mean distance 16 m. The lowest zinc levels in site 7 during wet season could be attributed to dilution. WHO (2003) has listed fever, nausea, vomiting, stomach cramps, and diarrhea as some of the health complications caused by Zinc poisoning. The zinc levels were below the values set by WHO, KEBS and NEMA of 0.3 mgl^{-1}, 0.5 mgl^{-1} and 0.5 mgl^{-1} respectively (Table 4.3).

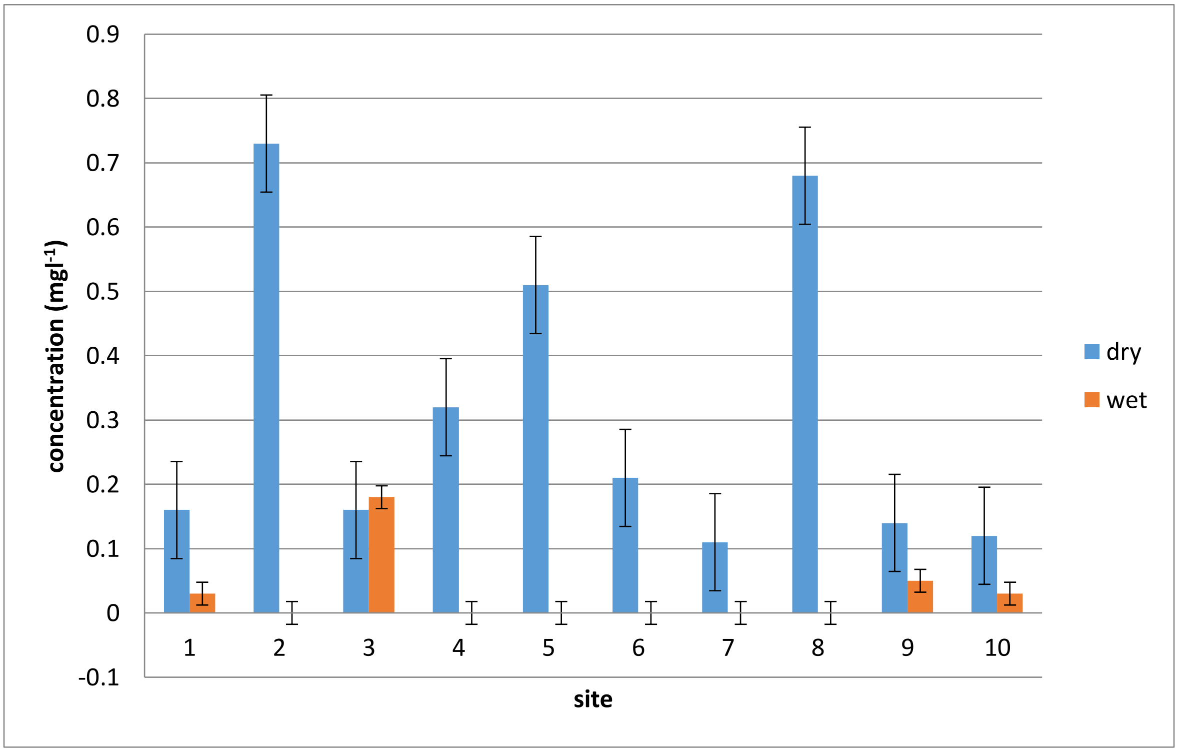

Figure 4.13: Seasonal variation of zinc levels in the ten borehole water samples

4.4.2: Seasonal variation of lead levels in the selected ten borehole water samples

The lead (Pb) levels in most samples were greater in the dry than the wet season (Figure 4.14). The lead-in water samples were in the minimum range of 0.220± 0. 010 mgl^{-1} to a maximum of 0.42 ±0.01 mgl^{-1} during the dry and with a minimum range of 0.28 ± 0.02 to a maximum of 0.29 ± 0.01 mgl^{-1} in the wet seasons (Table 4.3).

The lowest and highest lead levels in the dry season was recorded in Sites 7 and 5 in that order while the lowest and highest in the wet season were obtained from Sites 1 and 5 respectively

(Figure 4.14). The lead levels in all the sites was above the WHO, KEBS and NEMA maximum permissible limits of 0. 01 mgl^{-1}, 0.05 mgl^{-1} and 0.01 mgl^{-1} respectively in both the seasons (Table 4.3). Sites 1 and 7 are at Muslim Mosques, near very densely populated area near a slaughterhouses (Table 3.1). High human population/activities and waste water dischrges slaughterhouses could be contributing to high lead levels. Some of the effects of lead to human beings include: hypertension, brain damage, fatigue, anaemia and high quantities may cause metabolic poison which may result to death (Gautam *et al* 2014).

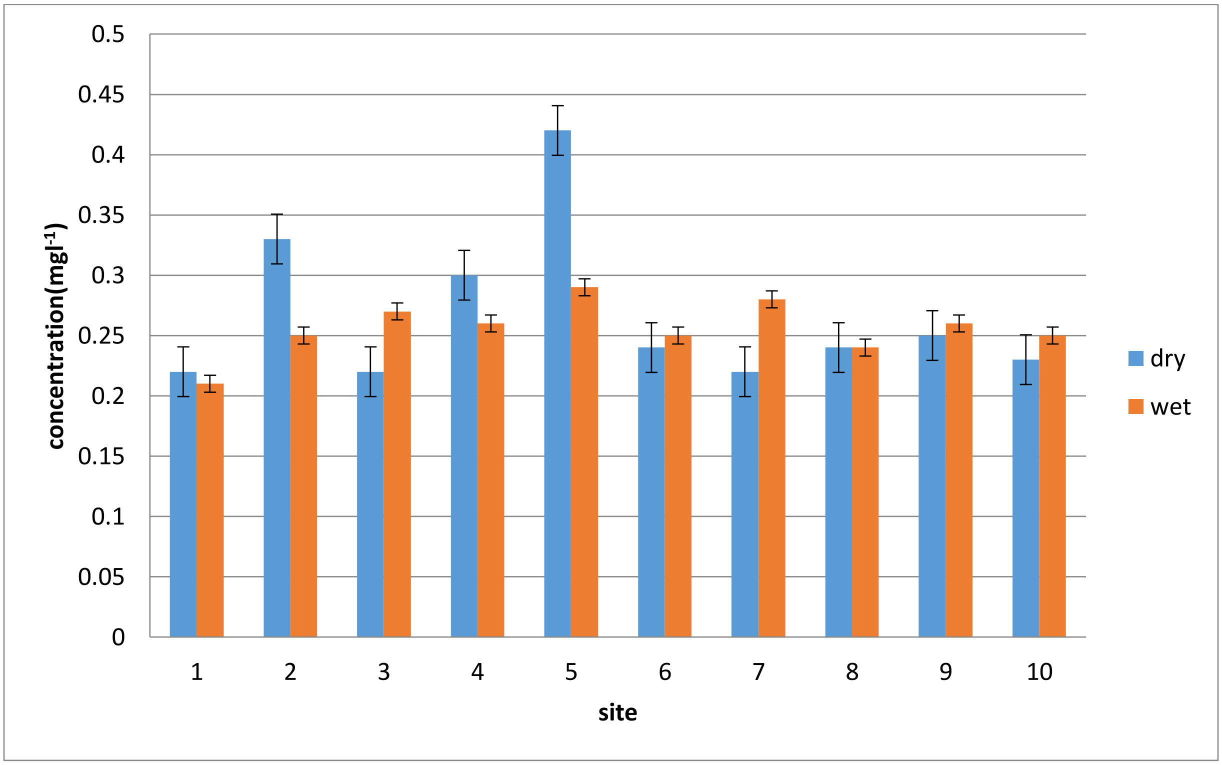

Figure 4.14: Seasonal variation of lead levels in ten borehole water samples

4.4.3: Seasonal variation of mercury levels in the selected ten borehole water samples

The mercury (Hg) levels in most samples were greater in the dry than the wet season (Figure 4.15). The mercury in water samples was in the range of 0.00020± 0.0001 mgl^{-1} to 0.0019.±0. 0001 mgl^{-1} during the dry season and with a minimum range of 0.0004± 0.0001 to a maximum of 0.0019±0.0001 mgl^{-1} in the wet season (Table 4.3)

The lowest and highest mercury levels in the dry season was obtained from Sites 10 and 4 respectively while the lowest and highest in the wet season were obtained from sites 10 and 9 (Figure 4.15). The levels of mercury in both dry and wet seasons were within WHO, KEBS and NEMA allowable limits of 0.006 mgl^{-1}, 0.001 mgl^{-1} and 0.001 mgl^{-1} respectively. Site 10 and 4 are at individual homesteads with low population of people, may not cause high contaminations. Mercury has been found to be carcinogenic and poisonous (Gautam *et al*, 2014), (LeBeau, 2008) reported that mercury caused impaired growth in babies. The borehole at site 4 for example has been in use for 15 years (Table 3.1)

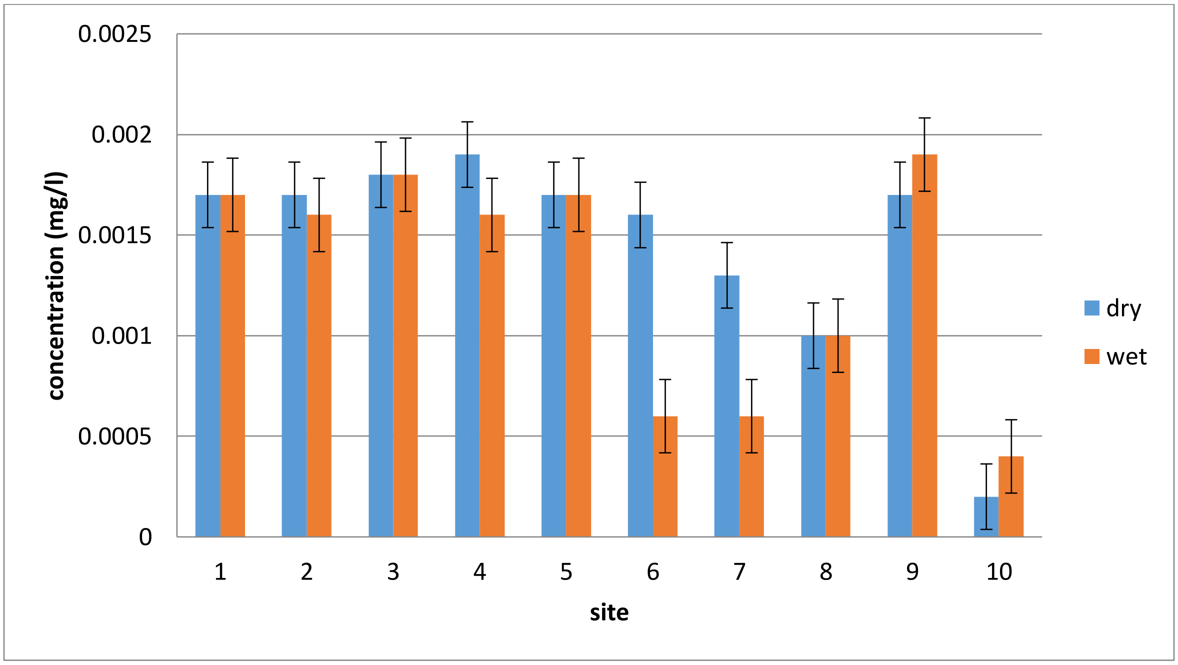

Figure 4.15: Seasonal variation of mercury levels in ten borehole water samples

4.4.4: Seasonal variation of manganese levels in the selected ten borehole water samples

The manganese (Mn) level in most samples were higher in the dry than the wet season (Figure 4.16). The manganese in water samples were in the minimum range of 0.03±0.01 mgl^{-1} to a maximum of 0.26±0.001 mgl^{-1} in the dry season with a minimum range of 0.04±0.001 mgl^{-1} to a maximum of 0.26±0.001 mgl^{-1} in the wet season (Table 4.3). The lowest and highest manganese levels in the dry season was observed from Sites 10 and 5 while the lowest and highest in the wet season were obtained from Sites 7 and 5 respectively (Figure 4.16) .

Manganese levels were generally higher in all the samples (Tables 4.3) than the recommended levels of 0.01 mgl^{-1} by WHO, KEBS and NEMA in drinking water (Table 4.3). Site 10 is Ndungu Ole Kapara borehole in a remote area with low population that may not contaminate the water. This could be attributed to high presence of manganese in rocks or soil in the area. Site 5 borehole is at the chief's camp in a densely populated area that can cause water contamination. Site 7 is a Muslim mosque and a slaughterhouse nearby in a densely populated area (Table 3.1) that may cause water contamination. According to Singh *et al* (2014), slaughterhouses are a significant source of water pollution and some of impacts include: release of highly polluted effluent containing blood and feacal matter which may find its way to water sources. Densely populated areas suffer from strain on available amenities that includes waste disposal systems and water (Abong'o *et al*., 2017). Some of health effects caused by Manganese include; hallucinations, Forgetfulness, nerver damage, Parkinson disease, Lung embolism and bronchitis (Gautam *et al*., 2014).

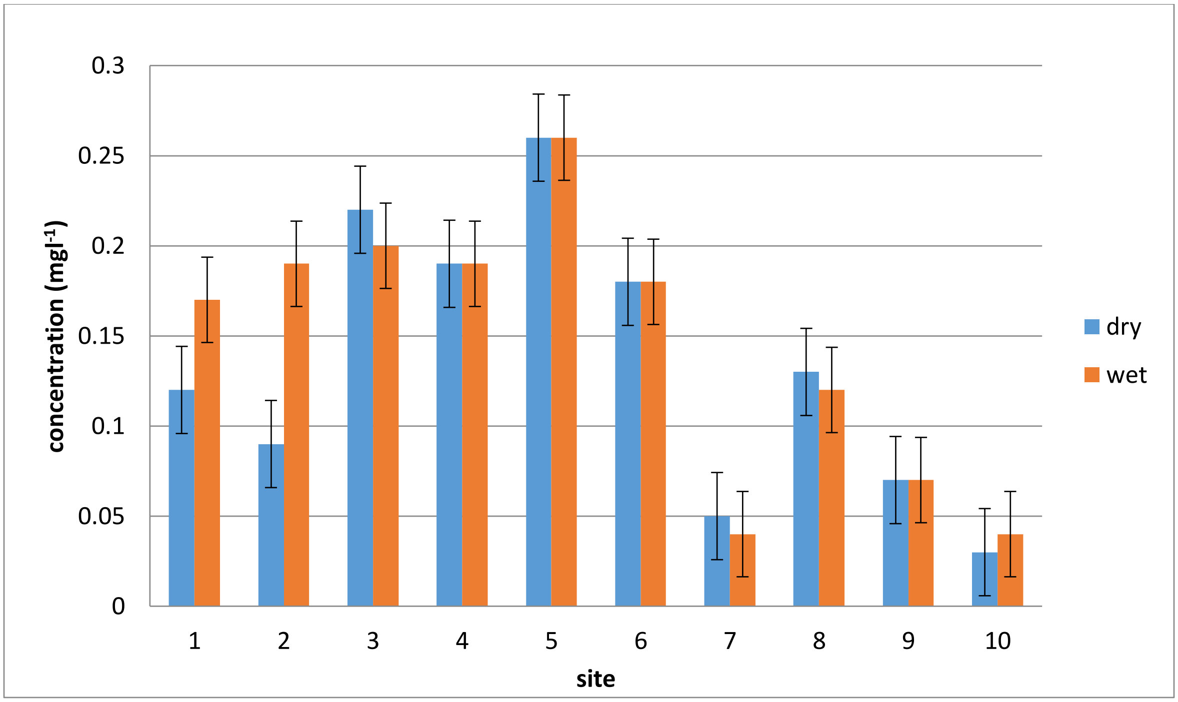

Figure 4.16: Seasonal variation of manganese levels in water samples

4.4.5: Seasonal variation of Cadmium and Chromium levels in the selected ten borehole water samples

The cadmium and chromium levels were below detectable limits (BDL) of 0.001 mgl^{-1} and 0.005 mgl^{-1} respectively in both the seasons for all the borehole water samples analyzed as displayed in Table 4.3. Some of the health effects caused by cadmium are: it causes serious damage to kidneys and bones in human, Bronchitis, emphysema, anemia, and acute effects in children (Gautam *et al*, 2014) On the other hand Chromium has been found to cause necrosis nephritis and death in people as well as irritation of the gastrointestinal lining. The study shows that seasonal variation had no effect on levels of cadmium and chromium.

4.5 Effects of septic tank distances on the levels of physico-chemical parameters and heavy metals in ten borehole samples

4.5.1: Effects of septic tank distances on physico-chemical parameters

4.5.1.1: Effects of septic tank distances on the levels of pH

Generally, the pH values were within the WHO and KEBS values as shown in Table 4.2 irrespective of the distances of the boreholes from the septic tanks. The pH during the dry season ranged from 7.4 ± 0.1 to 8.1. ±0.1 while during the wet season it ranged between 7.1 ± 0.1 to 7.7 ± 0.1 in the water samples (Table 4.2) while lowest and highest levels from WHO (2008) and KEBS (2007) are 6.5 to 9.2 and 6.5 to 8.85 respectively, however EPA (2001) suggests that public water systems should have a pH between 6.5 and 9.0, which is a formidable guide for individual borehole owners. Site 5, nonetheless, was found to have higher pH values of 8.6 and 8.5 in dry and wet seasons respectively, it is notable that it has 4 tanks within 15m while WHO recommends a distance of >15 m. The lowest pH was at site 3 (6.6 ±0.01) with the closest septic tank mean distance being at 24 m. Site 10 having a mean distance of 146 m from the tanks, still has pH values of 7.7± 0.01 within WHO and KEBS in the wet season. The distances of the septic tanks have no effects on pH levels in the borehole water. Hassan *et al* (2017), reported that pH was a significant parameter as it affected chemical and biochemical reactions. They further added that high or low pH values in water affected the biota, impeding recreational uses of water as well as altering the toxicity of the pollutants for instance heavy metals.

4.5.1.2: Effects of septic tank distances on the levels of Dissolved Oxygen (DO)

DO was generally highest during wet season than the dry season (Figure 4.3). The lowest DO in both the dry and wet seasons were obtained from Sites 2 (1.22± 0.01 mgl^{-1}) and 10 (3.75±0.01 mgl^{-1}) which are at mean septic distances of 60.8 m and 146 m respectively. The highest levels in the dry and wet seasons were obtained from Sites 8 (3.28 ± 0.01 mgl^{-1}) and 7(4.83±0.01 mgl^{-1}) respectively (Table 4.2). Sites 8 and 7 which had mean septic tanks distances of 33 m and 16 m (Table 3.2). The DO values obtained from all the ten borehole water samples were below WHO and KEBS recommended levels of DO of 6 mgl^{-1} (Table 4.2). Hence septic tanks have no effects on the borehole water DO values. Kibria (2004) stated that DO levels affected palatability levels of water and while Hassan *et al* (2017), reported that DO had great significance as a measure of quality of water.

4.5.1.3: Effects of septic tank distances on the levels of Electrical Conductivity (EC)

In general**,** electrical conductivity (EC) values were comparably high during the dry season than the wet season (Figure 4.9). Site 10 with a mean septic tank distances of 146 m recorded the highest values in both dry and wet seasons; of 312 ±1.0 µscm^{-1} and 301±0.01 µscm^{-1} respectively (Table 4.2)

The lowest value of 254±1.0 µscm^{-1} was for the dry at site 5 with mean septic tank of 16.2 m while during the wet season lower values of 233 ±1.0 µscm^{-1} at site 2 a mean distance of 33 m. All the values in both dry and wet seasons were observed to be below the WHO, KEBS and NEMA guidelines of 500 µscm^{-1}, 1000 µscm^{-1} and 1000 µscm^{-1} respectively (Table 4.2). EC is an indirect indicator of pollution due to its relationship with dissolved salts in water usually associated with sewage discharge hence a measure of water quality parameter (Hassan *et al* (2017). From the results, it can be concluded that the septic tank distances had no effect on EC levels.

4.5.1.4: Effects of septic tank distances on the levels of TDS

The lowest TDS in both the dry (639±1.05 mgl^{-1}) and wet (630±1.3 mgl^{-1}) seasons was obtained from Site 5 while the highest in the dry (980±1 mgl^{-1}) and wet (966±1 mgl^{-1}) seasons was obtained from Site 10 (Figure 4.10). Sites 5 and 10 which had mean septic tanks distances of 16.2 m and 146 m respectively (Table 3.2) gave the lowest and highest TDS values in dry and wet season respectively (Figure 4.10). According to WHO (2003), there are no health effects associated with TDS in drinking water. Therefore septic tank distance did not affect the level of TDS in the borehole water samples. All TDS values obtained were slightly above WHO recommended limits of 600 mgl^{-1} but within KEBS and NEMA limits of 1500 mgl^{-1} and 1200 mgl^{-1} respectively.

4.5.1.5 : Effects of septic tank distances on the levels of Turbidity

Turbidity was generally high during the wet season than the dry season. The highest values were recorded in sites 5 and 7 which have a mean distance of 16.2 m and 16 m respectively (Table 3.2). The values were 0.09±0.01 NTU and 0.07±0.01 NTU respectively in the dry season and 0.018±0.02 NTU and 0.017±0.01 NTU in the wet season (Table 4.2). The lowest values 0.04±0.01 NTU were recorded in borehole 10 at a mean of 146 m during the dry season while Site 3 and 6 recorded the lowest during the wet season, 0.06±0.01 NTU. Each site are at 60.8 m and 120 m respectively (Table 3.2). Sites closer to septic tanks were observed to have higher turbidity values in both dry and wet season.

Sites 6 and 5 have mean septic tanks distances of 120 m, and 16.2 m respectively (Table 3.2). Site 5 at mean septic tank distance of 16.2 m gave the highest turbidity values in dry and wet season, that were below WHO, KEBS and NEMA guide lines (Figure 4.11). Turbidity values obtained in both seasons are below the recommended guidelines of 5 NTU by WHO, KEBS and NEMA (Table 4.2). Turbidity, was reported no to have a significant effect on human health, it is affects the appearance of water (WHO 2008).

4.5.1.6: Effects of septic tank distances on the levels of TSS

Total suspended solids (TSS) values were highest during the wet as compared to the dry season. Site 1 recorded the highest values for both dry and wet season of 2.4±0.01 mgl^{-1} and 2.6±0.01 mgl^{-1} (Table 4.2) at a mean distance of 63 m (Table 3.2). Site 6 recorded the lowest values in both dry and wet season of 0.9±0.01 mgl^{-1} and 1.3 ±0.01 mgl^{-1} (Table 4.2) at a distance of 120 m (Table 3.2). Generally furthest sites recorded the least TSS values.

Site 1 with a mean septic tank distance of 63 m (Table 3.2) gave the highest TSS values in both seasons while Site 6 at mean septic tank distance of 120 m gave the lowest values (Figure 4.12). The high values in the wet season could be due to the influx of particles or run-off in boreholes. The low level during the dry season could be as a result of sedimentation and reduction in water level. The TSS values obtained from water samples were below WHO and NEMA values, 500 mgl^{-1} and 30 mgl^{-1} respectively. High levels of TSS in water makes it unpalatable, reduce efficiency of treatment of wastewater plants as well as affect industrial process that use raw water (US EPA 2002). There is no recommended TSS values by KEBS (Table 4.2).

4.5.2 Effects of septic tank distances on the levels of heavy metals

4.5.2.1: Effects of septic tank distance on the levels of Zinc

Zinc levels were higher during dry seasons irrespective of the distance from the septic tanks. Higher levels of 0.73± 0.01 mgl^{-1} were recorded in site 2 which is 33 m away, while the least was in site 7 and 16 m away, 0.11± 0.02 mgl^{-1} during the dry season (Table 4.3). Site 3 had the highest concentration of Zn at 0.18±0.01 mgl^{-1} during the wet season at 60.8 m (Table 3.2). The mean septic tank distance did not play a huge role in the levels of Zn in the water samples. Sites 2, 4, 5, 6, 7, and 8 had Zn levels below the detection limits (Table 4.3). The values were within WHO, KEBS and NEMA at 3.0, 5.0 and 5.0 mgl^{-1} respectively in the wet season. This could be due to the dilution effect of groundwater in the wet season, as likened to the dry season, where the groundwater flow levels were very low allowing more time for the galvanized steel pipes from the pump to be corroded.

Zinc levels were high in dry weather, probably due to zinc galvanized pipe corrosion. The level of zinc in the dry season was maximum in borehole number 5 situated in a high-density housing zone with a public toilet at an administration office, a church and a market, septic tank was 15m away, on flat ground. Zinc sources from the nearest households that could be disposed of as domestic wastewater would come from cosmetics, medicines, antiseptic products, coloring pigments, and ink therefore causing significant zinc levels. However, the level of Zn is within the WHO limit of 3.00 mgl^{-1}. In the wet season, Zinc was below detectable limit, except in site 9 (0.05±0.01) mgl^{-1}

at a mean 32 m from a septic tank, and a flat with about 30 houses and site 10 in a remote area, with a history of horticulture farming, and 146 m away from the septic tank. These two sites showed no significant seasonal variation for zinc.

Though naturally found in nature, there are also anthropogenic sources, looking at the average and minimum proximity distances from septic tanks, that household products containing zinc oxide and zinc sulfide for instance disposal of zinc chloride batteries. Zinc oxide is used to make various products including make-up, and prescription drugs. Including other dietary sources present in human feces, could avail zinc into the subsurface. The selected boreholes sites were all constructed with a 4 inch (diameter) steel casing and 2 inch galvanized pipes immersed below the water rest level to the pump. The intimate contact, in pH<7, likely anions present and dissolved oxygen >1ppm, makes the water corrosive (pourbiax relation), and likely to avail zinc ions in water (Hashim *et al*, 2011) The wet season samples showed lower levels of zinc, this is likely as a result of dilution.

Mobility of zinc in soil with low pH, due to precipitation had no significant rise in zinc levels as observed. Sites 2 and 7 with mean septic tanks distance of 33 m and 16 m (Table 3.2) gave the highest and lowest Zn values in dry and wet season respectively (Figure 4.13). The Zinc concentrations in both the dry and wet seasons were within WHO, KEBS and NEMA allowable limits of 3.0 mgl^{-1} , 5.0 mgl^{-1} and 5.0 mgl^{-1} respectively (Table 4.3).

4.5.2.2: Effects of septic tank distance on the levels of lead

The lead was observed in all water samples with the highest values in site 5 for both dry and wet seasons; 0.42 ±0.011 mgl^{-1} and 0.27±0.00 mgl^{-1} (Table 4.3). The mean septict tanks distance was 16m, however, tank A and B are within 9 m and 12 m respectively (Table 3.2). The lowest levels were recorded in site 1 at 63 m for both dry and wet season 0.22 ±0.02 mgl^{-1} and 0.21±0.01 mgl^{-1} respectively, (Table 4.3). Generally, the boreholes near the tanks had higher levels of Pb. The levels were above recommended levels by WHO 0.1 mgl^{-1} and NEMA 0.1 mgl^{-1} but within KEBS 0.5 mgl^{-1} levels for both dry and wet seasons.

The area is densely populated there is no elaborate waste disposal as well as waste management practices in the area. Chemicals used in farming over time could have accumulated in the environment and later contaminated groundwater, there is an abandoned horticulture farm (Oves *et al*., 2016). The septic tank waste disposal is not entirely effective, the waste may leak and contaminate groundwater.

The baseline values were not available, but the availability of lead in solution, based on the corrosivity of the water, shows that it is likely that human activity has had an accumulative effect to reach this level probably as a result of disposal of lead ions from human activity for instance fecal matter containing trace levels over time, disposal of leaded petroleum products, runoff from roads as particulate or as soluble lead into streams to groundwater recharge zones as non-point sources before the leaded petrochemicals were controlled (Oves *et al*., 2016). It is also notable that there is a glass manufacturing facility, upstream as seen from the map of Rongai, a non-point source.

In the wet season, the level of lead was lower due to dilution. Mobility of lead in soil with low pH would mean that factors on the surface for instance acidic precipitation, acidic domestic effluent but in this study, no significant rise in lead levels was observed. Sites 5 with mean septic tanks distance of 16.2 m gave the highest lead values in the dry and wet season while site 1 at 63 m (Table 3.2) had the lowest levels in dry and wet seasons (Figure 4.9).

4.5.2.3: Effects of septic tank distance on the levels of Mercury

Site 10 at a mean of 146 m had the least levels of Hg 0.0002 ±0.0001 mgl^{-1} and 0.0004 ±0.0001 mgl^{-1} for both dry and wet season (Table 4.3). Site 4 at 31.4 m had the highest levels of Hg during the dry season 0.0019 ±0.0001 mgl^{-1}, (Table 4.3) while 9 at 33 m had the highest levels of 0.0019 ±0.0001 mgl^{-1} in the wet season which was slightly above KEBS and NEMA Admissible levels. It was observed that boreholes closer to the septic tanks recorded higher levels of mercury in both dry and wet seasons. The levels were within both admissible levels of both WHO, KEBS and NEMA limits at 0.006, 0.001 and 0.001 mgl^{-1} respectively (Table 4.3)

Mercury was present in all water samples analyzed. The season did not have much effect on the levels of mercury in the samples. Highest levels were in the dry season, 0.0017 mgl^{-1} in site 1, 30 m away from the septic tank and lowest value in site 10, 146m away, in the dry season, 0.0002 mgl^{-1}. Below WHO maximum limit of 0.006 mgl^{-1}. The dense population in the area has probably put pressure on the available waste disposal system for instance the septic tanks.

Mercury can be found in cosmetic products, batteries, fluorescent light tube bulbs, (Oves *et al*., 2016). which could be incorrectly disposed of in wastewater together with feces in septic tanks, landfills, etc. Results of the wet season would suggest that the Hg from atmospheric deposition, from a non-point source or surface water, would have contributed to the detectable Hg concentrations in groundwater. Because no complaints or a crisis has arisen from mercury poisoning, the species of mercury likely detected in boreholes is not the bioavailable species.

Mercury emitted from anthropogenic sources include like landfills, dental treatments, and laboratory use, medical waste incinerators, burning municipal waste, manufacture of cement and other industrial processes (Gautam *et al*, 2014). The lower concentration of mercury in the rainy season would be due to dilution and proximity from point sources of pollution.

4.5.2.4: Effects of septic tank distance on the levels of Manganese

The highest levels were recorded in site 5 at 16.2 m for both dry and wet season, 0.26 ±0.001 mgl^{-1} (Table 3.2, and Table 4.3) respectively. Site 10 recorded the least levels in both dry and wet season, 0.04± 0.01 mgl^{-1} and 0.03 ±0.00 mgl^{-1} respectively (Table 3.2, Table 4.3). It was observed that boreholes near septic tanks had higher levels of manganese as likened to the ones that are far. Also, Mn levels were higher in all sites as compared to recommended values for WHO, KEBS and NEMA at 0.01mgl^{-1}. High levels of Mn were seen in boreholes closest to high-density onsite disposal of domestic effluent, where fecal matter/ human waste is rich in manganese.

Most steel alloys contain iron and manganese, probably contained in the 4 inch diameter steel casing used in boreholes construction. In the human diet, Mn is very common because tea and most diets are very rich in Mn (WHO 2011). The extent to which Mn dissolves in undergroundwater is influenced by the corrosivity of the water, the amount of oxygen in the water and, its pH. Precipitation in acidic soil, soil pH and human activity would mobilize Mn during recharge (WHO 2011)., if available. All sites had no significant increase in levels of manganese ions, even after the wet season, it could be because human activity has no significant contribution, and precipitation caused dilution in the boreholes. Site 5 with a mean septic tanks distance of 16.2 m (Table 3.2) gave the highest manganese values in the dry and wet season while site 10 at 146 m was observed to have the least values in dry and wet seasons (Figure 4.11).

4.5.2. 5: Effects of septic tank distance on the levels of Cadmium and Chromium

The quantities of Cd and Cr were below detectable limits irrespective of all the boreholes water from the septic tanks in the sites during both dry and wet season (Table 4.3). Cadmium and chromium were found to below detectable limits. This could mean that human activities for instance E-waste dumping, agrochemicals, some fertilizers possess Cd as impurities, especially phosphate fertilizers (Oves *et al*., 2016). had no influence on Cd and Cr residue levels. Cadmium is also used in the electric and electronic industry and as a pigment or improper landfills (Oves *et al*., 2016).

The poisonous species, hexavalent chromium, is highly soluble and easily moves within the environment was not observed; which was not evident in the area at the time of the study. The water samples can be concluded to be free from Cd and Cr contamination therefore safe for human consumption as they were below limits of detection yet the recommended limits by WHO, KEBS and NEMA are 0.003 mgl^{-1}, 0.005 mgl^{-1}, 0.003 mgl^{-1} respectively for Cd while Cr is 0.05 mgl^{-1} for all the three bodies (Table 4.3).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The physico-chemical parameters (total dissolved solids, turbidity, conductivity, pH and dissolved oxygen) of the borehole water that were analyzed showed no influence on the levels of heavy metals. There was a seasonal variation in the levels of heavy metals in the boreholes as it was observed that levels of heavy metals were higher in the dry season than in the wet season. However cadmium and chromium levels were below detectable limits (BDL) in both the seasons for all the borehole water samples analyzed.

The lead levels in all the sites were above the WHO, KEBS and NEMA maximum permissible limits of 0. 01 mgl^{-1}, 0.05 mgl^{-1} and 0.05 mgl^{-1} respectively in both the seasons. Manganese levels were generally higher in all the samples than the recommended levels of 0.01 mgl^{-1} and 0.03 mgl^{-1} by WHO and KEBS in drinking water respectively except Site 10 where the value was within the recommended level of 0.03 mgl^{-1} within KEBS limits of manganese in the dry season.

The proximity of the boreholes to the septic tanks had no strong significant effect on the levels of heavy metals in the water samples this is because some boreholes showed elevated levels of heavy metal yet they were far, but the levels of zinc, mercury , manganese, cadmium and chromium were within the levels recommended by WHO and KEBS. However, it was observed that human activities had a huge influence on the levels of heavy metals. The human activities included: slaughter houses, abandoned flowers farm, and increased population density for instance borehole 5 was in a densely populated area and had 4 septic tanks within the 15 m radius had high levels of heavy metals and physico-chemical parameters.

5.2 RECOMMENDATIONS

This study recommends that:

1. Regular analysis of the heavy metals in borehole water be conducted due to their accumulation nature with time.
2. WRMA to document the number of boreholes in the area and to provide guidelines on setting up new ones.
3. The residents should have their septic tanks checked concerning the location of water boreholes.
4. The microbiological assay should be done for the Ongata Rongai, borehole water.
5. The source of highly toxic metals like, Pb Hg, Cd, and Cr in water be investigated further.

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APPENDICES

Appendix 1: Sample Questionnaire

Questionnaire (for Heavy metal problems in borehole water in Ongata Rongai- to water vendors /borehole owners, health practitioners/ local dispensaries/ teachers/ nannies, residents and consumers). Q stands for Question.

Q: Are you aware of the quality of the water you drink / the level of water pollution?

Common indicators of high levels of metal ions include effects like objectionable taste (bitter first runs, metallic, or any other objectionable taste and smell), corrosion of plumbing fittings exposed to air, which appear as coloured stains; like black, white, grey, green, brown etc and leaking metal pipes/ tanks/ fittings.

Q: Have you noticed any of these effects? Which ones?

Q: Do you treat your water before consuming? If so, how?

Today, contamination of heavy metal in drinking water present a risk to humans and is often the origin of various fatal health effects such as cancer, organ damage and other detrimental health problems.

The availability of heavy metals cannot be observed with naked eyes however can be detected by a water test.

Q: Do you know about heavy metals?

Q: Is your water tested for heavy metals? If so do you have any data/ analysis report of it?

The heavy metals are gradual toxin to your health as they lack an instant effects in your body.

Q: Have you noticed any adverse/ unusual health related kidney, liver, cancer, mental conditions developing over time? (Five years).

Heavy metals ingress into the water sources through industrial, urban, and domestic effluents and also from acid rain emitting dangerous heavy metals into the undergroundwater reservoir and entering the water sources.

Q: Have you observed / concerned about these activities within this neighborhood?

Some heavy metals found in drinking water for instance lead, mercury, arsenic, and cadmium have no useful impact in the body. As a matter of fact, their build up in the body can lead to chronic health effects

Q: Have you diagnosed/ treated any of the symptoms or/ and health problems associated with toxicity of these heavy metal's by ingestion? If so, which are these? Any statistics?

Children are most vulnerable to the hazardous nature of heavy metals as they are still in developmental stages. The progressive build-up of heavy metals in their bodies may affect their nervous system which may translate to learning difficulties, amnesia and additionally, lead to behavioral changes in the form of aggression and hyperactivity.

Q: Have you noticed any of these issues with the resident children in your school? Any statistics?

Appreciate the interviewee and take any other notes related to this investigation.

Appendix 2: Single Way ANOVA for Physico-chemical parameters levels in water sampled from the 10 selected boreholes in dry and wet seasons

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
pH	20	151.7	7.585	0.306605
DO Mg/l	20	63.61	3.1805	1.462331
EC (µscm^{-1})	20	5499	274.95	457.2079
TDS Mg/l	20	16264	813.2	12613.01
Turbidity (NTU)	20	1.71	0.0855	0.001363
TSS Mg/l	20	31.8	1.59	0.176737

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10701570	5	2140314	982.3838	6.08E-92	2.293911
Within Groups	248371.1	114	2178.694			
Total	10949941	119				

Appendix 3: Single Way ANOVA for Heavy metals levels in selected ten borehole water samples in dry and wet seasons

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Zn mg/l	20	3.43	0.1715	0.049877
Cd ml/l	20	0	0	0
Cr mg/l	20	0	0	0
Pb mg/l	20	5.28	0.264	0.002288
Hg mg/l	20	0.0263	0.001315	3.21E-07
Mn mg/l	20	2.72	0.136	0.005362

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.258396	5	0.251679	26.24966	1.45E-17	2.293911
Within Groups	1.093021	114	0.009588			
Total	2.351417	119				

Appendix 4: FAAS Calibration curves for heavy metals

The calibration curves for zinc, lead, mercury, manganese, cadmium and chromium (Appendix 4, Figures 4A, 4B, 4C, 4D, 4E and 4F) were prepared using various concentrations of the selected heavy metals standards prepared in section 3.8.1.1 – 387.1.6 respectively and analysis was done with FAAS using the condition given in Table 3.3.

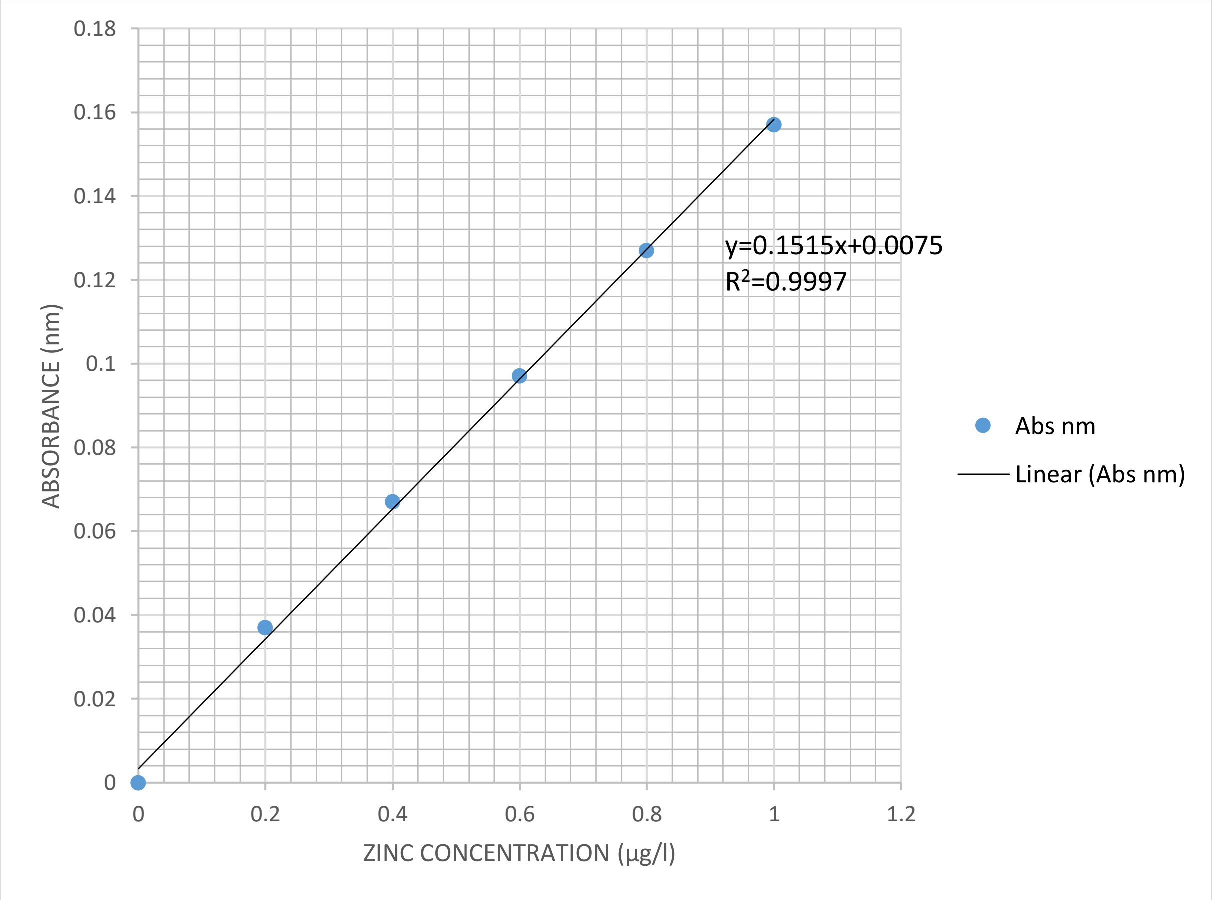


Figure 4A: Calibration curve for Zinc

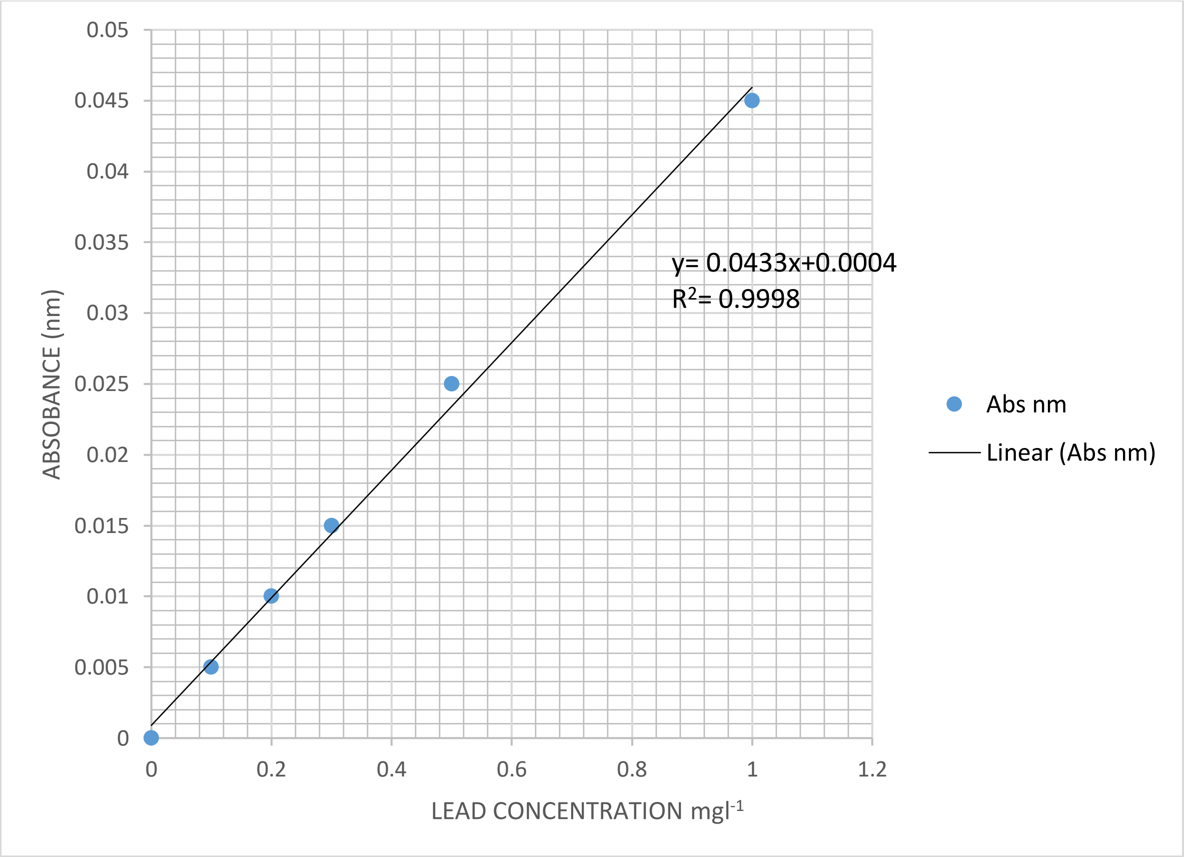


Figure 4B: Calibration curve for Lead

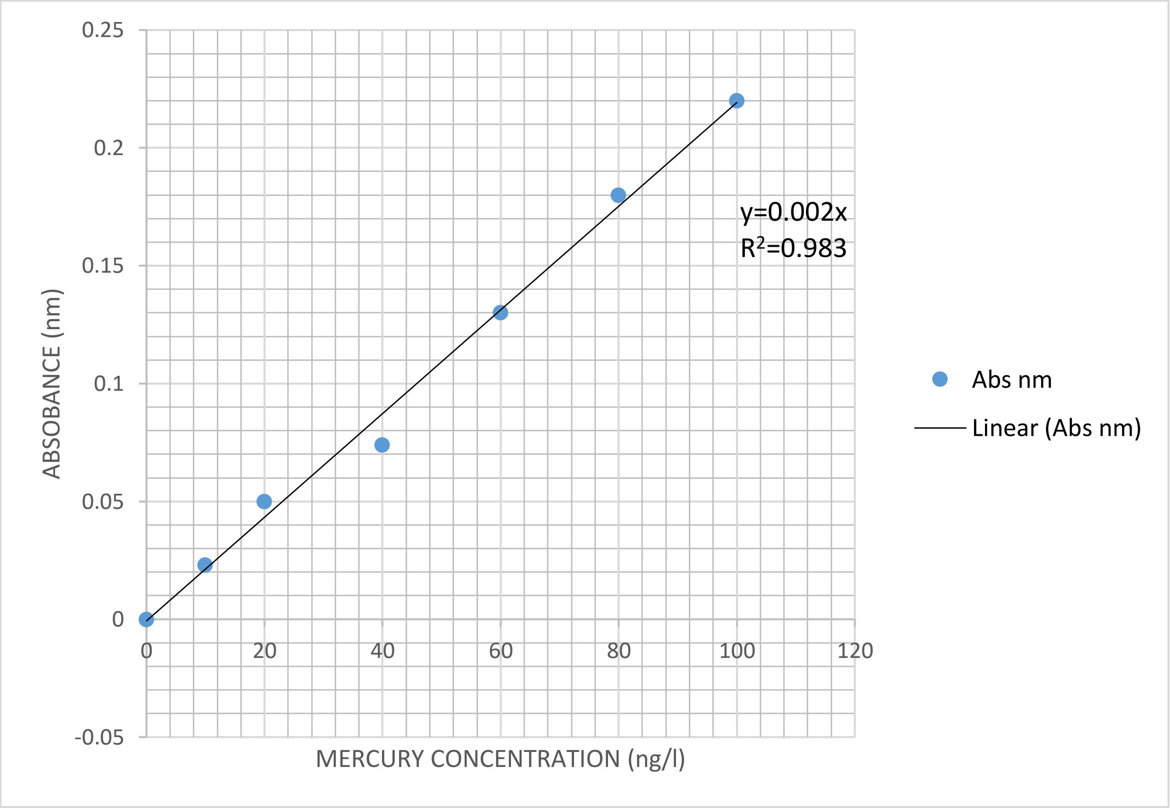


Figure 4C: Calibration curve for Mercury

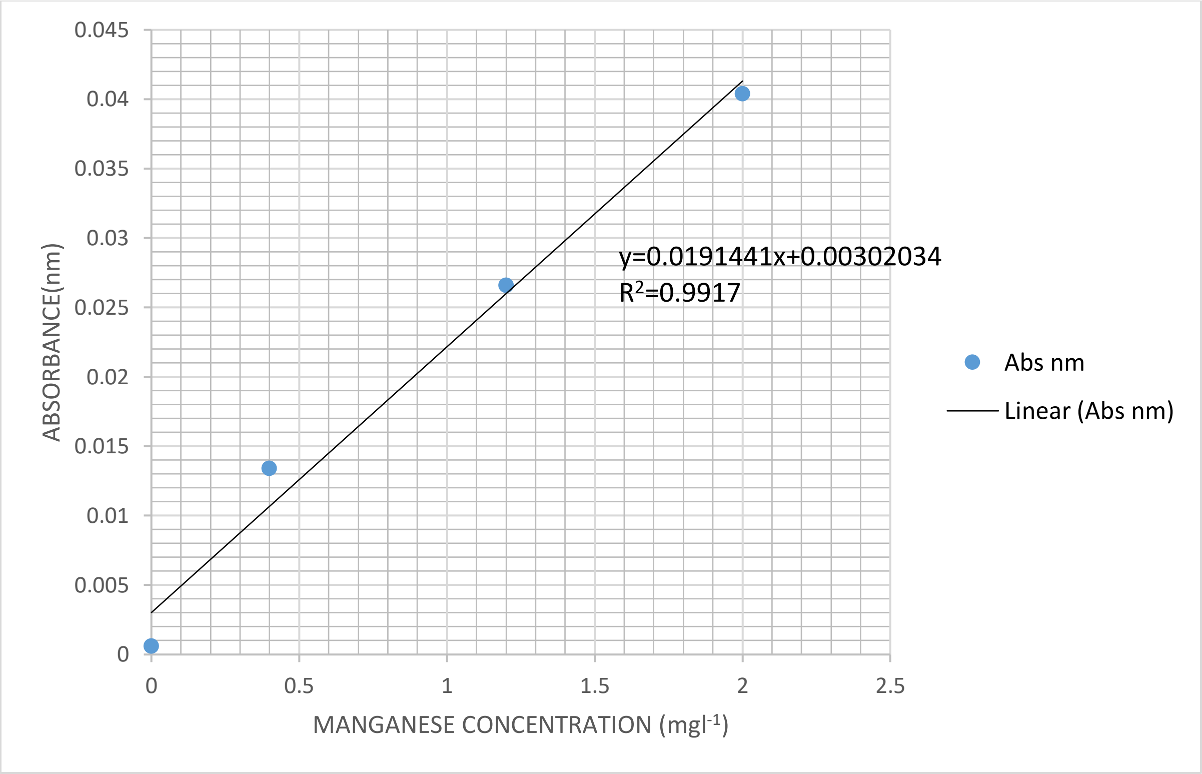
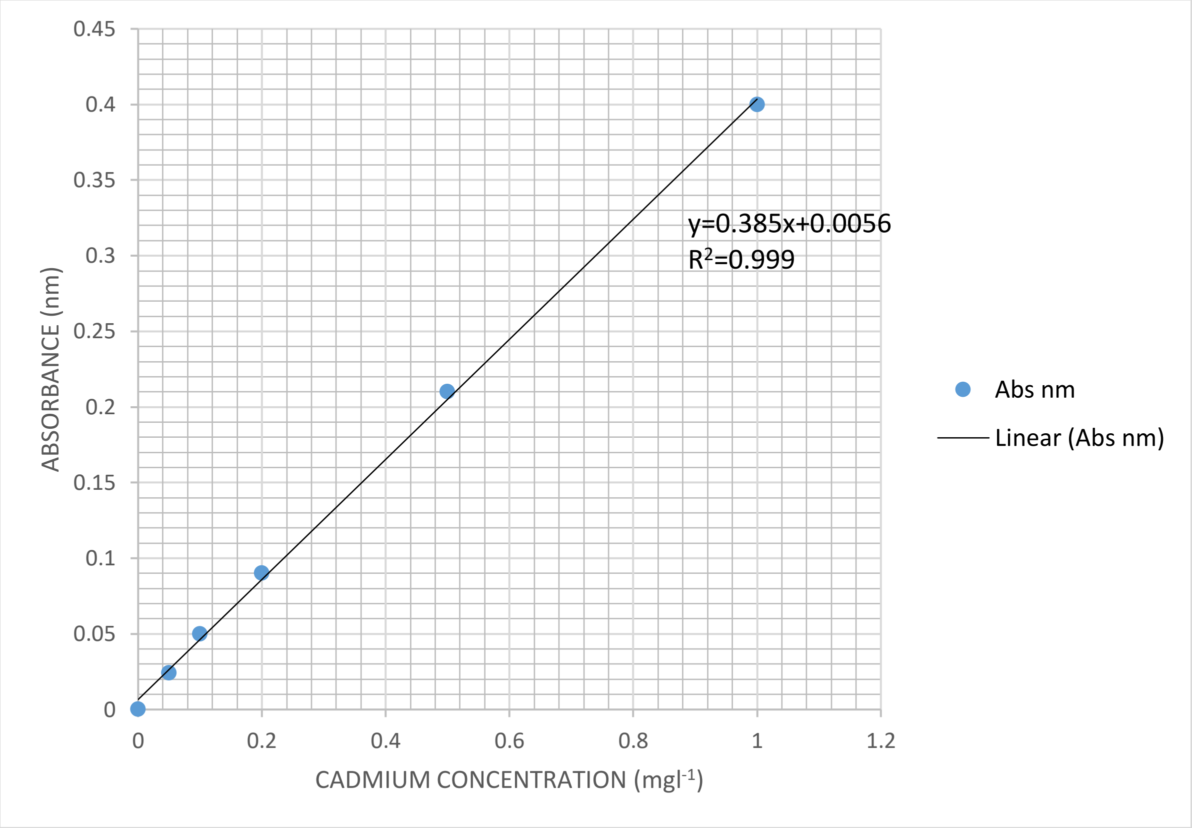


Figure 4D: Calibration curve for Manganese



Figures 4E: Calibration curve for Cadmium

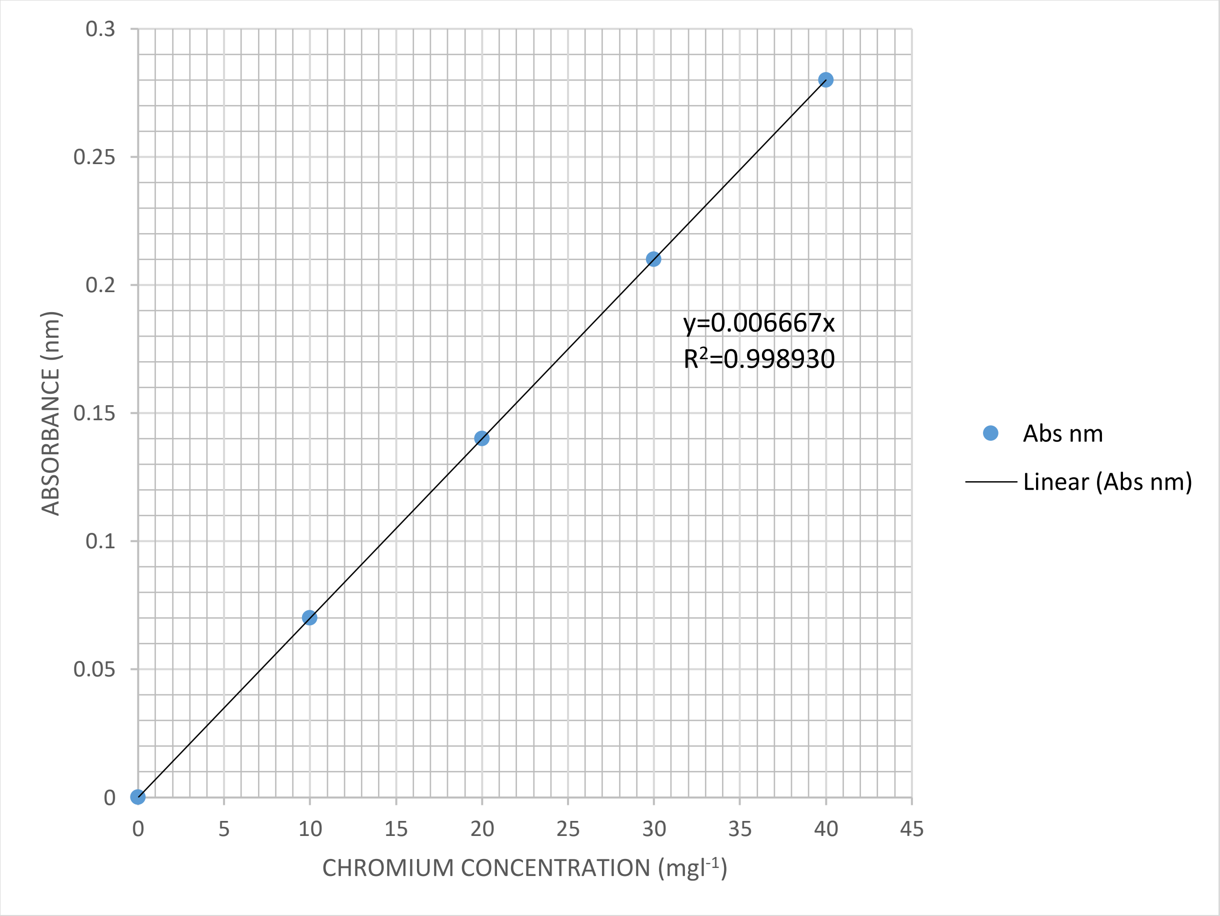


Figure 4F: Calibration curve for Chromium