UNIVERSITY OF NAIROBI

ASSESSMENT OF DISSOLVED IONS AND MICROBIAL COLIFORMS IN WATER FROM SELECTED SITES OF THE UPPER ATHI RIVER SUB-CATCHMENT AREA, KENYA.

BY

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DECLARATION

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

Signature. …………………………………….. Date………………………….

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DEDICATION

I dedicate this thesis to the Almighty God for the gift of life, and to my lovely wife Susan, son Brayden, mum Serah and brother Jonah. It has taken your support to complete this work and thank you for your love.

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ABSTRACT

The Upper Athi River sub-catchment area has experienced exponential growth of human population since the turn of the century. This has led to establishment of satellite towns such as Ngong, Kiserian, Ongata Rongai, Mlolongo, Kitengela and Ruai. These towns have either no or inadequate supply of water from the local governments, that is, Kajiado, Machakos and Nairobi. Communities in this area of study have therefore resorted to obtaining ground water through drilling boreholes and digging shallow wells for their domestic needs. This is done without proper information on whether the water meets quality standards set out by Kenya Bureau of Standards (KEBS). This study therefore sought to assess the water quality in this area to determine whether ground water meets these standards. It also compared these levels of dissolved ions and coliforms to those of river water in the recharge area of the Upper Athi sub-catchment area.

Twenty one water samples comprising of eleven boreholes, five shallow wells and five river water samples were collected from the Upper Athi sub-catchment area in the months of December 2011 which was a dry month and in May 2012 which was a wet month. The samples were analysed for dissolved ions and microbial coliforms. The metal ions analysed included Ca, Cd, Cr, Cu, Fe, Mg, Mn, Na, Pb and Zn while anions included Cl^-, CO_3^{2-}/HCO_3^-, F^-, NO_2^-/NO_3^- and SO_4^{2-} as well as faecal coliforms. Physical parameters analysed included pH, electrical conductivity (EC) turbidity, total dissolved solids and colour. The analysis of cations was carried out using atomic absorption spectrophotometry while chlorides and total alkalinity were analysed using titrimetric method. Levels of fluoride and nitrate were analysed using ion selective electrodes, sulphate using gravimetric method and microbial coliforms using lactose broth methods. The results showed that levels of dissolved ions in ground water were higher than in surface water while surface water had higher number of faecal coliforms. The high levels of dissolved ions in ground water was attributed to the geology of area while high levels of iron and faecal coliforms in river water samples was attributed to anthropogenic activities

The results from the samples analyzed show that pH of boreholes and shallow wells (ground water) water was higher than that of river water (surface water). pH levels ranged from 7.16±0.003 - 9.34±0.004 for ground water and 7.24±0.002-8.00±0.003 for surface water. Electrical conductivity was also higher in ground water ranging from 669±0.002μS/cm-1568±0.004μS/cm while that of surface water ranged from 382±0.003μS/cm-1202±0.002μS/cm at Magadi road. Turbidity was higher for surface water than that of ground water ranging from 74.3±0.004 NTU- 95.4±0.003 NTU and below detection limits (BDL) levels for ground water with the exception being borehole at Athi Primary school which had turbidity of 18.6±0.03 NTU. Colour was high for surface water ranging from 159±0.002 c.u to 343±.004 c.u while that of ground water ranged from 1.5±0.003 51.2±0.004 c.u in borehole 5 located at Athi Primary School. Total Dissolved Solids were higher in ground water ranging from 231.68.00±0.003mg/l - 1003.52±0.004mg/l in shallow well located at near Brookshine School, Kangundo road while that of surface water ranged from 244.48±0.002mg/l-769.28±0.003mg/l.

From the chemical parameters analysis, fluorides were significantly higher in ground water ranging from 0.37±0.003 to 9.36±0.002 ppm at Mlolongo which exceeded the KEBS limits for drinking water of 1.5ppm. Iron levels were higher in river water samples ranging from 2.11±0.002 to 18.401±0.003 ppm at Kangundo Road Bridge. Even though ground water had lower levels of iron that river water, it ranged from <0.001ppm to 1.93ppm against the 0.3ppm recommended by KEBS. Lead levels in ground water ranged from <0.001ppm to 2.64ppm at borehole BH4 located at Brookshine School. This was way above the recommended levels of 0.03ppm by KEBS.

The levels of microbial coliforms were higher in river water ranging from 140-294 c.f.u/100ml during the dry month of December 2011 and 156-309 c.f.u/100ml during the wet month of May 2012. Ground water recorded coliforms ranging from zero to 40 c.f.u/100ml. Within the ground water system shallow wells had a higher count of coliforms than in boreholes.

The high levels of fluorides have led to increased cases of dental fluorosis especially among young children in the area of study. Adults are at risk on increased bone fractures in their lifetime. High levels of lead in some ground water could lead to mental retardation since lead is a very toxic metal even at very low levels. There is therefore need to develop a long-term plan of providing safe drinking water by the county governments. There is also the need to establish regulations that require private water vendors and water companies to invest in water treatment plants that reduce levels of dissolved ions in ground water before distributing the water to local communities.

ABBREVIATION

AAS	Atomic Absorption Spectrometer
ANOVA	One Way Analysis of Variance
APHA	American Public Health Association
ATSDR	Agency for Toxic Substances and Disease Registry
AWSB	Athi Water Services Board
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
IOSHIC	International Occupational Safety and Health Information Centre
ISFR	India State of Forest Report
KEBS	Kenya Bureau of Standards
TDS	Total dissolved solids
ToxFAQs	Toxicity Frequently Asked Questions
UON	University of Nairobi
UNEP	United Nations Environmental Program
UNESCO	United Nations Scientific and Cultural Organization
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

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CHAPTER ONE INTRODUCTION

Clean and safe drinking water is essential to health and a basic constitutional right. (Chapman, 2007). Safe drinking water should have no adverse health effects when consumed over a long period of time. Children and the elderly are particularly the most vulnerable groups of people affected most by unsafe drinking water. (Kenya Water Report, 2004). There is an increasing demand for safe drinking water as the world population continues to increase against diminishing resources of fresh water that is safe for domestic purposes. For any meaningful prosperity to be realized, clean and safe drinking water that is readily available should be the point of focus by governments and local authorities according to water quality assessment of 2007 by the Ministry of Water and Irrigation (Kenya Water Report, 2004). Sustaining sufficient water supplies for domestic, agricultural and industrial use would be impossible without groundwater which is the largest and most reliable of all freshwater resources since it is being used by about two billion people worldwide; making it the most important natural resource. (Kenya Water Report, 2004).

By estimates, the world is producing about 9.087 trillion m^3 of water annually (Fischetti, 2012). Kenya in particular faces an acute water shortage both in urban and many rural areas. Of particular concern, is the ever-growing urban population especially in Nairobi according to (Mitullah, 2003). Several up-coming satellite towns around Nairobi are not supplied with safe drinking water from the licensed water companies (Kenya National Bureau of Statistics, 2009). This has forced residents in these areas to explore other possibilities such as digging shallow wells and drilling bore-holes in order to access water for domestic purpose, (Kenya National Bureau of Statistics, 2009).

Whereas ground water has become a panacea to many families, institutions and companies, its suitability has not been ascertained. Comprehensive studies in several areas of Athi basin have not been done to establish whether the groundwater meets the safety standards for human and animal consumption. Therefore, human population in areas whose ground water quality is not known faces a risk of illness such as weak bones resulting in fractures and dental fluorosis caused by high levels of fluoride ions (Amin et. al, 2009). This study was therefore to assess the levels of various cations, anions and coliform bacteria in ground and surface waters in selected areas of upper Athi River basin and compare them with WHO and KEBS specifications levels for drinking water.

1.1 Heavy Metals

Heavy metals are transition metals whose density is at least five times the density of water. Water has a density is 1g/cm3 at 4°C. Heavy metals with a density of greater than $5g/cm^3$ include zinc, iron, cadmium, arsenic, mercury, lead, manganese and chromium (Lide,1992), (Mahurpawar, 2015). If one is exposed to high levels of heavy metals for a long time their consumption could cause muscular dystrophy and Parkinson's disease. Prolonged exposure to some of these metals such as mercury could cause cancer. (Alesio et.al, 2012). Symptoms of acute toxicity include breathing difficulties, severe headaches, visual impairment and reduction in cognitive abilities (Mahurpawar, 2015). There are two categories of heavy metals namely; beneficial heavy metals and toxic heavy metals.

1.1.1 Beneficial Heavy metals

Beneficial heavy metals are metals are part of diet in living organisms as micronutrients. These metals include; copper, zinc, iron, chromium and manganese among others. Iron forms part of the haem group in haemoglobin molecule, zinc is required for the proper functioning of the immune system. Chromium is essential for breakdown of carbohydrates and fats as well as in breaking down insulin. Copper when combined with certain proteins produces important catalysts in the body while manganese is essential for the proper functioning of the central nervous system. (Alesio et.al, 2012).

1.1.2 Toxic heavy metals

On the other hand, heavy metals become toxic when the body fails to break them into forms that can be excreted by the body. They therefore accumulate in body tissues leading to body damage. The routes of exposure for heavy metals include breathing air that contain particles of these heavy metals, through food crops grown in areas contaminated with these heavy metals and consuming water contaminated with heavy metals (Mahurpawar, 2015). Children may develop toxic levels of heavy metals by ingesting contaminated soil or eating peels from lead oxide floors (Wauna, Okiemen, 2011). Other routes of exposure may result from procedures such as radiology, taking excessive doses of drugs containing these heavy metals and from broken pieces of mercury thermometer when not disposed of properly (Transande et.al, 2005)

1.2 Common toxic heavy metals

Most common heavy metals include; arsenic, lead, iron, copper, manganese, zinc, chromium and cadmium. This study assessed levels of seven heavy metals that are included in the Agency for Toxic Substances and Disease Registry's (ATSDR)which are; cadmium, chromium, copper, iron, manganese, lead and zinc (Amirah et.al, 2013).

1.2.1Cadmium

Cadmium is obtained as a by-product during the mining and smelting of lead and zinc. It is used to manufacture nickel-cadmium batteries in which cadmium are used as electrodes. It is also used as a catalyst in manufacture of plastics and is a component in paints. Cadmium is also used in agriculture in pesticides and fungicides and could therefore be found in soil and water systems through run-offs. Cadmium is also found in cigarettes since tobacco plants absorb cadmium and bio-accumulates it in their tissues. Cadmium is a useful metal in electroplating due to its lack of corrosion. Traces of cadmium are also found in lubricants and could therefore find their way into water systems and ambient air from exhaust fumes. Cadmium found in ambient air contributes to between 15-50% of total cadmium exposure while 2-7% of cadmium finds its way into human body through ingestion. Organs mostly affected by cadmium toxicity include liver, kidneys, lungs and bones. (Bernhoft, 2013).

1.2.2 Chromium

Chromium is amongst most common elements on earth. It reacts with oxygen and iron to form chromite ore. Chromium_has varied oxidation states ranging from oxidation states -II to +VI respectively. The most stable oxidation states of chromium are; 0, +III and +VI. In Industries chromium is useful in chrome plating and in small proportions as an alloy in stainless steel articles due to its resistance to corrosion. Chromium in oxidation state +III is needed in trace amounts by the body as part of dietary requirement in the production of insulin. Chromium in oxidation state +VI is the most dangerous if one is exposed in high amounts. Chromium (VI) is considered amongst carcinogenic substances due to the hydroxyl radicals produced when chromium +VI is reduced to chromium +III (USEPA, 2016); (ATSDR 2012); (Dayan and Paine, 2001).

1.2.3 Copper

Copper toxicity contribute to many health problems including fatigue, depression, anxiety, anorexia, migraine headaches, allergies, premenstrual syndrome and childhood hyperactivity and learning disorders (Ashish et.al. 2013). Copper toxicity can result in a manganese deficiency which is one of the main causes of loss of calcium from the bone which results in osteoporosis. Copper in excess also lowers zinc and potassium levels and cause deficiency of vitamin C and B6, inositol, folic acid and rutin.(McEvoy, 2011).

1.2.4 Iron

Iron is an important dietary mineral nutrient as component of haem group in haemoglobin molecules. Its toxicity is attributed to fact that it is used as a supplement tablet in persons with low levels of iron in their bodies. Children in particular by accident overdose when they consume iron tablets 300mg of iron is sufficient to cause acute toxicity in in children with a body mass of less than 14kg. (Baranwal and Singhi, 2003). Iron is easily absorbed in the digestive system when ingested in food, water or wine._Overdoses_of iron in children occur when children mistake red-coated ferrous sulphate tablets or adult multivitamin preparations in candies. However, in recent years incidences of over dosage in children has reduced since the introduction of packaging that is child-proof for iron supplements containing 250mg or higher of iron content. Iron can also find its way into human body from drinking water as well as cookery and cutlery equipment. Organs affected by iron toxicity are kidneys, liver and all circulatory system. (Mills and Curry, 1994).

1.2.5 Manganese

Manganese (II) ions are the most essential form of manganese in living organisms as cofactors in a number of enzymes. Of particular importance enzymes are those found in micro-organisms that covert superoxide's radicals to release oxygen. Manganese is also important in the photosynthetic process in plants. At a higher concentration manganese is neurotoxic. Persons suffering from manganese toxicity may develop depression, become moody as well as becoming psychotic. Manganese toxicity occurs by drinking water that is contaminated with manganese as well as through food. (Kwakye et.al., 2015). When one is exposed to high levels of manganese through inhalation leads to neurodegenerative illnesses (Santamaria 2008).

1.2.6 Lead

Lead toxicity is the leading cause of poisoning in young children (Mahurpawar, 2015). It is a soft metal and was used in pipes and drains. About 10,000 tons of lead all over the world is produced every year. Lead is mostly used in making car batteries while some proportion is used to manufacture solders, bullets and as radiation shields. Lead is considerably being reduced in its usage due to its toxicity. The most common routes of exposure for lead poisoning is through inhalation of air containing lead dust or drinking water contaminated with lead. Lead is a neurotoxin and damages the brain and other organs of the nervous system as well as accumulating in bone tissues (Alesio et.al, 2012)

1.2.7 Zinc

Zinc is bluish-white metal that is 24th most abundant element on earth. It's most common zinc ore is zinc blende. Due to its corrosion resistance properties, it is used in zinc plating of iron, a process known as galvanizing. Zinc is also useful in the manufacture of zinc batteries as well as constituent of brass alloy. Zinc compounds are also used as sources of zinc supplements, as anti- dandruffs and light illuminating paints._ Zinc is the second most important transition metal after iron and is found in almost every enzyme in the human body. Zinc is found in sufficient amounts in animal products as well as cereals. Excessive intake of zinc inhibits absorption of iron and copper resulting in their deficiency. Symptoms of zinc toxicity include; nausea, vomiting, diarrhea, headache, and abdominal pain and loss of smell. (Fosmire, 1990).

1.3 Other Metals

Other metals such as Ca and Mg cause hardness in water forcing people to use a lot of soap while washing laundry. High levels of Na and Cl^- make water unpalatable due to the salty taste and can cause hypertension in very high levels.

1.4 Anions

Anions are negatively charged ions that combine with metallic ions to form dissolved salts. Commonly known anions in water include; fluoride, carbonate, chloride, hydrogen carbonate and nitrate and nitrite and sulphate, have been assessed in this study.

1.4.1 Fluoride

Fluoride exposure is evidenced by dental fluorosis or browning of teeth. Fluorosis has been on the rise in both frequency and severity in areas with high levels of fluorine in water which results in excessive intake of fluoride. Water treated with fluorine and fluoride-containing toothpastes contain fluoride that is higher than that required by young children (ISFR, 2002). In humans, high levels of fluoride lead to a reaction between calcium in blood with fluorine to form calcium fluoride which precipitates in blood vessels which can be fatal. High levels of fluoride ions in drinking water could lead to both skeletal and dental fluorosis (Pratusha et.al, 2011).

1.4.2 Chloride

An adult human body contains about 115 g of chloride. Since an adult human body loses approximately 530 mg of chloride per day, the daily dietary requirement is 9mg/kg of body weight. This translates to daily intake of 1g of table salt per person per day. In children under the age of 18 years, the daily dietary requirement is 45mg per day (Zoetman, 1980). Chloride is an important ion in the process of homeostasis as well as in conducting electrical impulses along the neurons. Excessive intake of chloride salt could result in high retention of fluids in the body as well as causing high blood pressure due to presence of sodium and potassium ions (Morales, 1987). Effects of chloride toxicity are rare except those that arise from impaired sodium chloride metabolism such as in congestive heart failure (Wesson, 1969). Human body can tolerate high amounts of chloride ions on condition that such intake of salt is accompanied by daily water intake of about 2 litres (Zoeteman,1980). Chloride increases the ability of water to conduct electricity and therefore increases how corrosive the water becomes. In metal pipes, chloride reacts with metal ions to form soluble salts (Morales, 1987) thus increasing levels of dissolved metals ions in drinking-water. In lead pipes, a protective oxide layer is formed but chloride enhances galvanic corrosion (Gregory, 1990)

1.4.3 Total alkalinity

Alkalinity is a measure of the ability of a substance to neutralize acids. Total alkalinity is the measure of the total number of moles of hydrogen carbonate ions and carbonate ions. The most common source of total alkalinity is when carbonate rock weathers as a result of acid rain and the ions reach ground water systems (Snoeyink and Jenkins, 1980). Other salts that contribute to total alkalinity albeit to small extent are those of weak acids such as silicates, borates, phosphates, ammonia and organic bases from natural organic matter (Sawyer and McCarty, 1978). The units for measuring alkalinity are mg/L $CaCO_3$. According to (Standard methods, 1992) alkalinity or acidity has no known adverse effects of health, however, highly acidic and alkaline water is unfit for drinking. The amounts of carbonates and bicarbonate ions in water is crucial in understanding how such water would be affected by acid rain. Turbidity is removed from drinking water by coagulation and flocculation, a process that releases H^+ into the water. H^+ ions released from the process needs to be neutralized for coagulation and flocculation to occur. (Standard methods, 1992). Hard waters are frequently softened by precipitation methods. The knowledge of how alkaline the water is, is required in order to calculate the calcium hydroxide and sodium carbonate requirements for precipitation to occur.

Alkalinity in ground water is due to the following equilibria.

$$CO_2 + H_2O \leftrightarrow H_2CO_3^* \qquad (1.1)$$

$$H_2CO_3. \leftrightarrow HCO_3^- + H^+ \qquad (1.2)$$

$$HCO_3^- \leftrightarrow CO_3^{2-} + H^+ \qquad (1.3)$$

Where $H_2CO_3^*$ represents total concentration of dissolved CO_2 and H_2CO_3. Equation 1.1 represents equilibrium of CO_2 in the water. The equilibrium constant for this reaction is:

$$K_{CO2} = \frac{[H_2CO_3]}{[CO_2]}$$

The equilibrium relationships for equations 1.2 and 1.3 may be expressed as follows.

$$K_1 = \frac{[H^+][HCO_3^-]}{H_2CO_3]}$$

$$K_2 = \frac{[H^+][CO_3^{2-}]}{[HCO_3^-]}$$

1.4.4 Nitrate and Nitrite

Nitrate and nitrite ions form part of the nitrogen cycle. The nitrate ion (NO_3^-) is the most stable form of combined nitrogen while nitrite ion (NO_2^-) is unstable. Chemical and biological processes can further reduce nitrite to various compounds or oxidize it to nitrate (WHO, 2011). In agricultural lands commercial fertilisers are applied to boost yields. More often than not nitrogen containing fertilisers may contain nitrates which find their way into water systems through run-offs and leaches to the underground water systems. Under anaerobic conditions nitrates are reduced to nitrites by *nitrosomonas* bacteria. Nitrite is the most common toxic as it oxidizes normal haemoglobin to methamoglobin which is unable to transport oxygen to the body tissues. This leads to reduced energy production and can cause suffocation. (Pollack and Pollack, 1994); (Hanukoglu and Danon, 1996); (Zeman et al., 2002). Prevalence of methemoglobin reductase formation could also occur in pregnant women and people suffering from deficiency of glucose-6-phosphate dehydrogenase or methemoglobin reductase (Speijers et al., 1989).

1.4.5 Sulphate

Sulphate is found in most natural waters at concentrations ranging from a few tenths to several thousand milligrams/liter (mg/L). Sulphates are considered to be from a range of sources which include those from atmospheric pollution, rocks containing sulphate as well as from decomposition of dead decaying matter since sulfur is part of cells in living organisms. Industries and exhaust fumes from diesel engines contribute to a significant amount of sulphur dioxide in the atmosphere which combines with water vapour to form acid rain. The sulphate concentration in seawater is about 2,700 mg/L (Hitchcock, 1975) and ranges from 3 to 30 mg/L in freshwater lakes (Katz, 1977). Sulphate content in drinking water ranges from 0 to 1,000 mg/L in the United States (Trembaczowski, 1991). Acute toxicity of sulphate exposure in animals has been linked to diarrhoea. However, these effects are not observed for longer term exposures. This could be due to acclimatization to sulphate over time. (Iowa DNR, 2009).

1.4.6 Turbidity

Turbidity relates to how cloudy a water body is. Turbidity arises when soil particles are present in water which are transported by water into rivers and lakes leading to siltation. Turbidity affects the oxygen content and light penetration of the water while sedimentation can change the physical structure of habitats, stress organisms within the water body and smother water insects. Causes of high turbidity include: soil erosion, wastewater discharges, urban runoff, farming and forestry practices, eroding stream banks, and excessive algae growth. Turbidity can range from less than 1 NTU to more than 1,000 NTU. At 5 NTU, water appears cloudy while at 25 NTU the water is murky. Sediments are categorized into sand, silt and clay. Sand is further classified into very coarse sand which has a size of about 1.5mm, medium at 0.375mm and very fine sand at 0.094mm.

Silt on the other hand is classified into very coarse silt with a size of 0.047mm, medium at 0.0117mm and very fine silt at 0.0049mm respectively. Clay is usually less than 0.00195mm (Friedman et. al, 2005). Surface water or shallow wells usually have higher levels of turbidity. Suspended particles allow disease-causing micro-organisms to thrive without being properly eliminated during disinfection which can lead to digestive tract infections. Organic matter can contribute to the formation of harmful by-products such as trihalomethanes (THMs) which are considered carcinogenic. Particles such as lead can find its way into the body if turbid water is ingested. Drinking turbid water can be especially risky for vulnerable people such as cancer patients, as well as HIV patients.

1.4.7 pH

The pH of a solution is the negative logarithm to base ten of hydrogen ions concentration.

$$pH = -\log [H^+] \tag{1.4}$$

The pH of water refers to the acid–base equilibrium and is controlled by the equilibrium established between carbon dioxide–bicarbonate–carbonate species. High concentration of carbon dioxide in water makes the water to have a low pH, whereas a low level of carbon dioxide makes the pH of water to increase and therefore become more basic. Temperature also influences the equilibrium and the pH. In pure water, a decrease in pH of about 0.45 occurs as the temperature is raised by 25 °C. The presence of bicarbonate, carbonate, and hydroxyl ions in water acts as buffers and thus this temperature effect is modified (APHA, 1992). The pH of natural waters lies within the range pH 6.5 to pH 8.5. Water with extreme pH values causes irritation to the eyes, skin, and mucous membranes. Eye irritation and increased risk of skin disorders have been associated with pH values greater than 11. In addition, solutions of pH 10–12.5 have been reported to cause swelling of hair fibres. (WHO, 2006). Individuals with sensitive gastrointestinal tract have reported cases of irritation. Similar effects can arise from exposure to low pH which include redness and irritation of the eyes whose severity increases with decreasing pH. Below pH 2.5, the epithelium is irreversibly and extensively damaged (WHO, 2006). In addition, the degree of corrosion of metals as well as disinfection efficiency is affected by pH and it may have an indirect effect on health.

1.4.8 Total Dissolved Solids

Total dissolved solids (TDS) are used to describe dissolved salts and trace amounts of organic matter dissolved in water. The most common dissolved ions include; calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen-carbonate, chloride, sulfate, and nitrate anions. Water will taste differently depending on the amount and type of cations and anions present. (Bruvold and Ongerth, 1969). The taste in water has a relationship to total dissolved solids in that excellent water has less than TDS of 300 mg/litre, good water has TDS of between 300 and 600 mg/litre; fair, between 600 and 900 mg/litre; poor, between 900 and 1200 mg/litre; and unacceptable, greater than 1200mg/litre. Water with extremely low concentrations of TDS may also be unacceptable because it is tasteless (Bruvold and Ongerth, 1969). There is no known relationship between amounts of TDS in drinking water to any health effect, however, some earlier studies suggested inverse proportionality between incidences of cancer and TDS. (Burton and Cornhill, 1977) coronary heart disease (Schroeder, 1960), arteriosclerotic heart disease and cardiovascular disease (Sauer et al, 1975). Total mortality rates were reported to be inversely correlated with TDS levels in drinking-water. Certain components of TDS, such as chlorides, sulfates, magnesium, calcium, and carbonates, affect corrosion or encrustation in water-distribution systems (Sawyer and McCarty, 1975). High TDS levels (>500mg/litre) result in excessive scaling in water pipes, water heaters, boilers, and household appliances such as kettles and steam irons (Tihansky, 1974). Such scaling can shorten the service life of these appliances (McQuillan and Spenst, 1976).

1.5 Faecal coliform

Faecal coliforms are anaerobic bacteria that naturally reside in the intestines of mammals without causing any harm. The most common faecal coliform is *Escherichia coli*. An analysis of water could indicate some presence of E. coli, but that does not mean the water is harmful, however, at high levels this may give indications of the failure to treat the water properly. This may indicate that the water system has come into contact with human and animal faecal matter. Poorly done septic tanks and sewage systems could lead to faecal coliforms finding their way into the ground water systems. Large numbers of faecal coliform could also indicate that other disease- causing pathogens could be present in water. The pathogens contamination could lead to waterborne diseases such as dysentery, typhoid fever and hepatitis A. (APHA, 1992).

1.6 Problem statement

Consumption of ground water without the prerequisite treatment poses a great risk to human health (WHO, 2006). Since water is a scarce resource, people tend to access water from wherever source to meet their needs without prior knowledge that some of the water may not be fit for human consumption. As a result, ground water from shallow wells and bore-holes has been developed. There is need to assess the concentrations of dissolved ions and coliform to establish the residue level and conformity to the WHO water quality guidelines.

1.7.1 Overall Objective

The objective was to undertake the water quality of the upper Athi River sub-catchment area and compare these values with KEBS and WHO water quality guidelines where it exists.

1.7.2 Specific objectives were to:

1. Determine the ground water quality in boreholes, shallow wells and river water in the selected areas of the upper Athi River sub-catchment.
2. To evaluate the level of dissolved ions in the ground water and surface water with respect to KEBS and WHO standards.

1.8 Justification

Continuous uptake of water with dissolved ions exceeding those of WHO water quality guidelines for drinking water, poses a major threat to human health. Metal ions such as Cd^{2+}, Cr^{6+}, and Pb^{2+} usually accumulate in the body over a long period of time (Kiffney and Clements, 1993). Excessive intake of fluoride ions in drinking water could lead to both skeletal and dental fluorosis (Pratusha et.al, 2011). This is evidenced by the browning of teeth both in adults and children (Chawla et.al, 2016). High calcium and magnesium levels upset phosphorus absorption (Craun and McGabe, 1975). High levels of Ca^{2+} and Mg^{2+} cause to water hardness which leads to scaling of water heaters as well as scum formation during laundry (Kwakye et. al., 2015). Presence of microbial coliforms water indicate contamination with human and animal wastes. The study was therefore to determine water quality in both ground water and surface water of the Upper Athi sub-catchment basin and to assess its suitability for human consumption.

CHAPTER TWO LITERATURE REVIEW

The study area (Figure 1) is located in the East-Southeast of Kenya and lies between latitude 1° 15' to 1° 30'S and longitude 36° 39' to 37° 05'E. The area stretches about 45km along the Upper Athi Sub-catchment area. The area is rapidly growing in terms of human population and therefore ground water in form of shallow wells and boreholes has become an essential natural resource for domestic, industrial and agricultural and livestock use. (AWSB, 2003).

According to (Saggerson, 1991), the geology of the Upper Athi basin comprise of the Ngong basic alkaline larva, Nairobi phonolites, Kandizi phonolites, Kapiti phonolites, Mbagathi phonolitic trachytes, and the Athi tuffs and lake beds overlain by clay soil. Phonolitic rocks contain feldspar mineral rich in potassium and sodium silicates as well as sodium-rich amphiboles. Trachytes' chemical composition includes silica, potassium and sodium oxides. Both phonolites and trachytes form good aquifers. Athi tuffs are formed from volcanic ash that is rich in silica, iron and magnesium. Tuffs rocks are aquifers only when fractured which is the case in the upper Athi basin where fault lines run the north-south direction along the eastern branch of the Great Rift Valley (Mulwa.et.al,2015). The rocks also contain a range of sulphates and halides especially fluorides and chlorides from fresh volcanic ash.

Weathering of the rocks in the Athi river basin is strongly influenced by temperature and by the amount and the distribution of rainfall. According to (FAO, 2005), the rainfall distribution pattern is bimodal with long rains falling from March to June and short rains from October to November while temperature ranges from 25°C-35°C. (Tucker and Sear, 2001) observed that the climate of the area was characterized by alternating wet and dry seasons that favour weathering reactions to produce considerably large amounts of inorganic matter. In the Athi basin, the prolonged weathering of the pyroxenes, amphiboles and apatite have been associated with relatively higher concentrations of calcium, magnesium, and fluoride in ground water. (Saggerson, 1991), observed the arid climate favours high concentrations of dissolved weathering products by evaporation to give rise to water that is high in dissolved solids.

Other studies in the The Maji ya Chumvi (salt water) beds in Mariakani, has water that is characterized by extremely high total dissolved solids concentration which is usually above 7000ppm, (Onyancha and Nyamai, 2014). Buried faults and fractures striking in the north-south direction cause water to migrate through surface fissures to underlying aquifers (Guth and Wood, 2013). The recharge of ground water by rainfall is controlled by the subtractive effect of evaporation, transpiration and interception, (AWSB, 2003). According to (Ojany and Ogendo, 1973), it has been observed that the climate of the Athi basin is characterized by annual potential evaporation which by far exceeds annual rainfall. This is worsened by the poor rainfall in terms of its reliability, annual amount and distribution. Consequently, the rainfall contribution to the recharge is considered to be low. According to (Mulwa, 2001), it has been observed that Ngong hills forms the major catchment of numerous streams that flow eastwards to join Rivers Mbagathi and Kiserian which are tributaries of Athi River. The major tributaries that feed the Athi River basin are Kiserian, Nor Chola, Kandisi and Mbagathi rivers. The streams have their head waters in the Ngong Hills and drain into Mbagathi River on the eastern side. Ngong area which is on the upper Athi basin receives an average rainfall of between 918-1200mm annually. Part of this rain infiltrates underground to replenish the aquifers in the Athi basin (Mailu, 1983).

Studies have been done in the upper Athi basin to determine the aquifer parameters through calibration of ground water flow models which give information on the sustainable management of ground water resources in the area (Mulwa, 2001). This study sought to determine levels of dissolved ions and faecal coliforms in ground water and soil sediments in selected areas of Athi basin with a view of providing solutions to the local communities on how best they could use the water with minimal risk of exposure.

Studies by (Mutonga, 2007) in the Baringo-Bogoria basins in the former Rift Valley Province found that fluoride levels exceeded the recommended limit of 1.5ppm in most areas. From the study, it was noted that high incidences of fluorosis in Kenya were located in areas with low levels of Ca^{2+} and Mg^{2+} concentrations (Nanyaro et al, 1984). These findings were consistent with the results from the studies by (Chandra et al, 1981) and (Teotia et al, 1981) which reported that water with low Ca^{2+} and Mg^{2+} levels present the highest risk of fluorosis. (Patel et.al, 2017).

Ground water assessment report in Kisauni Mombasa County, according to report of Water Quality Assessments, 2004 showed that most water abstraction facilities in the area are wells, with some of the older facilities found in the coral zone being partially protected. Various major ions were investigated such as sodium, potassium, magnesium, calcium, chloride and total hardness. Results showed increasing levels towards the ocean for sodium ions. High Levels of nitrate in Tudor creek was as a result of pit latrines for sewage management and disposal of faecal matter. Faecal coliforms were highest in June during the wet season and lowest in July when it was dry. The presence of *E. coli* indicated that the primary source of contamination is human waste as a result of on-site disposal of domestic sewage. (Mwashote et al, 2010) found only 8% and less than 10% respectively of ground water facilities examined produced water of acceptable standard.

Studies done by (Francisca et. al., 2017) in Makindu District in South Eastern Kenya found out that the levels of fluoride ions in ground water was between 1.62mg/L to 4.2mg/L. The study also found out that 38.4% of people taking part in the study had mottled teeth which was directly linked to the intake of water containing high levels of fluoride above the 1.5mg/L recommended by WHO.

Evaluation of ground water quality in Mubi town in Adamawa State Nigeria by (Alexander, 2008) based on the physico-chemical parameters and concentrations of heavy metals revealed that the water samples were slightly acidic alkaline (near neutral pH 6.3 to 7.52) and were good for drinking and domestic purposes.

Other studies done in Africa along the Nile basin (Martins and Probst, 1991), showed that the water had high levels of dissolved salt content. The White and Blue Nile Rivers flow through arid regions and carry water with high concentration of dissolved ions. In addition, due to evaporation from Lake Nasser and additional loss of water during the dry seasons increases the total ion concentration (Kempe, 1989). After the closure of Aswan high dam, the total dissolved solids have increased by approximately 33% as measured in Cairo. Studies have shown that the hot climate and intensive irrigation accelerates the chemical weathering and hence the release of elements in the dissolved forms. The dominant cations are ($Na^+ > Mg^{2+} > Ca^{2+}$) and anions ($HCO_3^- > SO_4^{2-} > Cl^-$ in that order (Degens et.al, 1991). These ions are not only obtained from soil for dissolved ions but also points to a major influence of limestone in the Nile basin.

(Ravichandran and Jayaprakash, 2011), studied ground water in India and found several dissolved ions at varying concentrations as a result of chemical and biochemical influence between water and the rocks found geologically. Inorganic contaminants including, chloride, fluoride, nitrite, nitrate, iron and arsenic were determined as a requirement for the suitability of ground water for drinking purposes. Water samples collected from shallow wells and aquifers were analysed for both metal ions and anions. Based on the results, it was found that ground water contained majorly calcium bicarbonate and the total salinity of water was below 500mg/l corresponding to electrical conductance of 750µS/cm at (25^{o}C).

Chloride ranged between 250-1000mg/l confined in States of Southern Punjab, Southern West Bengal. Fluoride concentration in ground water in some states in India exceeds 1.5mg/l. The occurrence of Arsenic in ground water was reported in West Bengal in India to have exceeded the 0.05mg/l and this was mainly found in aquifers up to a depth of 100 metres. (Ghosh et. al. 2016). The study revealed a relatively higher percent (48%) of children from Hirakud township having teeth mottling and erosion in comparison to the control sites of Deogarh and Kuchinda which had 34% and 26% cases of teeth mottling respectively. In all these sites (both industrial and control), either piped water supply or well water was the source of drinking water and all the children used Colgate/Close-up/Pepsodent as tooth paste. There was also no apparent difference in the food habit as rice was the main food during day time and in the night 20-60% of children ate roti with 60% in Hirakud.

CHAPTER THREE METHODS

3.1 Sampling

Surveys and identification of the sampling sites along the upper Athi River sub-catchment area (Figure 1) was done in the month of November 2011, by visiting various boreholes, shallow wells, and the Athi River and its tributatry, Mbagathi River sites. 11 boreholes, 5 shallow wells and 5 river water sampling sites were identified. Water samples were collected from the various identified boreholes (Table 1), from shallow wells (Table 2) and on the river sites (Table 3). The samples were taken to the Department of Chemistry's laboratory, University of Nairobi for analysis. Sampling was done in two different months, in the December 2011 (dry month) and May 2012 (wet month). This was mainly to find the effects of seasons and human activities on the residue levels of dissolved ions and the number of coliform present.

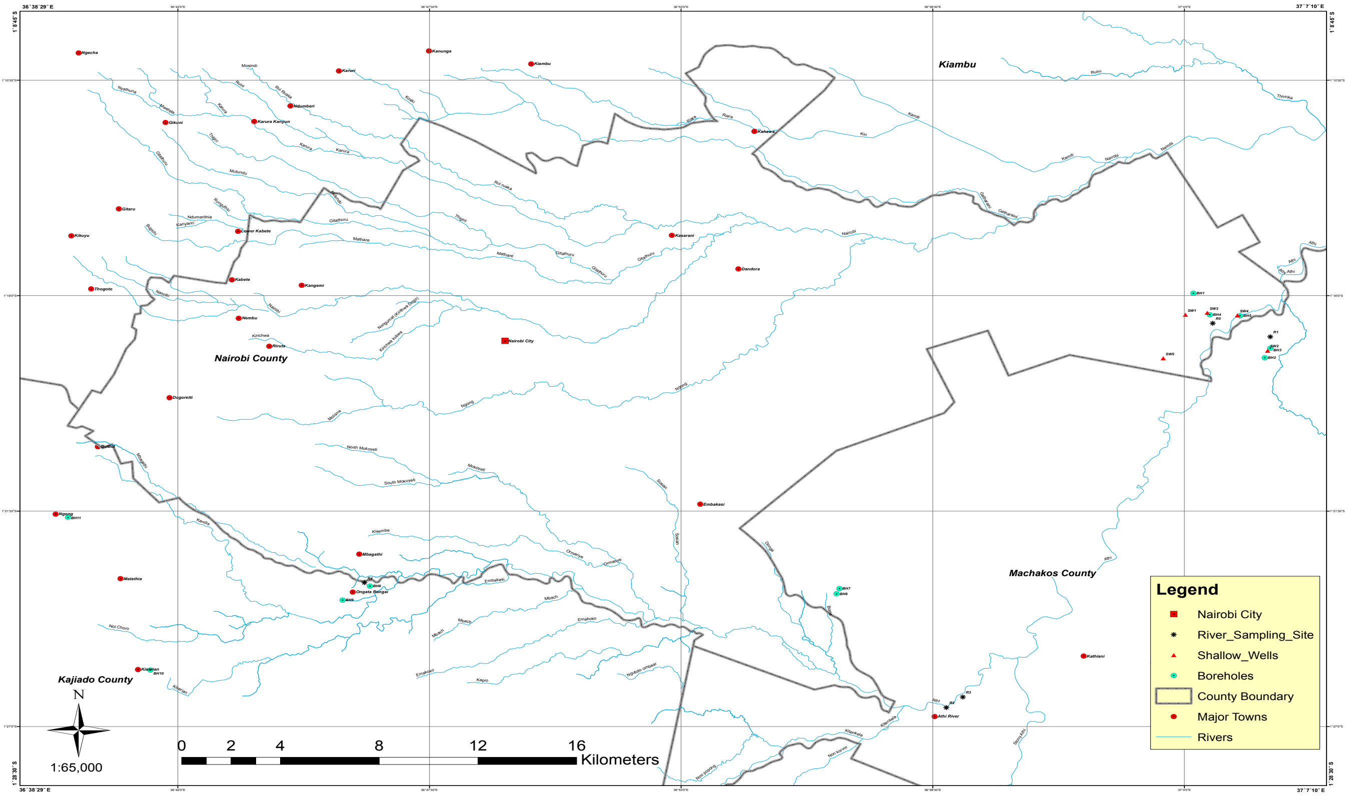

Figure 1: Map of upper Athi River sub-catchment area showing sampling sites.

Table1: Locations and human activities around the boreholes water sampling sites in the Upper Athi River sub-catchment

Site	Local Name	GPS Position	Human activities
BH1	Makanga, Ngundu	S 01, 15'56.3" E037, 04'22.6"	mixed farming
BH2	Samdante, Joska	S 01, 17'35.0" E037, 05'45.1"	dairy farming
BH3	Abagas borehole	S 01, 17'20.8" E037, 05'52.5"	residential area
BH4	Brookshine School	S 01, 16'29.3" E037, 04' 34.6"	education institution
BH5	Wanga’s borehole	S 01, 16'30.6" E037, 05'14.4"	drip irrigation
BH6	Mlolongo Water Co.	S 01, 23'36.6" E 036, 56'26.4	residential area
BH7	Mlolongo borehole	S 01, 23'28.6" E036, 56'26.8"	residential area
BH8	Mbagathi borehole	S 01, 23'24.8" E036, 46'07.4"	real estate
BH9	Rongai borehole	S 01, 23'45.9" E036, 45'35.6"	real estate
BH10	Kiserian borehole	S 01, 25'32.5" E036, 41'08.8"	road transport
BH11	Ngong borehole	S 01, 21'39.6" E036, 39'27.3"	catering service

Table 2: Locations and human activities around the shallow well water sampling sites in the Upper Athi River sub-catchment.

Site	Local Name	GPS Position	Human activities
SW1	De Paul well	S01, 16' 29.0" E 037,04' 01.9"	Education institution
SW2	Kariukis well	S 01, 17'25.3" E037, 05'49.6"	Poultry rearing
SW3	Dauwo’s well	S01, 16’26.4’’E037, 04’30.3”	Maize farming
SW4	Ciru’s well	S 01, 16'29.3" E037, 05'11.2"	Green-house farming
SW5	Njogu’s well	S01, 17’35.4” E037, 03’ 34.0”	Green-house farming

Table 3: Locations and human activities around the river water sampling sites in the Upper Athi sub-catchment.

Site	Local name	GIS location	Human activities
R1	Kangundo road bridge	S01, 17'02.9" E037, 05' 52.5"	irrigation farming
R2	Mombasa road Bridge	S 01, 26'30.4" E036, 59' 01.3"	steel making/cement
R3	Mombasa road Dam wall	S 01, 26'14.8" E036, 59' 11.2"	irrigation farming
R4	Ongata Rongai bridge	S 01, 23'19.7" E036, 46, 06.4"	motor vehicle garage
R5	Brookshine bridge	S 01, 16' 41.9" E037, 04'36.7"	irrigation farming

3.2 Instruments used and reagents

Hot plate (Gallenkamp 180 model), pH, conductivity and TDS meter (Hanna Instruments 4321-01 model). Analytical balance (Sartorius 1213 MP model), turbidity meter (Hach 2100Q model) and colour meter, (Lovibond, comparator 2000 model). Chloride ion selective electrode meter (Hach HQ440D with ISECL181 Ion Selective Electrode), Nitrate Ion Selective Electrode (Hanna Instruments 4113 model), Atomic Absorption Spectrophotometer (Varian AA 240 model), sample bags and bottles. De-ionized water was prepared in the analytical laboratory section at the department of Chemistry using the water deionizer (Ionizer Mk 8).

3.2.1 Instrumentation of AAS (Varian AA 240 model).

The sample was drawn up into the capillary tube into the nebulizer and it converted into fine droplets. The fine droplets were then carried by the carrier gases into the burner where the flame is. The carrier gases had two roles, first to sweep the sample into the burner and secondly to act as a fuel once inside the burner at a temperature of above 1000^{o}C. The solvent disolvated leaving the compounds which decomposed due to the high temperatures forming free ions and atoms from the sample. A cathode lamp produces light of a particular wavelength which is absorbed by electrons at they move from ground state to an excited state. The amount of light photon absorbed is proportional to the concentration of metal ions in the solution. Each cathode lamp releases light of a particular wavelength specific to the metal ion of interest. For example, when analyzing sodium ion, a sodium cathode lamp was used.

3.2.2 Reagents

Stock solutions each of 1000ppm of iron, sodium, calcium, magnesium, chromium, cadmium, copper, zinc, lead, and manganese. Stock solution of 1000ppm iron was prepared dissolving 8.607g of ferric ammonium sulphate dodecahydrate, ($NH_4Fe(SO_4)_2.12H_2O$, in 50ml of concentrated sulfuric acid. The solution was then topped into 1000ml in a volumetric flask.

1000ppm stock solution of sodium ions was prepared by dissolving 2.543g of sodium chloride in deionized water and the solution made to 1000ml in a volumetric flask. 1000ppm of magnesium ions was prepared by dissolving 3.971g of magnesium chloride in deionized water and the solution made to a 1000ml in a volumetric flask. 1000ppm of chromium ions was prepared by dissolving 7.692g of chromium nitrate nonahydrate, $Cr(NO_3)_3.9H_2O$, in 200ml of deionized water and then further diluted to make 1000ml. 2.036g of cadmium chloride was dissolved in 250 ml deionised water. The solution was then diluted to 1000ml in a volumetric flask.

To prepare 1000ppm of copper ions, 3.798g of $(Cu(NO_3)_2.3H_2O$ was dissolved in 250ml of deionised water. The solution was then diluted to 1000ml in a volumetric flask with deionised water.

Calcium solution was prepared from 1000ppm of calcium using 2.498g of $CaCO_3$ and transferred into 1 litre volumetric flask. 10ml of concentrated HCl was added for dissolution of $CaCO_3$ and then topped to the mark with deionized water.

In order to prepare 1000ml of zinc ions, 1.000g. of zinc metal was dissolved in 30ml of 5M hydrochloric acid. Then solution was then diluted to 1000ml mark in a volumetric flask using deionized water.

1.000g of zinc metal was dissolved in 30ml of 5M hydrochloric acid and the solution diluted to 1000ml mark in volumetric flask.

1000ppm lead stock solution was prepared by dissolving 1.5980g of lead nitrate ($Pb(NO_3)_2$) in 100ml of deionised water. The solution was then diluted to 1000ml in a volumetric flask.

To prepare 1000ppm stock solution of manganese, 3.6077g. of manganese chloride ($MnCl_2.4H_2O$) in 50ml. conc. hydrochloric acid. The solution was then diluted to 1000ml in volumetric flask.

Buffer solutions of pH 4 and 9.2, concentrated Nitric acid, concentrated Hydrochloric acid, Barium chloride, Potassium chromate indicator solution, 0.1N Standard Silver nitrate solution, phenolphthalein and methyl orange indicators.

3.3 Samples preparation

For each site, water samples were obtained from boreholes (Table 1) from shallow wells (Table 2) and river water samples (Table 3) were collected and placed in pre-cleaned polyethylene bottles.

3.4 Samples digestion

The water samples were acid digested following methods developed by Association of Official Analytical Chemists (Official Methods of Analysis 1995) and (Hinga, G. et al. 1980). To each beaker, 25 ml of 10 % hydrochloric acid (2.5 ml Concentrated acid + 22.5 ml deionized water) was added. The contents were filtered through the Whitman filter paper No. 1 and filtrate collected in a 250ml beaker. The residue in the filter paper was washed 4 times with 50 ml hot deionized water, the washings collected with the 250ml beaker and allowed to completely cool. The solution in the 250ml beaker was transferred into correspondingly labelled 250ml volumetric flasks. The beaker was rinsed and volume of the solution in the 250ml volumetric flask made to the mark with the deionized water.

3.5. Determination of physical parameters

3.5.1 pH

The pH meter was calibrated with a buffer solution at pH 7, then at pH 4 and again at pH 9.2. The electrode was then cleaned using deionized water and dipped in 50ml of the water sample in a reagent bottle and the pH values were recorded.

3.5.2 Turbidity

The turbidity meter was calibrated using standard cuvettes. The cuvette was then filled with water sample and placed inside the slot in the turbidity meter and readings were then taken.

3.5.3 Electrical conductivity

The electrical conductivity meter probe was immersed in 50ml of water sample and stirring was done. After a few seconds the readings stabilized, and the reading was recorded.

3.5.4 Colour

A cell containing blank (distilled water) was placed in the compartment of spectrophotometer with transparent sides facing light and calibrated to zero absorbance. A fresh sample of water was then poured into the cell and placed in the compartment. The colour level was then recorded.

3.5.5 Total dissolved solids

Total dissolved solids were calculated as a function of electrical conductivity using the formula in the equation below.

Total dissolved solids (ppm) = 0.64 x E.C

Where E.C is the electrical conductivity of the water samples.

3.6 Determination of chemical parameters

3.6.1 Titrimetric determination of chloride.

200ml of the water sample was transfered into a 400ml beaker. 5ml of concentrated nitiric acid was added to neutralize calcium carbonate until no reaction further occurred. The solution was boiled for 5 minutes and then filtered through filter paper No.1(150mm). 100ml of the solution was pippeted in a porcelain dish. 1ml of K_2CrO_4 indicator solution was added and well mixed. The solution was then titrated against 0.1N Silver Nitrate solution until the colour changed from yellow to brown. The readings of silver nitrate was taken. The procedure was repeated twice to obtain consistent results. The above procedure was repeated for all the samples and the results recorded.

Calculations

$$\text{Chloride as Cl ppm} = (\text{ml } AgNO_3 \text{ sample} - \text{ml } AgNO_3 \text{ blank}) \times \text{normality of } AgNO_3 \times 10 \times 35.5 \quad (3.1)$$

3.6.2 Potentiometric determination of Fluoride by use of ion selective electrode.

The fluoride was determined potentiometrically using a Fluoride ion meter by dipping the fluoride electrode meter into 50 ml of the sample and reading the levels of fluoride in the sample at Central water testing laboratory at Industrial Area.

3.6.3 Determination of total alkalinity of carbonate and bicarbonate using Titration method

0.1M of NaOH was prepared by measuring 2.000g of sodium hydroxide of analytical grade from the Department of Chemistry, using the analytical balance and dissolving it in distilled water in a 100ml beaker. The solution was then poured into a 250ml volumetric flask and diluted to the mark. This solution was used to standardize hydrochloric acid. Hydrochloric acid of analytical grade of molecular weight 36.46, 1.18 specific gravity and 37% purity was used. The molarity of the stock solution was calculated using equation 3.2

$$\text{Molarity of concentrated HCl} = \text{molecular weight x assay/ (specific gravity x 100)} \qquad (3.2)$$

$$\text{Molarity}= (36.46\text{g/mol x } 37)/ (1.18\text{g/ml x } 100) = 11.43\text{M}$$

8.7ml of concentrated 11.43M HCl was poured carefully into a 10ml measuring cylinder and then transferred into a 1000ml volumetric flask containing 300ml of distilled water. The solution was then diluted to 1000ml mark. This solution was then standardized using a standard 0.1M sodium hydroxide.

100ml of the sample was measured and transfered into a porcelain boat. 2 drops of phenolphathein indicator was added. The mixture was titrated slowly using 0.1M hydrochoric acid while stirring gently with a glass rod until the colour just disappeared. The volume of the acid used (X) was noted. To the same sample, 2 drops of methyl orange indicator was added. The sample was further titrated slowly till the first sign of change from yellow was noted. The total volume of the acid used including the volume used in the titration using phenolphthalein indicator (Y). The procedure was repeated twice for consistence. The above procedure was repeated for all the samples and the results recorded.

Calculations

Alkalinity to phenolphthalein as mg/ 1ml(ppm) $CaCO_3$

$$= \frac{X(\text{ml of } 0.1M\ HCl) \times 5 \times 1000}{\text{ml of the sample taken}} \qquad (3.3)$$

$(1\ \text{ml}\ 0.1M\ HCl \equiv 5\text{mg}\ CaCO_3)$

Alkalinity to methyl orange mg/l(ppm) $CaCO_3$

$$= \frac{Y(\text{ml of } 0.1M\ HCl \times 5 \times 1000}{\text{ml of the sample taken}} \qquad (3.4)$$

Total alkalinity = alkalinity to phenolphthalein + alkalinity to methyl orange

3.6.4 Gravimetric determination of sulphate ions

100ml of water sample was pippeted into 250ml beaker. 2ml 1:1 HCl was added. The mixture was boiled while adding an excess 10%(10g $BaCl_2.2H_2O$ in 100ml distilled water) solution slowly while stirring. The precipitate was digested for 2 hours at 80^oC. The precipitate was then filtered through filter paper No. 542 and washed with warm distilled water till free from chloride(tested with $AgNO_3$ solution). The residue was dried and ignited at 800°C to constant weight. The above procedure was repeated for all the samples.

Calculating the Sulphate content; SO_4^{2-}ppm = weight of residue in mg x 0.4115 x 10 (3.4)

3.6.5 Analysis of metal ions using atomic absorption spectrophotometer.

Analysis of metal ions was done using atomic absorption spectrophotometer, (Model AAS Varian spectra AA 10) at Mines and Geology Department.100ml of water sample was measured using a 100ml volumetric flask and then transfered into a 250ml conical flask.10ml of concentrated nitric acid was added into the flask and stirred. The mixture was then digested at 80°C for two hours. The solution was then filtered through Whatman filter paper No.1 into a 100ml volumetric flask and filled to the mark using distilled water.

3.6.6 Analysis of Nitrates and Nitrites

Presence of nitrates in water samples were determined by preparing standards, that is, 0.01ppm to 20ppm from 100ppm stock nitrate soluton. The standards were then transferred into a beaker and 1ml of nitrate buffer $(NH_4)SO_4$ was added. The nitrate electrode was inserted into the beaker starting with the lowest standard. Then, 50ml of the sample was put into a beaker and 1 ml of buffer added. The nitrate electrode meter was inserted into the solution and the concentration was measured.

For Nitrites, the formation a reddish azo dye at pH 2.0-2.5 was determined by coupling diazotizedsulfanilamide with N-(1-naphthyl)ethyldiaminedihydrochloride (NED dihydrochloride). To 50ml of the sample, 2ml of colour reagent was added and mixed thoroughly. Any colour change was noted as an indication of presence of nitrite ions.

3.7 Analysis of total coliform and *E. coli*

Feacal coliforms and *E.coli* was done by inoculating a 50ml sample and five 10ml samples in lactose broth for 48 hours at 35^0C or 37^0C total coliform and 24 hours at 44^0C for thermo tolerant coliform and the Most Probable Number (MPN) index determined from specific tables to the combination of tubes and dilutions.

3.8 Statistical Data Analysis

Data analysis was done using Microsoft excel. Correlations between the seasonal variation and the level of selected cations, anions and faecal coliforms were done using Statistical Package for Social Sciences tools (SPSS). Results obtained was represented by use of text, graphs and statistical tables to show the interrelationships of various variables such as pH, TDS, electronic conductivity, sample type on levels of selected cations, anions and faecal coliforms in boreholes, shallow wells and river water samples.

CHAPTER FOUR RESULTS AND DISCUSSIONS

4.0.1 Physical and microbial parameters of water samples

The results of physical and microbial parameters of both surface and ground water are contained in tables 4-6 below. These tables contain the physical and microbial parameters of shallow wells sampled in the month of December 2011 which was a dry month. Further analysis of each physical and microbial parameter is analysed in figures 2 to 15 below.

Table 4: Physical and microbial parameters in shallow wells in December 2011

sampling Site	pH	Electrical conductivity (µS/cm)	Turbidity(NTU)	Colour (c.u)	TDS(mg/L)	coliform c.f.u/100ml
SW 1	8.24 ±0.02	813 ±0.01	<0.1	1.7 ±0.0817	504±0.94	BDL
SW 2	7.81 ±0.03	805 ±0.03	<0.1	1.6 ± 0.1	499±1.24	BDL
SW 3	8.47 ±0.01	832 ±0.02	<0.1	1.9 ±0.2	516±0.816	25±2.87
SW 4	8.16 ±0.02	669 ±0.03	<0.1	1.5 ±0.2	415±1.63	BDL
SW 5	9.34 ±0.01	943 ±0.01	<0.1	2.7 ±0.1	585±2.05	BDL

See explanations of the abbreviations of the shallow wells sampling sites in Table 1

Table 5: Physical and microbial parameters in boreholes water in December 2011

Sampling Site	pH	Electrical Conductivity (μS/cm)	Turbidity(NTU)	Colour(c.u)	TDS(mg/L)	coliform (c.f.u/100ml)
BH 1	8.49±0.02	794±1.63	<0.1	<0.1	508.16±0.87	17±2.45
BH 2	7.54±0.01	891±0.816	<0.1	<0.1	570.24±0.75	BDL
BH 3	7.78±0.01	758±1.63	<0.1	<0.1	485.12±0.42	BDL
BH 4	8.59±0.03	840±1.24	<0.1	2.7±0.12	521.35±0.69	BDL
BH 5	9.34±0.04	943±0.816	13.6 ±0.245	46.5±0.04	585.81±0.18	BDL
BH 6	8.65±0.02	975±2.05	<0.1	3.2±0.08	605.64±0.36	13±2.05
BH 7	8.47±0.01	1000±1.63	<0.1	1.2±0.12	620.76±0.25	BDL
BH 8	7.93±0.03	449±1.63	<0.1	<0.1	278.63±0.43	BDL
BH 9	7.28±0.02	362±0.816	<0.1	6.8±0.04	224.92±0.54	BDL
BH 10	8.23±0.01	440±1.63	<0.1	1.4±0.12	273.59±0.78	BDL
BH 11	7.75±0.03	743±1.24	<0.1	0.3±0.08	461.25±0.61	BDL

See explanations of the abbreviations of the boreholes sampling sites in Table 2

Table 6: Physical and microbial parameters in Rivers water samples in December 2011.

Sampling Site	pH	Electrical Conductivity (µS/cm)	Turbidity(NTU)	Colour(c.u)	TDS(mg/L)coliform	(c.f.u/100ml)
R 1	7.32±0.02	647±1.63	81.6 ±0.163	226±0.08	401.24±0.18	140±3.03
R 2	7.47±0.01	516±1.24	79.4 ±0.129	256±0.12	320.38±0.41	215±2.86
R 3	7.43±0.03	463±0.816	84.4 ±0.153	219±0.04	287.45±0.36	294±2.54
R 4	7.33±0.04	382±2.05	75.5 ±0.173	159±0.04	237.62±0.27	275±1.89
R5	7.24±0.02	752±0.816	74.3 ±0.183	198±0.12	462.71±0.34	193±3.68

See explanations of the abbreviations of the rivers sampling sites in Table 3

Table 7: Physical and microbial parameters of shallow wells water samples collected in May 2012. (Wet month)

Sampling Site	pH	Electrical Conductivity (µS/cm)	Turbidity(NTU)	Colour(c.u)	TDS(mg/L)	coliforms (c.f.u/100ml)
SW 1	7.72±0.02	502±1.24	<0.1	2.1±0.04	321.28±0.19	10±2.24
SW 2	7.16±0.04	938±0.816	<0.1	1.7±0.02	600.28±0.59	16±1.98
SW 3	7.36±0.01	1568±1.63	<0.1	2.0±0.03	1003.28±0.37	40±3.03
SW 4	8.45±0.03	635±1.24	<0.1	1.6±0.04	406.20±0.52	12±2.64
SW 5	8.06±0.03	913±0.82	<0.1	3.2±0.04	584.32±0.47	18±2.32

See explanations of the abbreviations of the shallow wells sampling sites in Table 1

Table 8: Physical microbial parameters of boreholes water samples collected in May 2012. (wet month)

Sampling Site	pH	Electrical Conductivity (µS/cm)	Turbidity(NTU)	Colour(c.u)	TDS(mg/L)	coliforms (c.f.u/100ml)
BH 1	8.14±0.02	1001±0.89	<0.1	2.1±0.02	640.64±0.1	25±2.0
BH 2	8.03±0.01	1118±0.46	<0.1	1.5±0.03	715.52±0.2	BDL
BH 3	7.27±0.03	1154±0.38	<0.1	2.6±0.01	738.56±0.1	BDL
BH 4	7.34±0.02	1271±0.49	<0.1	3.0±0.04	813.44±0.4	BDL
BH 5	8.78±0.03	1146±0.77	18.4±0.03	51.2±0.03	733.41±0.3	BDL
BH 6	8.29±0.01	1124±0.63	<0.1	4.1±0.02	719.36±0.2	19±3.0
BH 7	7.75±0.04	1343±0.54	<0.1	1.5±0.01	859.52±0.2	BDL
BH 8	7.89±0.05	741±0.71	<0.1	0.4±0.04	474.24±0.3	BDL
BH 9	8.52±0.03	472±0.85	<0.1	7.3±0.03	302.08±0.4	BDL
BH 10	8.03±0.02	540±0.43	<0.1	2.2±0.02	345.6±0.5	BDL
BH 11	7.98±0.01	955±0.36	<0.1	1.4±0.03	611.2±0.3	BDL

See explanations of the abbreviations of the boreholes sampling sites in Table 2

Table 9: Physical and microbial parameters of river water samples collected in May 2012.

Sampling Site	pH	Electrical Conductivity(µS/cm)	Turbidity(NTU)	Colour(c.u)	TDS(mg/l)	coliforms (c.f.u/100ml)
R 1	6.89±0.02	587±0.57	95.4±0.03	331±0.01	375.86±0.1	156±2.00
R 2	8.00±0.03	873±0.74	86.7±0.02	343±0.03	558.72±0.4	228±1.50
R 3	7.07±0.01	816±0.48	94.6±0.01	304±0.02	522.24±0.3	309±3.41
R 4	6.91±0.04	1202±0.39	80.2±0.02	296±0.04	769.28±0.2	297±2.68
R5	7.80±0.05	629±0.46	78.3±0.03	327±0.02	402.56±0.3	266±3.21

See explanations of the abbreviations of the rivers sampling sites in Table 3

4.0.1.1 pH

The Figures 2 and 3 shows the pH values of boreholes and shallow wells while figure 4 shows pH values of river water samples.

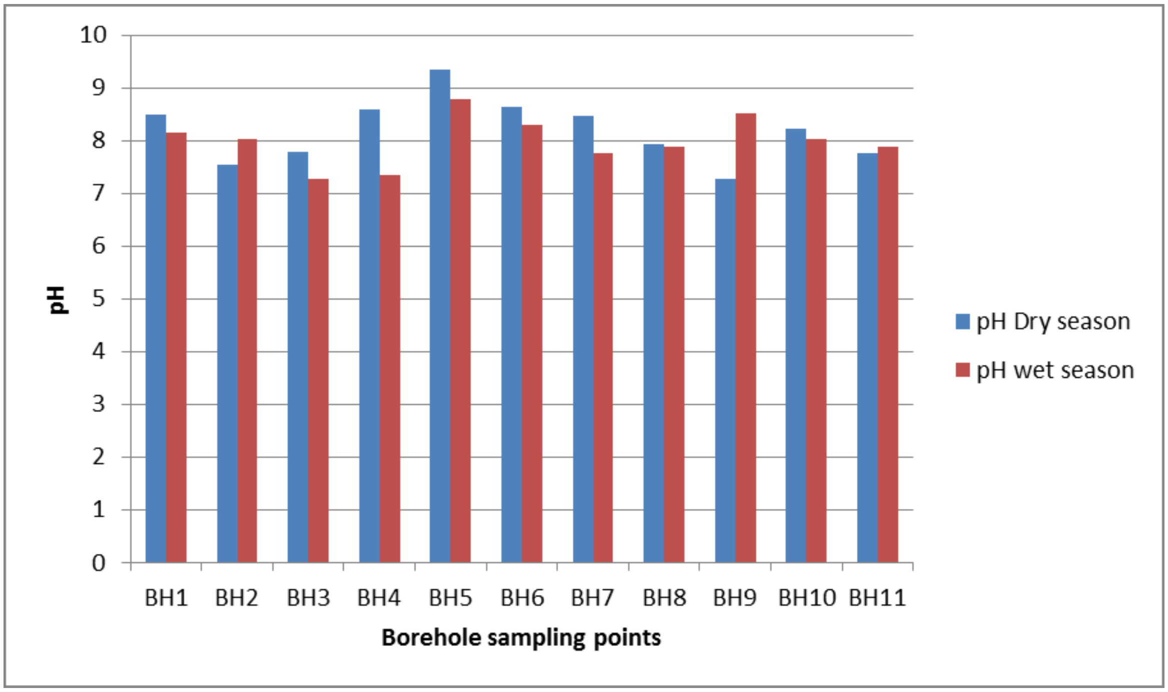

Figure 2: pH levels in boreholes water samples in wet and dry months.

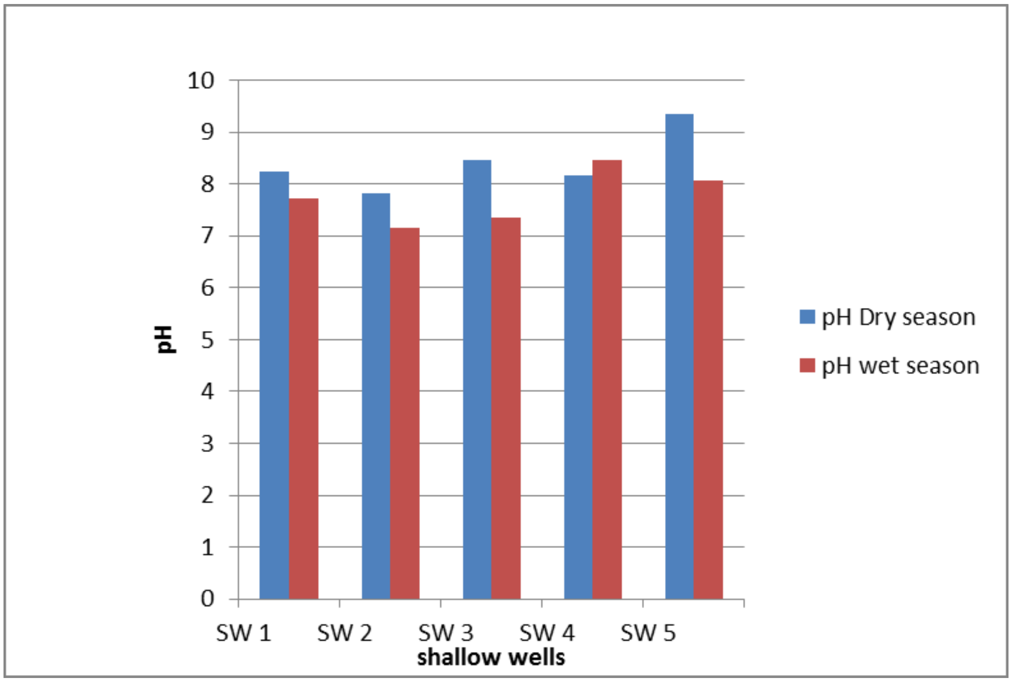

Figure 3: pH values in shallow wells water samples in wet and dry months.

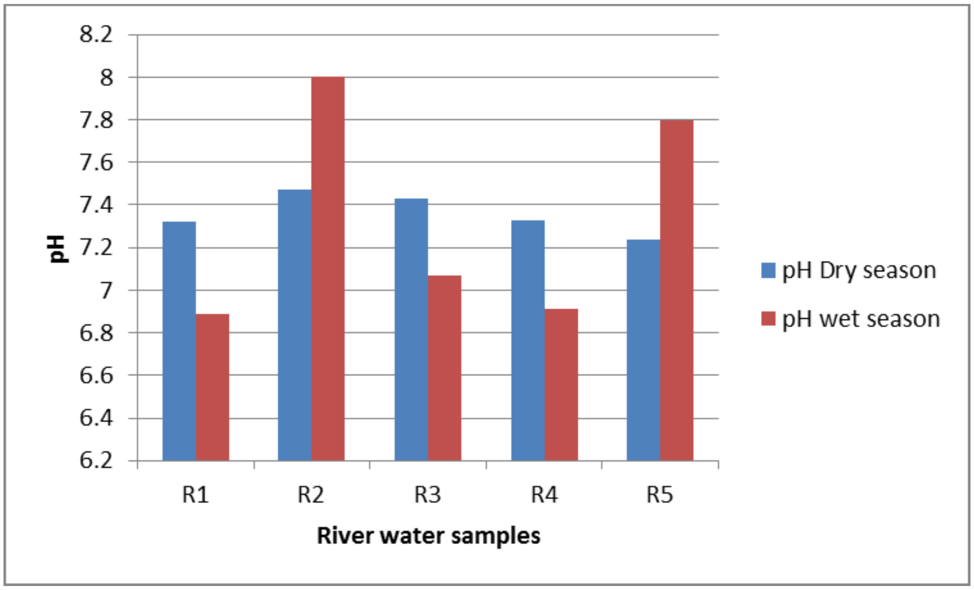

Figure 4: pH values in River water samples in wet and dry months.

pH of boreholes in the dry month of December 2011 ranged from 7.28±0.02 to 9.34±0.04 while pH in shallow wells ranged from 7.81± to 9.34±0.01. These samples constituted underground water samples. River water samples which constituted surface water had pH ranging from 7.24±0.03 to 7.47±0.01. From the results, pH of underground water was significantly higher than that of surface water.

Seasonal variation was also considered and sampling was done in May 2012 which was a wet month. The data for physical and microbial parameters during the wet month of May 2012 is shown in tables 7 to 9. pH of underground water, that is, water from boreholes and shallow wells. The levels of pH ranged from 7.27±0.03 to 8.78±0.03, 7.28±0.02-9.34±0.04 respectively. pH values of surface water from river water samples ranged from 6.91±0.04-8.00±0.03.

The pH of underground water did not change significantly between the two seasons. However, surface water showed a trend of pH varying from neutral to weakly alkaline.

River sample R1 had the lowest pH at 6.89±0.03 while R2 had the highest pH at 8.00±0.02 (Figure 4).

The high pH values obtained in ground water were due to high levels of HCO_3^-/CO_3^{2-} ions. These ions in solution are weakly alkaline and are responsible for the high pH values in ground water. On the other hand, pH of surface water ranged from slightly acidic to weakly alkaline. The acidic nature of the surface water could be due to human activities such as use of inorganic fertilizers by communities along the Athi River and its tributaries as well as use of detergents for laundry purposes. There was seasonal variation in pH values with water samples collected during wet season having lower pH values than water collected during dry season. This is due to the dilution effect by the rain water.

4.0.1.2 Electrical conductivity

Figures 5 to 7 show electrical conductivity levels comparatively between the dry month of December 2011 and the wet month of May 2012. Tables 4,5 and 6, show the electrical conductivity of boreholes water samples, shallow wells and river water respectively during the dry month of December 2011. Tables 7, 8 and 9 show results of physical and microbial parameters for the wet month of May 2012.

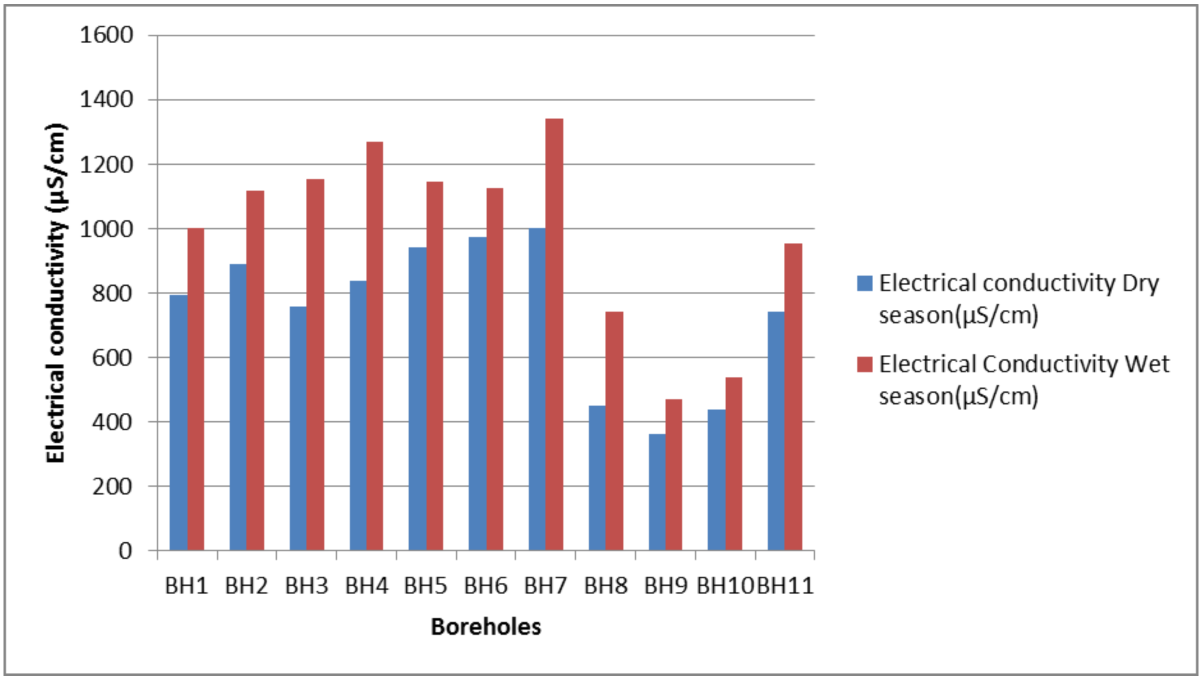

Fig. 5: Electrical conductivity in boreholes water samples for dry and wet months.

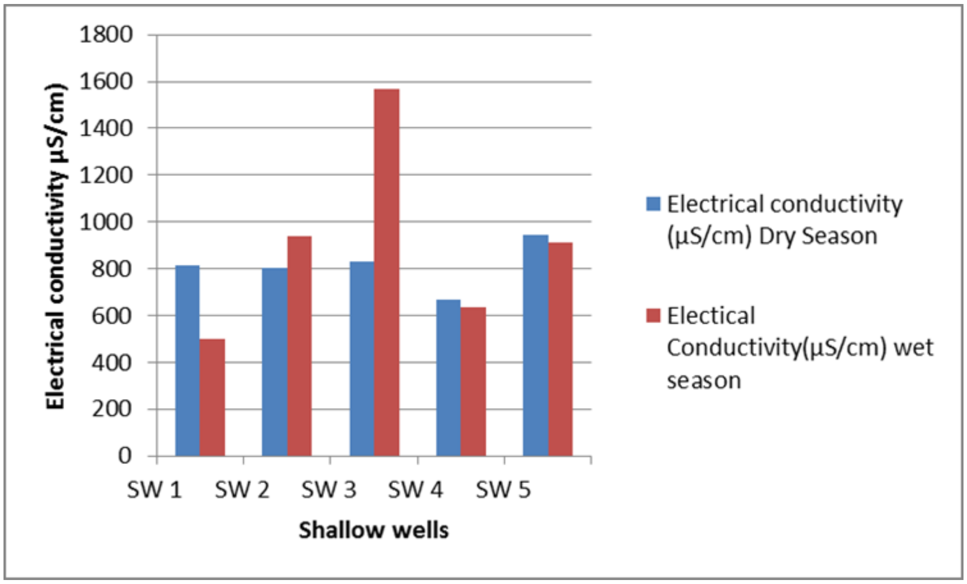

Figure 6: Electrical conductivity values in shallow wells water samples in wet and dry months.

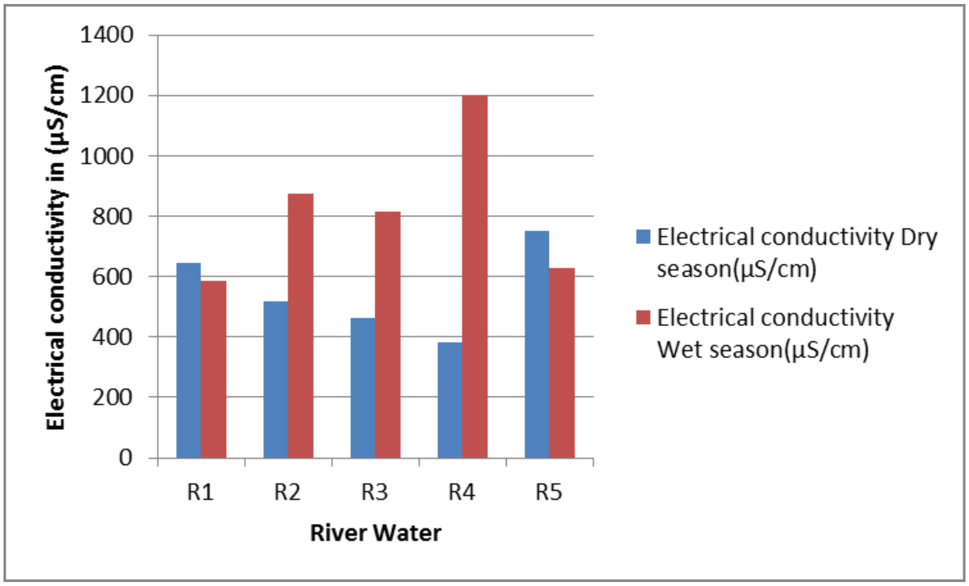

Figure 7: Electrical conductivity levels in river water samples in wet and dry months.

Results showed that Borehole (BH9) had the lowest value at 362±0.02µS/cm while borehole (BH7) had the highest electrical conductivity value at 1343±0.03µS/cm. There was also seasonal variation with wet season having lower electrical conductivity values than during the wet season.

Figure 6 shows the electrical conductivity levels in shallow wells which ranged from 502±0.04µS/cm in shallow well (SW1) to a high of 1568±0.02µS/cm in shallow well SW3. Samples collected during wet season had higher electrical conductivity levels than those collected during dry season (Figure 6).

Figure 7 shows electrical conductivity for river water samples. Electrical conductivity ranged from 382±0.03µS/cm in the river samples (R4) and 1202±0.04µS/cm in the same river water sample. Seasonal variation indicated that electrical conductivity values were high during wet season compared to dry season.

The electrical conductivity of ground water was higher than that of surface water as shown in figures 5, 6 and 7. This is due to presence of minerals in rocks that dissolve as water percolates through the porous rocks into the underground impervious layers. On the other hand, surface water has lower electrical conductivity due to the fact that surface water runs on bedrocks of impervious layers.

4.0.1.3 Colour

Figures 8, 9 and 10 show colour levels of water in boreholes, shallow wells and river water samples respectively for both the dry month of December 2011 and wet month of May 2012. The data for colour levels is also shown on tables 4,5 and 6 for the dry month of December 2011 while tables 7, 8 and 9 shows the colour levels during the wet month of May 2012.

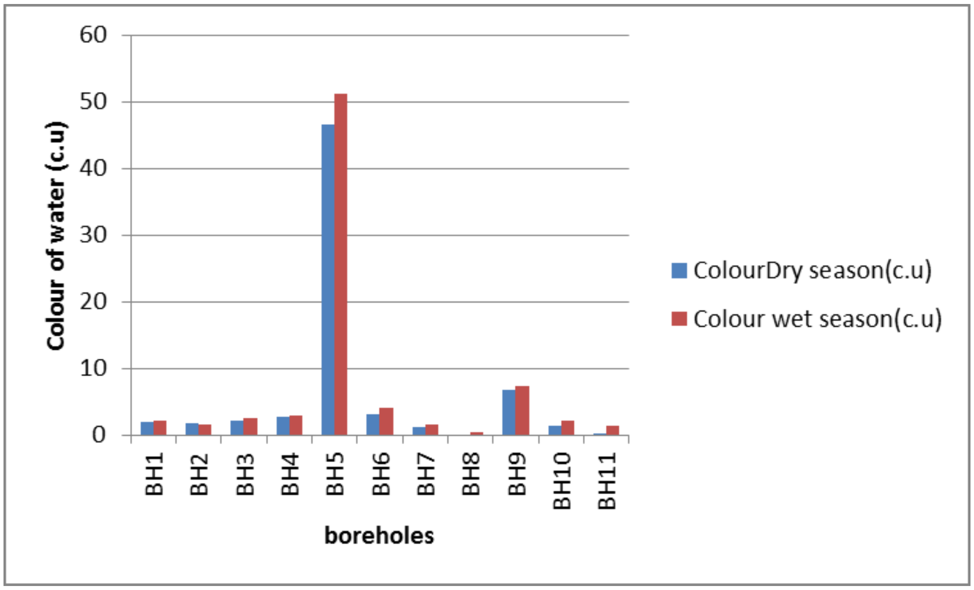

Figure 8: Colour levels in boreholes water samples in wet and dry months.

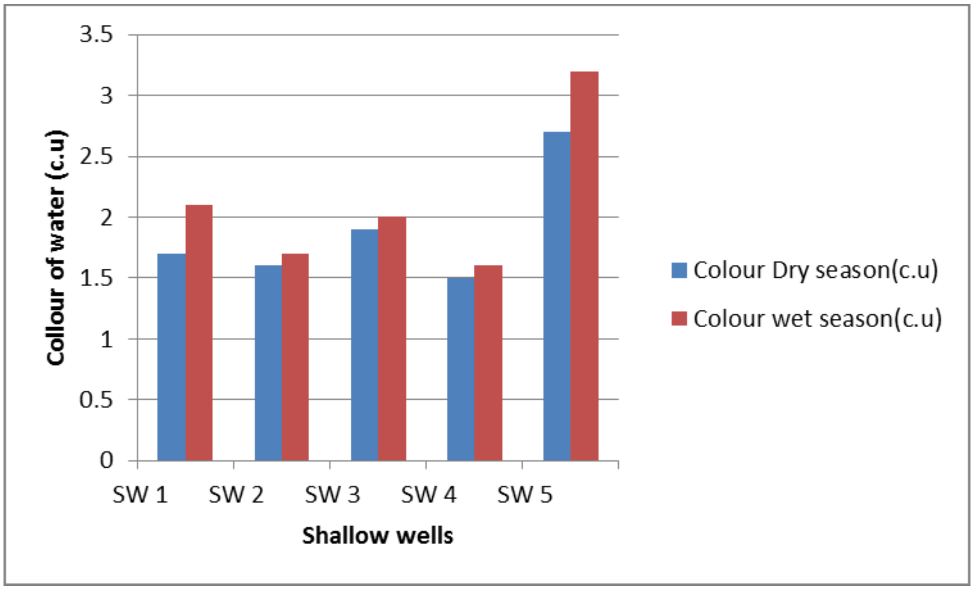

Figure 9: Colour levels in shallow wells water samples in wet and dry month.

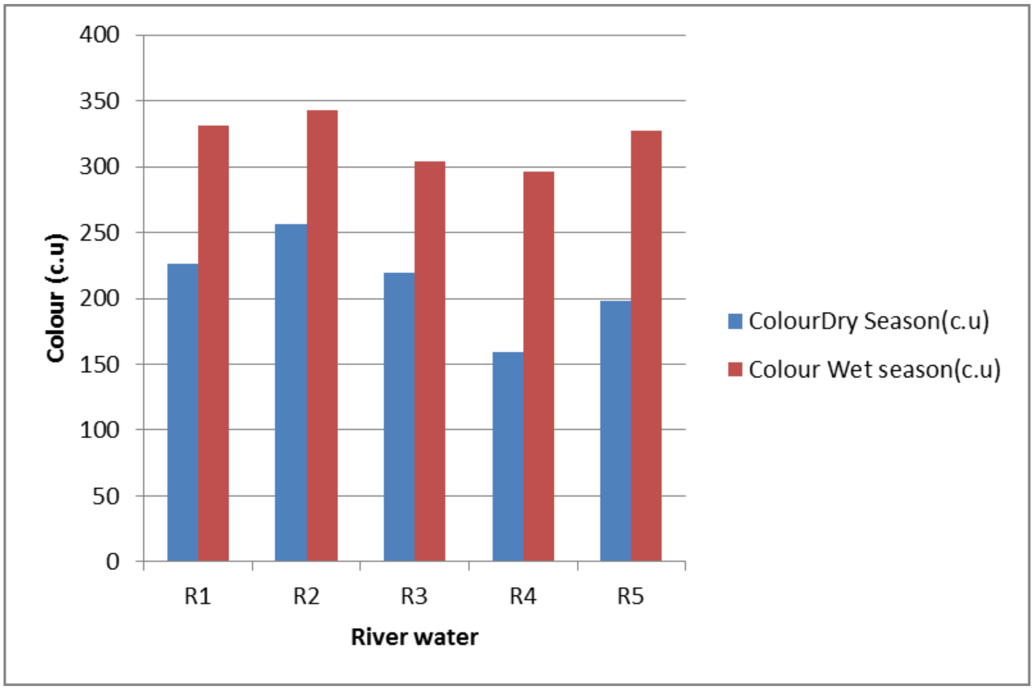

Figure 10: Colour levels in river water samples in wet and dry month.

The colour of boreholes water ranged from 0.4±0.01 c.u at borehole (BH8) to 51.2±0.03 c.u at borehole (BH5) as shown in figure 8. Seasonal variation was evident in the wet season having higher levels of colour in water as compared to dry season. Shallow wells had low levels of colour in water as shown in Figure 9. Colour levels ranged from 1.5±0.03c.u in shallow well SW4 to 3.2±0.02c.u in shallow well SW5 during the dry season. Though the variation was marginal water samples collected during wet season had higher colour levels than those collected during dry season. River water samples had high colour levels ranging from 159±0.03 c.u in river water sample R4 to 343±0.04 c.u in R2 as shown in Figure 10.

Seasonal variation was noted with water samples having high colour levels during wet season compared to dry season. Colour in surface water was higher than that of ground water. This is due to the fact that surface water had suspended soil sediments thus giving it colour. Underground water had low levels of colour in with exception of borehole BH5 located near Athi Primary School that had colour levels 51.2±0.03 c.u. This was unusually high for underground water. Total dissolved solids were higher in ground water compared to surface water. This is due to dissolution of ions as water percolates through the rocks.

4.0.1.4 Total dissolved solids (TDS)

Figures 11, 12 and 13 show the comparison between total dissolved solids (TDS) for the dry month of December 2011 and the wet month of May 2012 in boreholes, shallow wells and river samples respectively. The data for these results is shown in tables 8, 9 and 10.

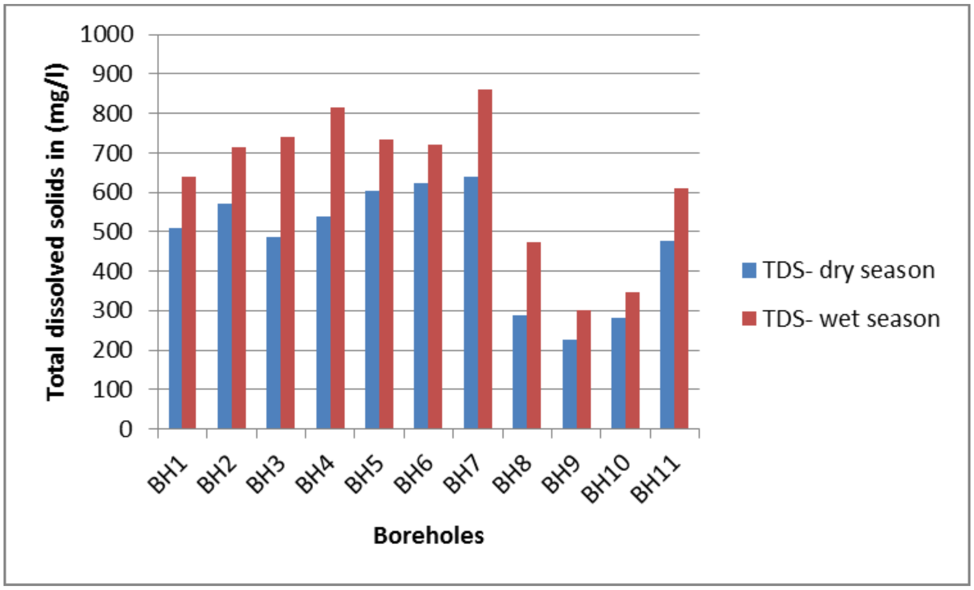

Figure 11: Total dissolved solids levels in boreholes water samples in wet and dry month.

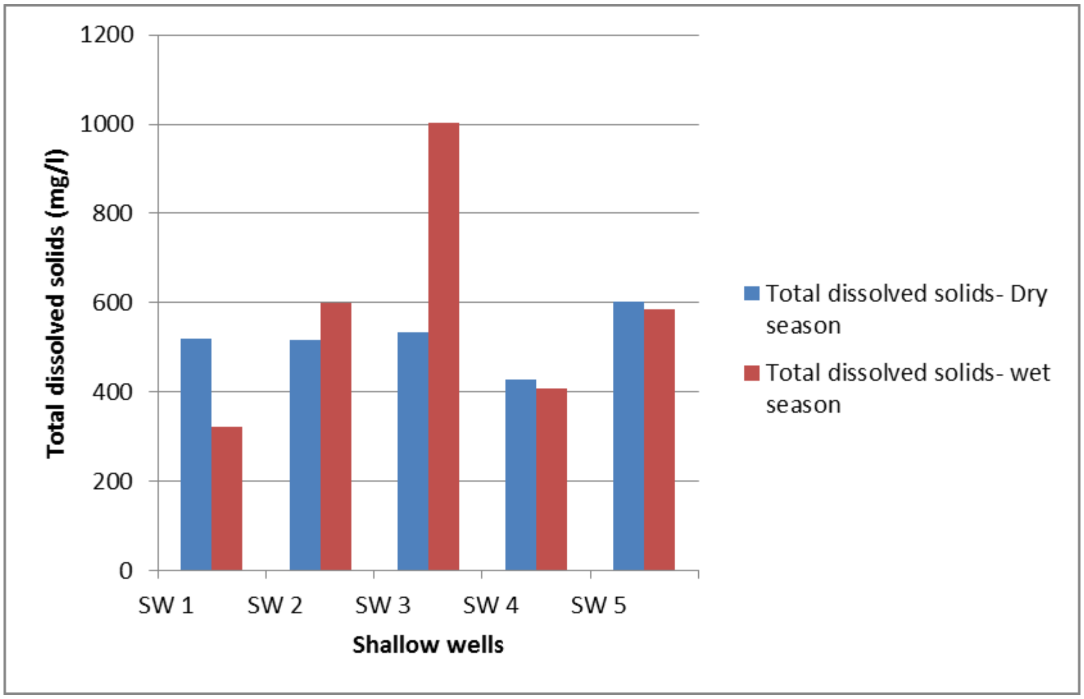

Figure 12: Total dissolved solids in shallow wells water samples in wet and dry month.

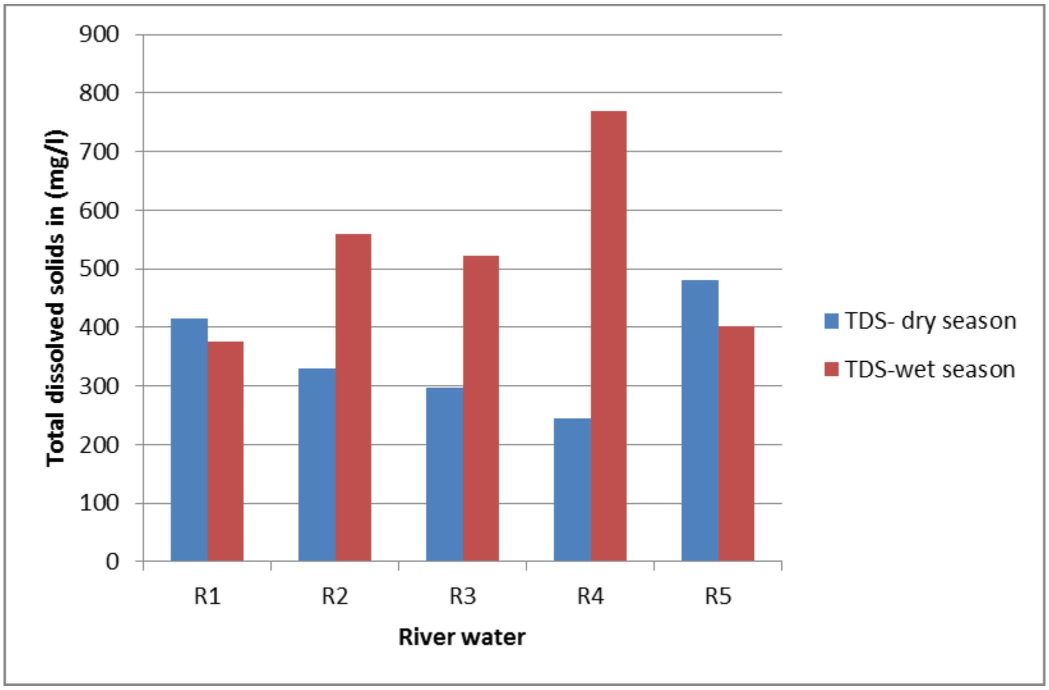

Figure 13: Total dissolved solids in river water samples in wet and dry month.

The levels of total dissolved solids in boreholes are shown in Figure 11. The levels ranged from 224.92±0.54mg/l in borehole (BH9) to 589.52±0.43mg/l at borehole (BH7). Total dissolved solids levels were higher during the wet season compared to dry season (Figure 11). Figure 12 shows levels of total dissolved solids in shallow wells which ranged from 321.28±0.02mg/l in shallow well SW1 to a higher value of 1003.28±0.03mg/l in shallow well SW3. River water had total dissolved solids ranging from 244.48±0.03mg/l- 769.28±0.04mg/l in the river R4 water sample as shown in Figure 13. There was seasonal variation with high total dissolved solids in wet season as compared to dry season. The reason for the high total dissolved solids is further discussed in section 4.2 under chemical parameters.

4.0.1.5 Turbidity

Figures 14 and 15 show the comparison between turbidity in boreholes, shallow wells and river water samples during the dry month of December 2011 and the wet month of May 2012. The results for turbidity are also contained in tables 4,5 and 6 for the dry month of December 2011 and 7,8 and 9 for the wet month of May 2012.

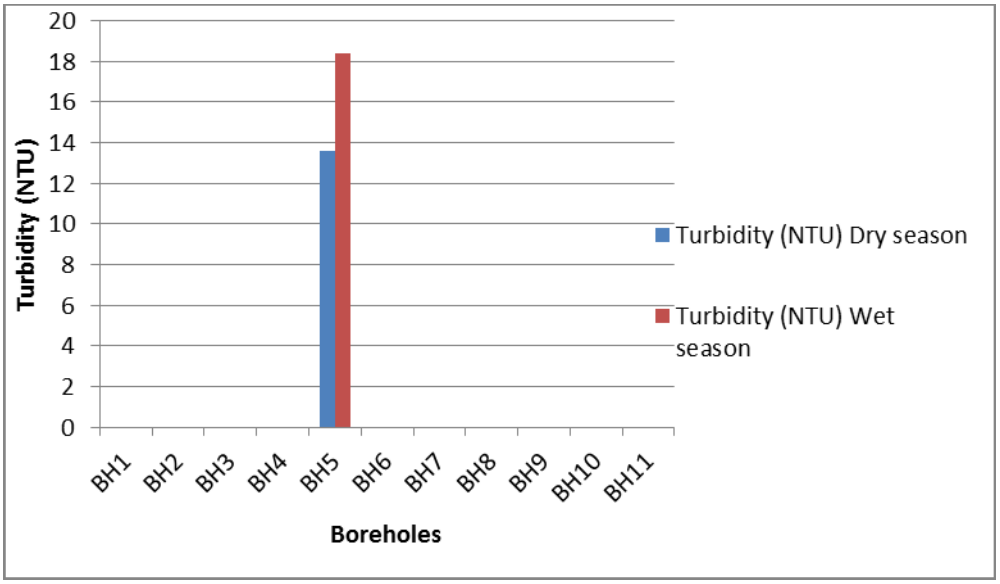

Figure 14: Turbidity levels in boreholes water samples for dry and wet month.

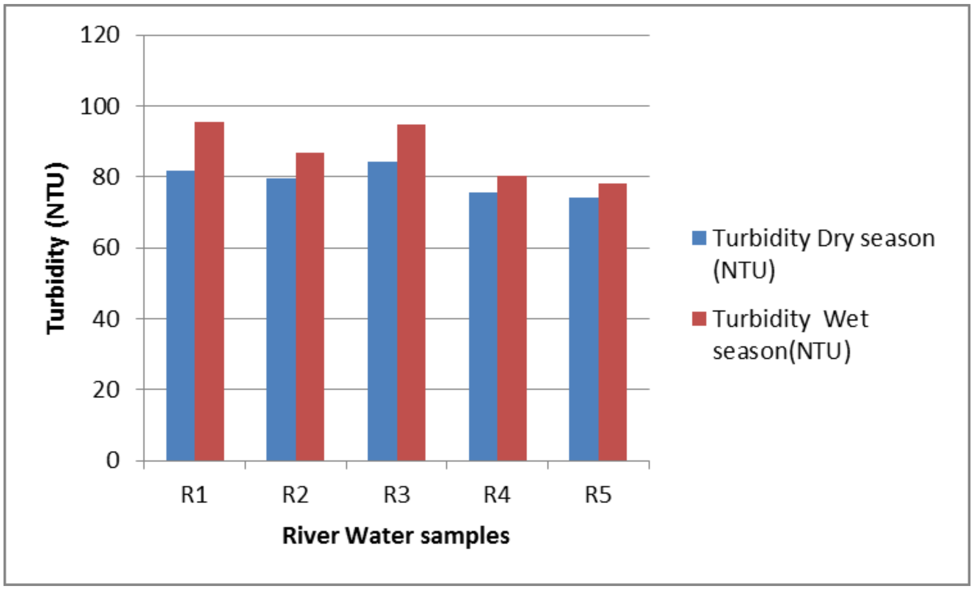

Figure 15: Turbidity levels in river water samples in wet and dry month.

Borehole 5 (BH5) located near Athi Primary School had high turbidity levels ranging from13.6±0.03 NTU to 18.4±0.02 NTU during the wet season as shown in figure 14. All the other boreholes recorded a turbidity level of below detection limit for both dry and wet seasons.

Shallow wells recorded turbidity levels of below detection limit (BDL) for both dry and wet seasons as shown in figure 15. River water samples had high turbidity levels compared to boreholes and shallow wells as shown in Figure 16. Turbidity levels ranged from 74.5±0.05 NTU in river water sample R5 to 95.4±0.02 NTU in river water sample R1. Seasonal variation in turbidity was noted with high turbidity levels in wet season as compared to dry season.

Ground water had lower turbidity levels of below detection limit as compared to surface water that had turbidity levels of between 73 and 95.4 at R1 located in Kangundo Road Bridge. High level of turbidity in surface water was due to suspended solid particles. On the other hand, ground water had low turbidity levels due to the fact that as water percolates through the porous rocks, suspended solid particles are trapped and there do not find their way into the underground impervious rocks.

4.1 Coliforms

The graphical representations of microbial coliforms in boreholes, shallow wells and river water samples are shown in Figures 16, 17 and 18. The results are contained in tables 4,5 and 6 for the dry month of December 2011 and in tables 7,8 and 9 for the wet month of May 2012.

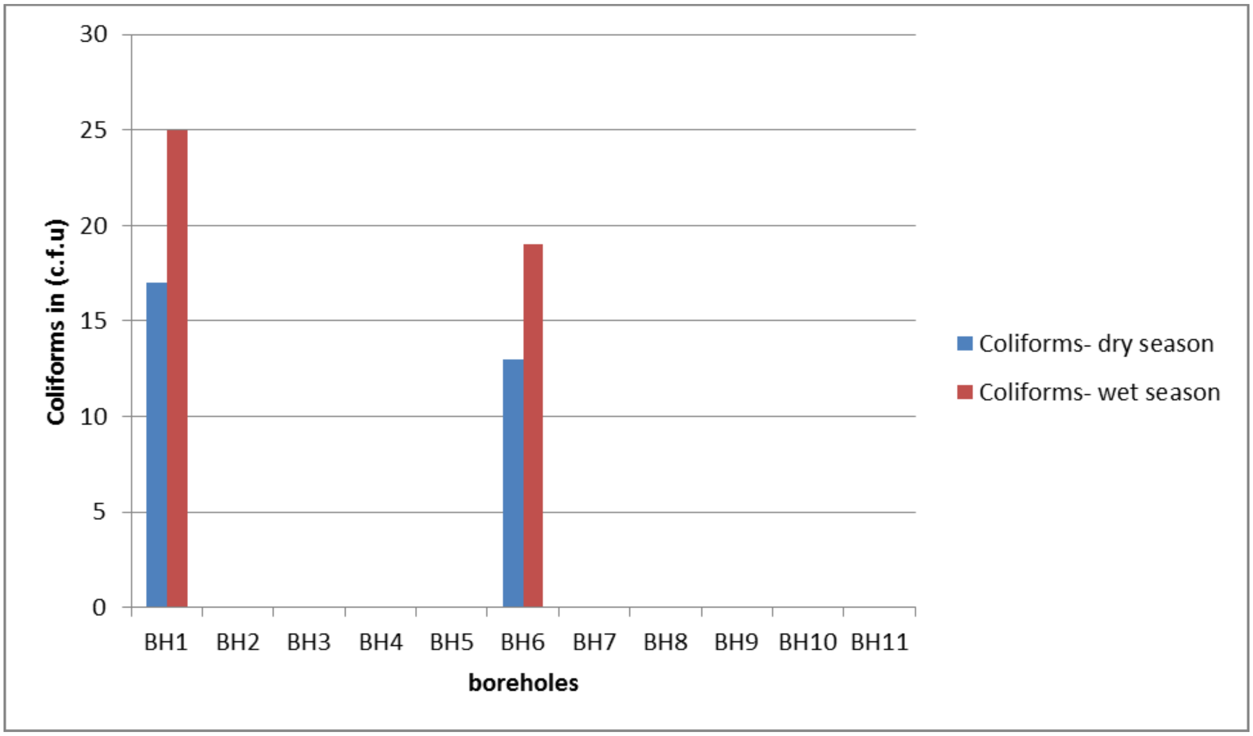

Figure 16: Number of coliforms in boreholes water samples in dry and wet months.

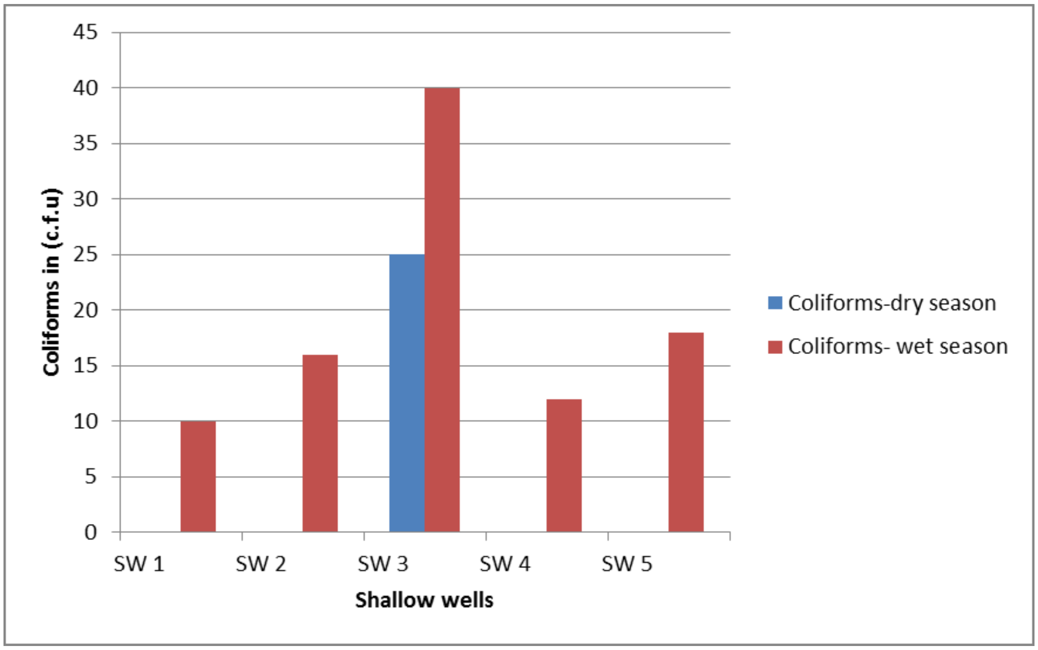

Figure 17: Number of coliforms in shallow wells water samples during dry and wet months.

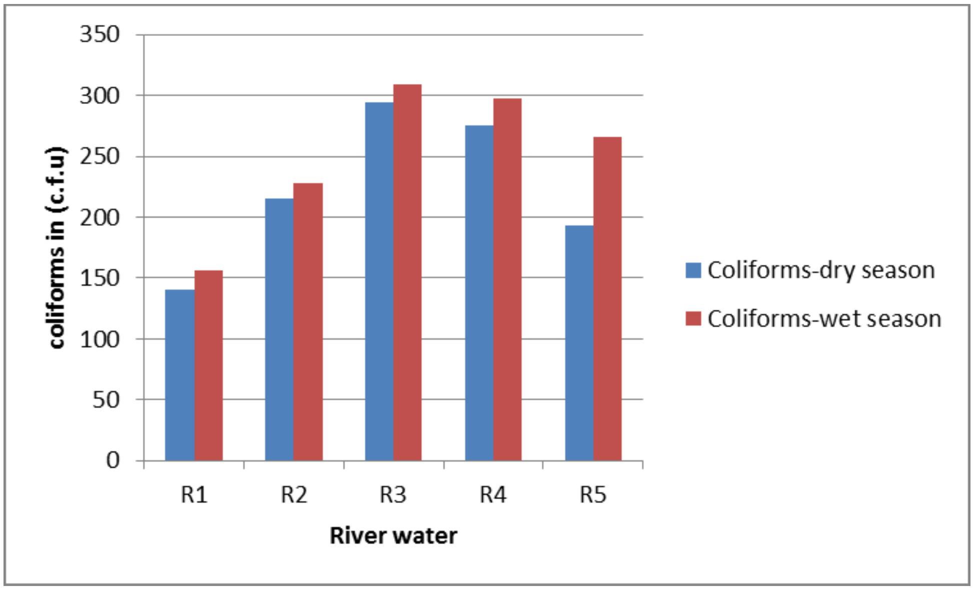

Figure 18: Number of coliforms in river water samples during dry and wet month.

Most boreholes recorded no coliform in the water samples collected with the exception of boreholes BH1 and BH6 as shown in Figure 36 which had coliforms of between 18-26 c.f.u/100ml in BH1, and 14- 20 c.f.u/100ml in BH6. The number of coliforms were higher during wet season compared to dry season (Figure 16). Number of coliforms in shallow wells ranged from 10 c.f.u /100ml in shallow well SW1 to 40 c.f.u /100ml in shallow well SW3 during the wet season. The number of coliforms were higher during the wet season as compared to the dry season (Figure 17). River water samples had high number of coliforms ranging from 140 c.f.u/100ml in R1 to 309 c.f.u/100ml in R3 (Figure 18) during the wet season. Seasonal variation was noted with water samples collected during wet season having a higher number of coliform as compared to those collected during dry season.

Ground water had lower number of coliforms than surface water because water takes long to percolate and as such microbial organisms are trapped by rocks closer to the surface. The low levels of microbial coliforms were a result of little contamination of groundwater water by human and animal waste. (Odiyo and Makungo, 2017). On the other hand, surface water had high levels of coliforms. This could be due to human and animal activity around the rivers such as disposal of domestic waste water into river channels as well as animal waste from communities around the Athi River finding their way into surface water systems. Within ground water, shallow wells had higher number of coliform than boreholes water samples. This could be due to handling of water in shallow wells during its extraction from underground. Most people use pulley system to extract water and equipment used to draw water is not free from contamination. Water samples from Boreholes BH1 and BH3 had some coliform. This was due to the location of taps that were too close to cow sheds and this could have contributed to contamination with animal waste.

4.2 CHEMICAL PARAMETERS.

4.2.1 Heavy Metals

Figures 19-24 show graphical representation of levels of heavy metals in boreholes, shallow wells and river water comparatively for the dry month of December 2011 and wet month of May 2012. These results are also contained in Tables 10-12 for the dry month and 13-15 for the wet month.

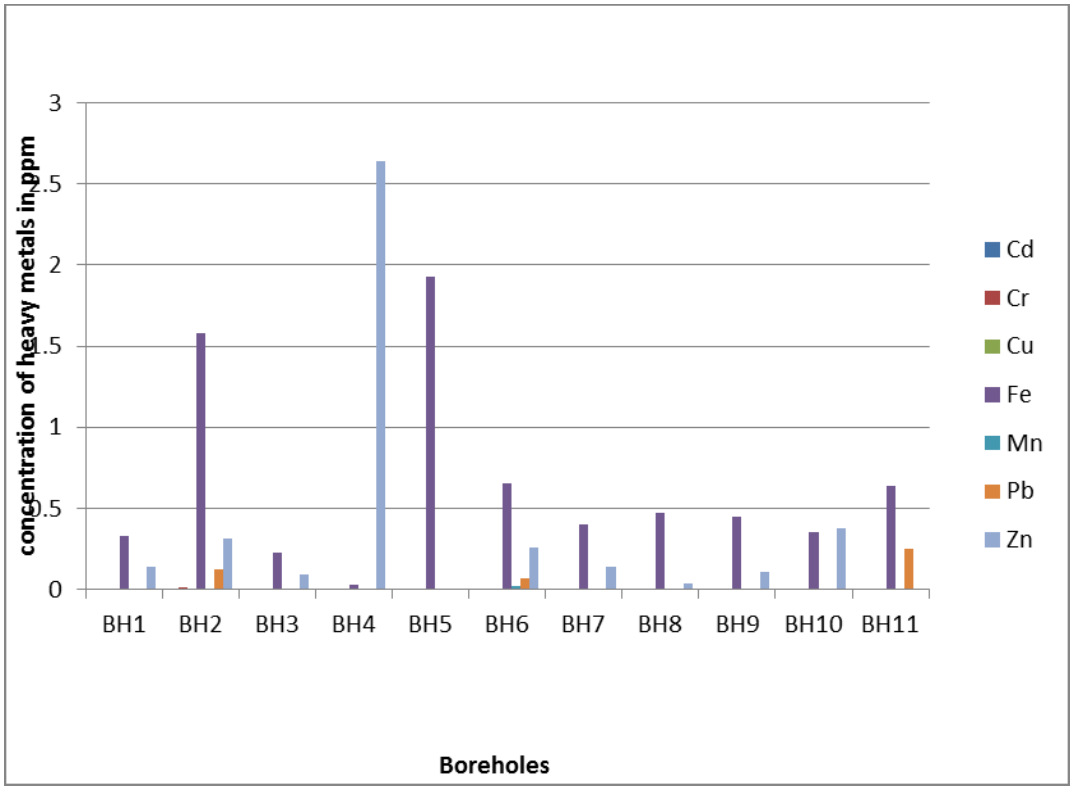

Figure 19: Heavy metals levels in boreholes water samples during dry month.

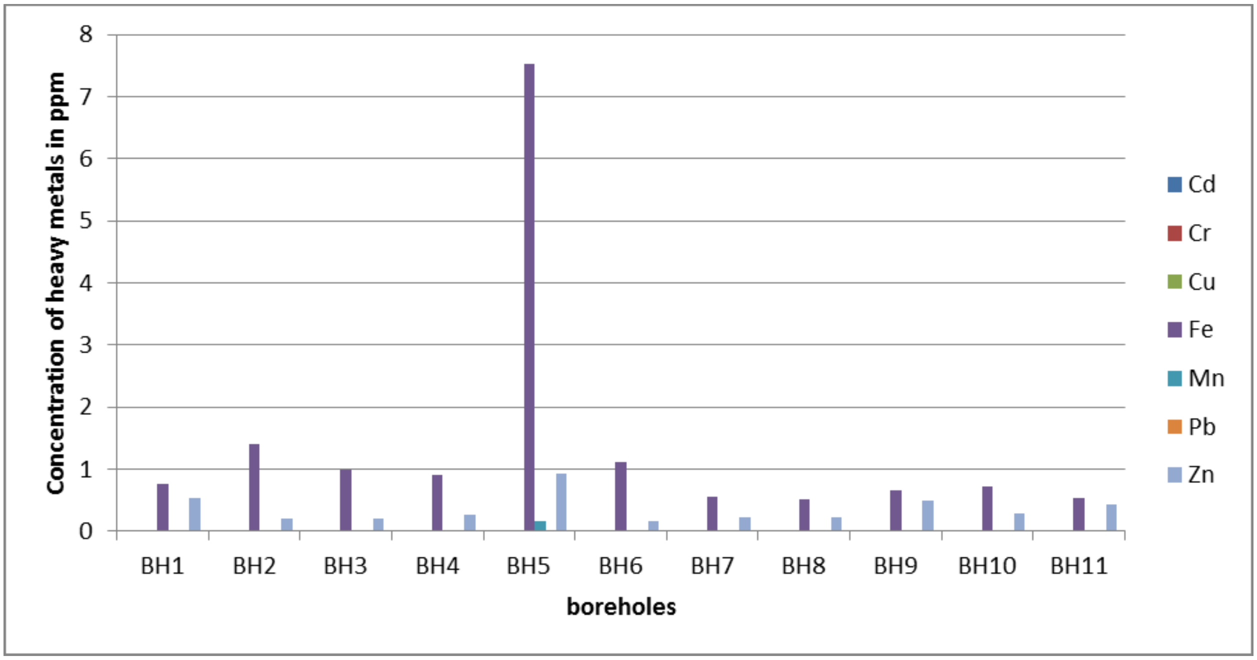

Figure 20: Heavy metals levels in boreholes water samples during wet month.

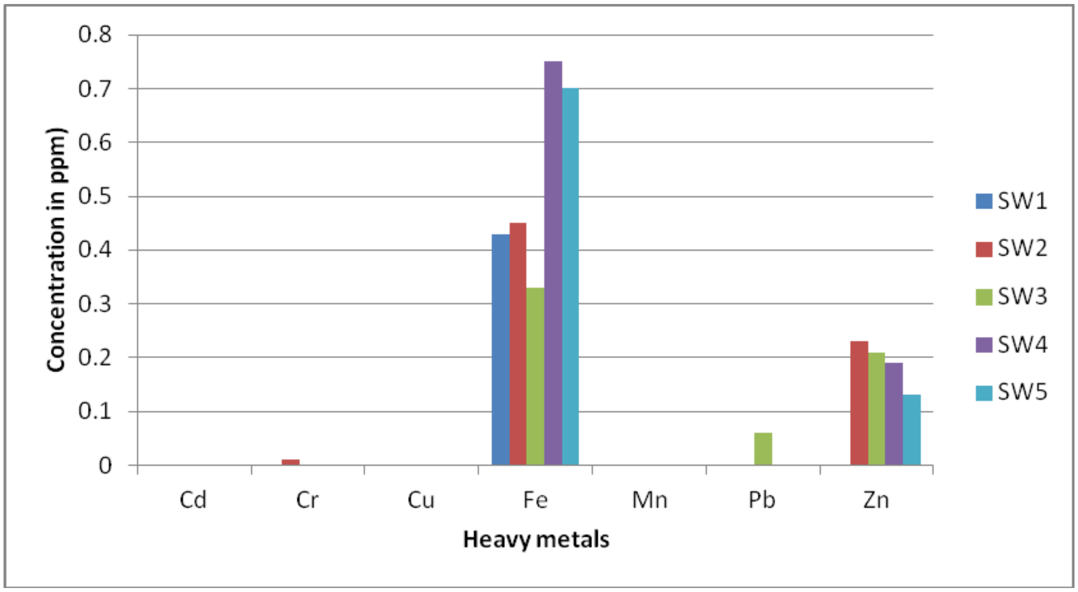

Figure 21: Variation in heavy metals levels in shallow wells during dry month.

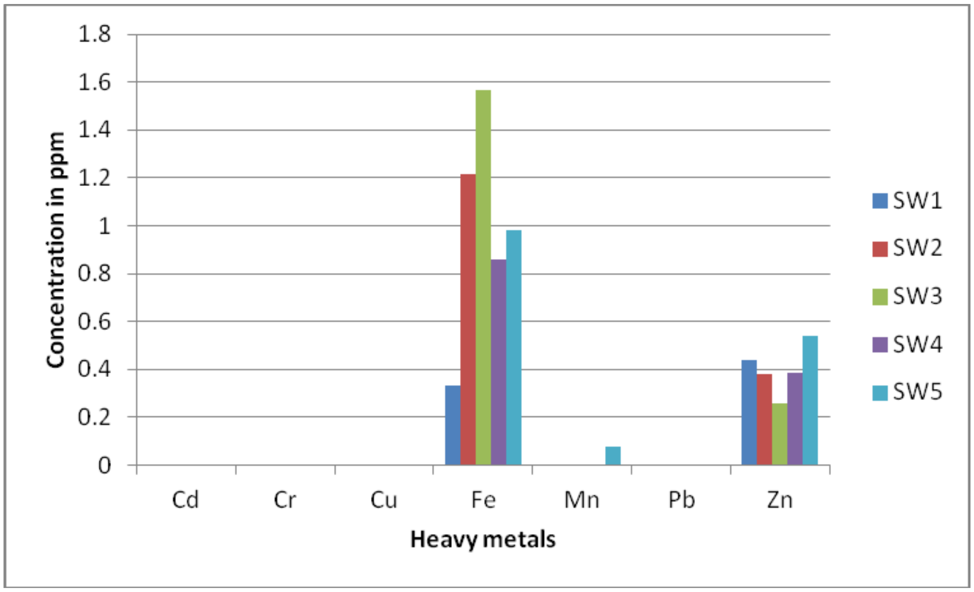

Figure 22: Heavy metal levels in shallow wells during wet month.

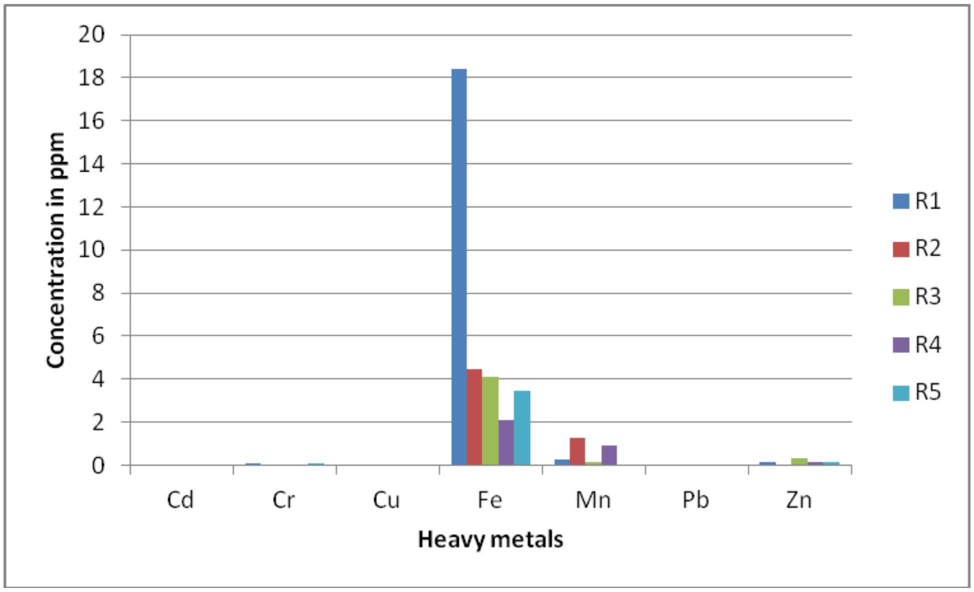

Figure 23: Heavy metals in river water samples during dry month.

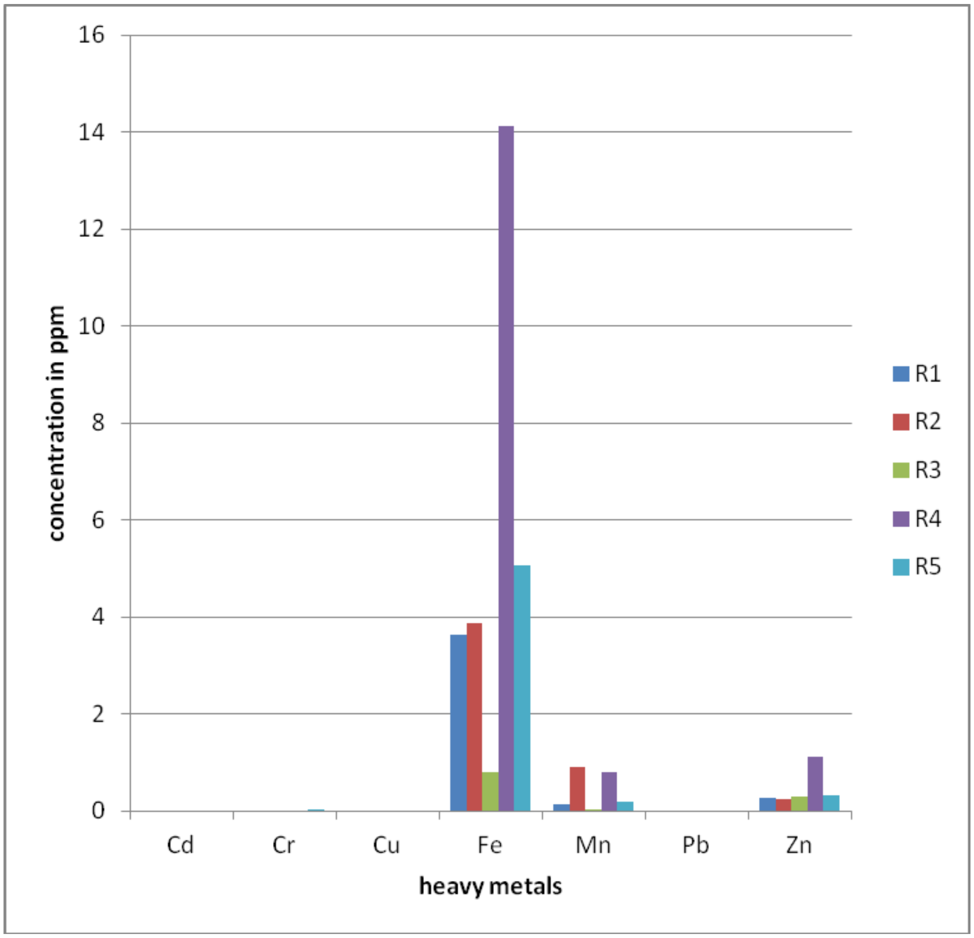

Figure 24: Heavy metals in river water samples during wet month.

There was higher level of iron in surface water as compared to underground water ranging from 0.795±0.004 ppm to 18.40±0.003 ppm at river sample located at Kangundo Road Bridge. There were higher levels of zinc in ground water as compared to surface water. Zinc levels in ground water ranged from 0.06±0.003 ppm to 0.935±0.002 ppm at borehole at Athi primary school. There were higher traces of lead in ground water ranging 0.04±0.003 ppm to 2.64±0.002 ppm in borehole located at Brookshine School as compared to surface water whose lead levels ranged from 0 to 0.33±0.002 ppm. There were higher levels of Manganese in surface water ranging from below detection limit to 0.900±0.002 ppm in sample R2 located at Mombasa Road bridge compared to ground water which ranged from below detection limit to 0.165±0.003 ppm in borehole 5 located at Athi Primary school.

Surface water had higher levels of iron compared to ground water. There was unusually high level of iron in River sample R1 located at Kangundo Road Bridge during the dry season and R4 located at Mbagathi River in Ongata Rongai in wet season. This could be due to agricultural activity happening in these two areas through use of iron-containing chemicals that found their way into the river channels as well as disposal of domestic wastes that could contain iron such as iron-containing medicinal drugs.

Zinc levels in ground water ranged from 0.06±0.003 ppm to 0.935±0.002 ppm at borehole at Athi primary school. The high level of zinc in ground water as compared to surface water was due to presence of zinc in rock structure of area under study. There were higher traces of lead in ground water ranging 0.04±0.003 ppm to 2.64±0.002 ppm in borehole located at Brookshine School as compared to surface water whose lead levels ranged from 0 to 0.33±0.002ppm. This could be attributed to percolation of leaded gasoline used for a long time in Kenya which is the main source of lead in water bodies near highways. There traces of Chromium in both surface and ground water ranging from below detection limit to 0.03±0.001 and could therefore not provide conclusion.

There were higher levels of Manganese in surface water ranging from below detection limit to 0.900±0.002ppm in sample R2 located at Mombasa Road bridge compared to ground water which ranged from below detection limit to 0.165±0.003ppm in borehole 5 located at Athi Primary school. The high level of manganese in ground water was due to disposal of chemicals containing manganese into the river channel.

Table 10: heavy metals in shallow wells water in December 2011.

				(Concentration in ppm)			
Site	Cd	Cr	Cu	Fe	Mn	Pb	Zn
SW 1	<0.01	<0.01	<0.01	0.43±0.03	<0.01	<0.01	<0.01
SW 2	<0.01	0.01±0.001	<0.01	0.45±0.02	<0.01	0.23±0.03	<0.01
SW 3	<0.01	<0.01	<0.01	0.33±0.05	<0.01	0.21±0.03	0.06±0.01
SW 4	<0.01	<0.01	<0.01	0.75±0.01	<0.01	0.19±0.03	<0.01
SW 5	<0.01	<0.01	<0.01	0.70±0.03	<0.01	0.13±0.03	<0.01

See explanations of the abbreviations of the shallow wells sampling sites in Table 1

Table 11: heavy metals in boreholes water in December 2011.

Site	Cd	Cr	Cu	Fe	Mn	Pb	Zn
BH 1	<0.01	<0.01	<0.01	0.33±0.003	<0.01	0.14±0.002	<0.01
BH 2	<0.01	0.01±0.007	<0.01	1.58±0.003	<0.01	0.31±0.005	0.12±0.004
BH 3	<0.01	<0.01	<0.01	0.23±0.002	<0.01	0.09±0.001	<0.01
BH 4	<0.01	<0.01	<0.01	0.03±0.001	<0.01	2.64±0.004	<0.01
BH 5	<0.01	<0.01	<0.01	1.93±0.003	<0.01	<0.01	<0.01
BH 6	<0.01	<0.01	<0.01	0.65±0.005	0.02±0.00	0.26±0.002	0.07±0.001
BH 7	<0.01	<0.01	<0.01	0.40±0.003	<0.01	0.14±0.003	<0.01
BH 8	<0.01	<0.01	<0.01	0.47±0.001	<0.01	0.04±0.001	<0.01
BH 9	<0.01	<0.01	<0.01	0.45±0.002	<0.01	0.11±0.002	<0.01
BH 10	<0.01	0.02±0.001	<0.01	0.35±0.002	<0.01	0.38±0.002	<0.01
BH 11	<0.01	<0.01	<0.01	0.64±0.002	<0.01	<0.01	0.25±0.003

See explanations of the abbreviations of the boreholes sampling sites in Table 2

Table 12: Heavy metals in Rivers water samples in December 2011.

				mg/L			
Sampling Site	Cd	Cr	Cu	Fe	Mn	Pb	Zn
R1	<0.01	0.03±0.001	<0.01	18.40±0.002	0.25±0.001	0.12±0.004	<0.01
R2	<0.01	<0.01	<0.01	4.45±0.003	1.27±0.002	<0.01	<0.01
R3	<0.01	<0.01	<0.01	4.08±0.004	0.13±0.002	0.33±0.002	<0.01
R4	<0.01	<0.01	<0.01	2.11±0.001	0.94±0.002	0.17±0.001	<0.01
R5	<0.01	0.03±0.001	<0.01	3.43±0.001	<0.01	0.12±0.001	<0.01

See explanations of the abbreviations of the rivers sampling sites in Table 3

Table 13: Heavy metals levels in Shallow wells collected in May 2012. (Wet month)

			Concentrations in (ppm)				
Sampling Site	Cd	Cr	Cu	Fe	Mn	Pb	Zn
SW 1	<0.01	<0.01	<0.01	0.330±0.03	<0.01	<0.01	0.440±0.003
SW 2	<0.01	<0.01	<0.01	1.215±0.02	<0.01	<0.01	0.380±0.02
SW 3	<0.01	<0.01	<0.01	1.565±0.01	<0.01	<0.01	0.260±0.01
SW 4	<0.01	<0.01	<0.01	0.860±0.02	<0.01	<0.01	0.385±0.04
SW 5	<0.01	<0.01	<0.01	0.980±0.04	0.075±0.03	<0.01	0.540±0.03

See explanations of the abbreviations of the shallow wells sampling sites in Table 1

Table 14: Heavy metals levels in Boreholes collected in May 2012. (Wet month)

Sampling Site	Cd	Cr	Cu	Fe	Mn	Pb	Zn
BH 1	<0.01	<0.01	<0.01	0.755±0.0003	<0.01	<0.01	0.545±0.0002
BH 2	<0.01	<0.01	<0.01	1.395±0.0003	<0.01	<0.01	0.195 ±0.0004
BH 3	<0.01	<0.01	<0.01	0.995 ±0.0002	<0.01	<0.01	0.195±0.0003
BH 4	<0.01	<0.01	<0.01	0.915±0.0001	<0.01	<0.01	0.265±0.0002
BH 5	<0.01	<0.01	<0.01	7.535±0.0003	0.165±0.0002	<0.01	0.935±0.0003
BH 6	<0.01	<0.01	<0.01	1.105±0.0005	<0.01	<0.01	0.170±0.0001
BH 7	<0.01	<0.01	<0.01	0.550±0.0003	<0.01	<0.01	0.235±0.0002
BH 8	<0.01	<0.01	<0.01	0.520±0.0001	<0.01	<0.01	0.230±0.0004
BH 9	<0.01	<0.01	<0.01	0.670±0.0002	<0.01	<0.01	0.485±0.0003
BH 10	<0.01	<0.01	<0.01	0.725±0.0002	<0.01	<0.01	0.290±0.0002
BH 11	<0.01	<0.01	<0.01	0.540±0.0002	<0.01	<0.01	0.430±0.0003

See explanations of the abbreviations of the boreholes sampling sites in Table 2

Table 15: Heavy metals levels in River water samples collected in May 2012. (Wet month)

	(concentration in ppm)						
Sampling Site	Cd	Cr	Cu	Fe	Mn	Pb	Zn
R1	<0.01	<0.01	<0.01	3.625±0.0004	0.135±0.0001	<0.01	0.272±0.0003
R2	<0.01	<0.01	<0.01	3.860±0.0002	0.900±0.0003	<0.01	0.251±0.0002
R3	<0.01	<0.01	<0.01	0.795±0.0004	0.032±0.0002	<0.01	0.305±0.0004
R4	<0.01	<0.01	<0.01	14.120±0.0001	0.785±0.0002	<0.01	1.105±0.0002
R5	<0.01	0.03±0.001	<0.01	5.066±0.0001	0.175±0.0004	<0.01	0.310±0.0003

See explanations of the abbreviations of the rivers sampling sites in Table 3

4.2.2 Sodium and chloride ions.

Tables 16, 17 and 18 contain results of sodium and chloride ions in boreholes, shallow wells and river water samples for the dry month of December 2011. Tables 19,20, and 21 represent results of sodium and chloride ions in boreholes, shallow wells and river water samples for the wet month of May 2012. Figures 25, 26 and 27 provide a graphical representation of data obtained when sodium and chloride ions were analyzed for both dry and wet months.

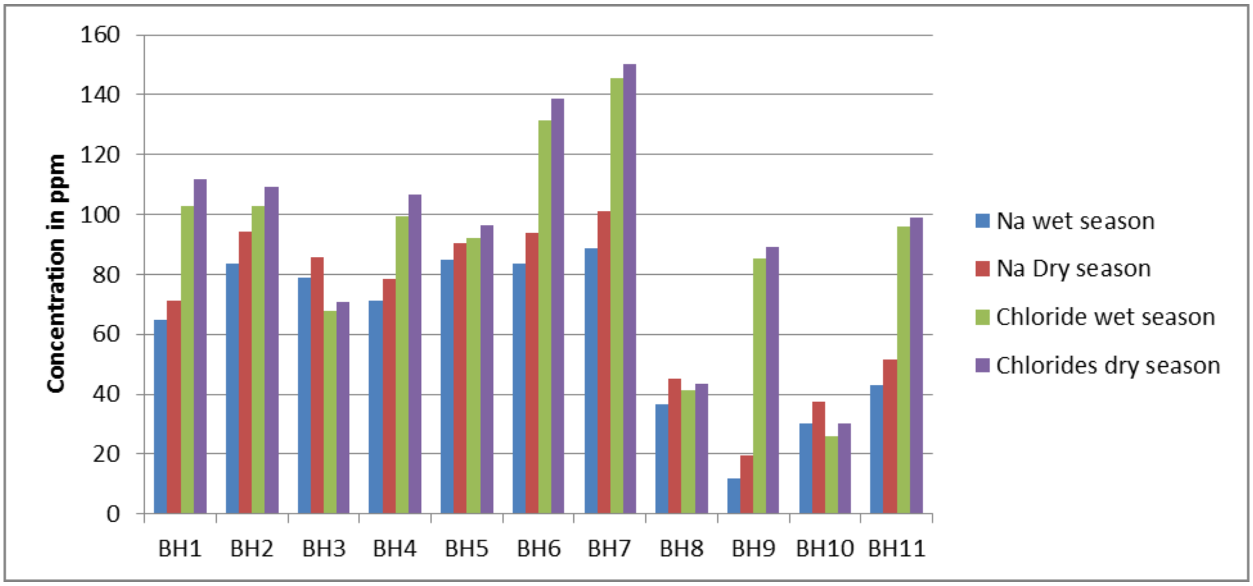

Figure 25: Sodium and chloride levels in boreholes water samples in wet and dry months.

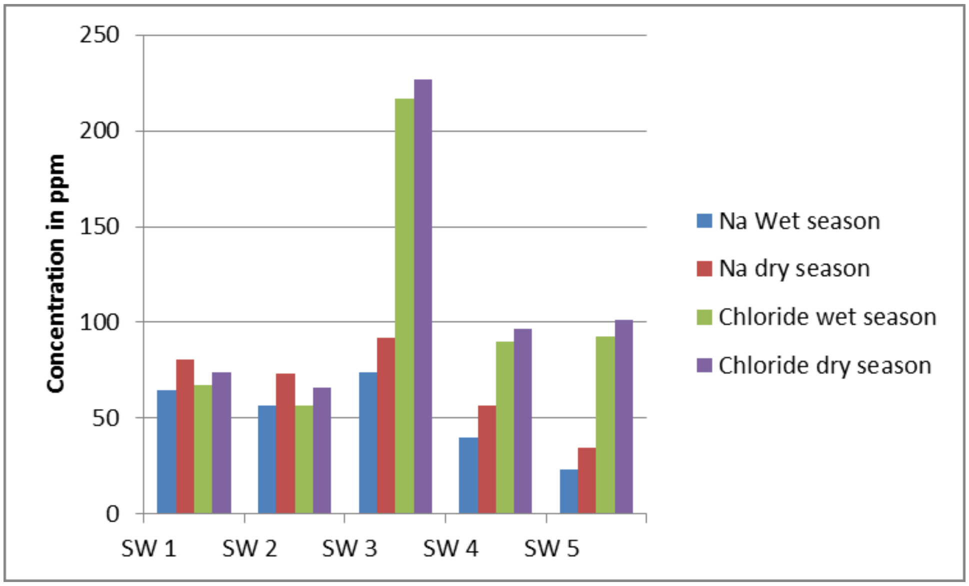

Figure 26: Sodium and chlorides levels in shallow wells water samples in wet and dry months.

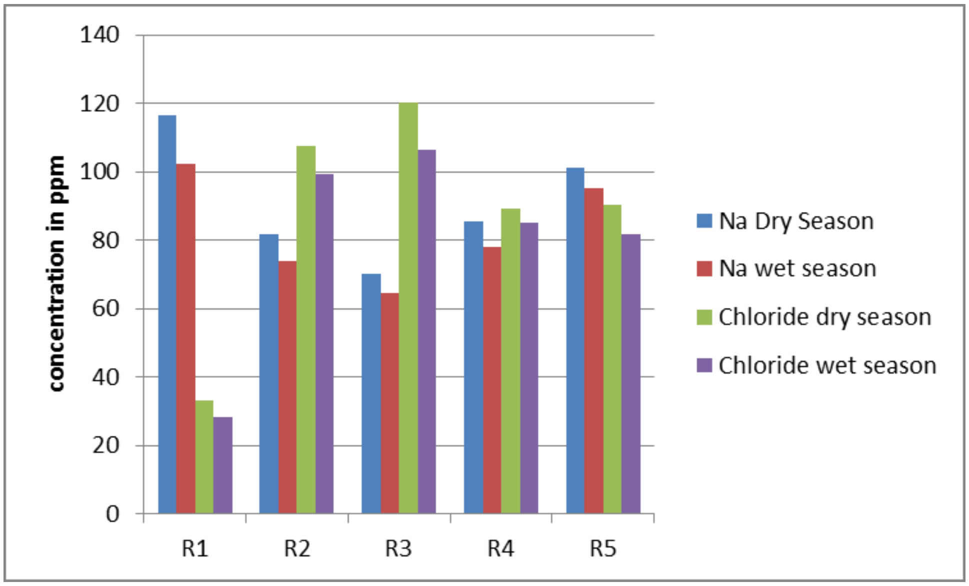

Figure 27: Sodium and chlorides levels in river water samples during in wet and dry month.

There were higher levels of Sodium in surface water than ground water ranging from 70.180±0.03 ppm to 116.65±0.02 ppm at Kangundo Road Bridge. There were higher levels of chlorides in ground water ranging from 30.04±0.02 ppm to 226.49±0.04 ppm from shallow well located at near

Brookshine School as shown in figures 20, 27 and 34. The unusually high levels of chlorides in River water sample at R4 whose levels were 120.3±0.03 ppm was found.

Both ground water and surface water had high levels of sodium. Surface water has high levels of sodium due to domestic waste water finding its way into river channels. Ground water on the other hand had high levels of sodium due to dissolution of sodium from the underground rocks. Ground water had higher levels of chloride compared to surface water because chloride containing rocks that dissolves as water percolates into the underground impervious rocks.

Table 16: Na, Mg, Ca and anions in shallow wells samples in December 2011.

Sampling Site	Na^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}/HCO_3^-	Cl^-	F^-	SO_4^{2-}	NO_3^-	NO_2^-
				(concentration in ppm)					
SW 1	80.43±0.03	50.43±0.02	3.78±0.03	56.41±0.05	74.11±0.03	1.67±0.02	36.14±0.04	2.98±0.02	<0.01
SW 2	73.28±0.04	44.75±0.03	9.03±0.05	43.69±0.03	65.91±0.06	2.85±0.03	75.68±0.03	3.01±0.01	<0.01
SW 3	91.75±0.02	201.29±0.04	11.65±0.02	30.11±0.02	226.49±0.04	4.26±0.04	230.76±0.04	13.45±0.03	<0.01
SW 4	56.63±0.01	170.81±0.01	10.89±0.01	36.24±0.03	96.38±0.01	3.94±0.02	41.40±0.01	8.62±0.04	<0.01
SW 5	34.67±0.05	20.36±0.03	5.44±0.03	43.65±0.06	101.27±0.03	4.32±0.01	38.58±0.01	4.73±0.02	<0.01

See explanations of the abbreviations of the shallow wells sampling sites in Table 1

Table 17: Na, Ca, Mg and anions in boreholes water samples in December 2011

(concentration in ppm)

Sampling Site	Na^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}/HCO_3^-	Cl^-	F^-	SO_4^{2-}	NO_3^-	NO_2^-
BH 1	71.263±0.02	30.411±0.02	6.143±0.03	52.327±0.01	111.75±0.05	4.24±0.02	69.231±0.03	2.84±0.04	<0.01
BH 2	94.341±0.03	41.285±0.02	7.894±0.03	50.649±0.05	109.23±0.02	2.45±0.03	74.645±0.01	3.05±0.03	<0.01
BH 3	85.761±0.03	28.789±0.04	3.91±0.02	48.416±0.05	70.84±0.02	3.96±0.03	101.137±0.04	2.13±0.01	<0.01
BH 4	78.569±0.02	40.324±0.03	3.642±0.02	31.726±0.01	106.56±0.04	4.02±0.02	21.398±0.03	3.29±0.04	<0.01
BH 5	90.238±0.03	36.681±0.02	5.012±0.03	64.117±0.01	96.42±0.03	4.51±0.04	65.613±0.05	1.86±0.01	<0.01
BH 6	93.655±0.01	32.973±0.03	2.723±0.04	38.981±0.05	138.58±0.03	9.36±0.04	140.804±0.02	1.77±0.03	<0.01
BH 7	101.294±0.04	38.214±0.03	3.319±0.03	40.435±0.01	150.11±0.02	8.79±0.04	155.338±0.06	5.01±0.03	<0.01
BH 8	45.365±0.04	26.178±0.01	2.960±0.02	35.631±0.04	43.29±0.03	2.06±0.04	17.297±0.02	9.68±0.01	<0.01
BH 9	19.673±0.04	30.216±0.05	5.298±0.06	37.422±0.01	89.14±0.04	0.37±0.03	15.114±0.02	8.32±0.01	<0.01
BH 10	37.456±0.01	44.334±0.03	5.921±0.02	29.656±0.03	30.04±0.02	3.11±0.03	19.723±0.02	2.11±0.01	<0.01
BH 11	51.528±0.03	160.753±0.04	14.385±0.02	41.57±0.03	99.18±0.02	1.01±0.01	43.836±0.03	5.98±0.04	<0.01

See explanations of the abbreviations of the boreholes sampling sites in Table 2

Table 18: Na, Ca, Mg and anions levels in river water samples in December 2011

	(concentration in ppm)								
Sampling Site	Na^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}/HCO_3^-	Cl^-	F^-	SO_4^{2-}	NO_3^-	NO_2^-
R1	116.65±0.02	38.47±0.03	7.589±0.04	8.21±0.03	33.1±0.02	0.73±0.04	506.24±0.02	7.39±0.03	<0.01
R2	81.93±0.03	31.45±0.05	8.461±0.03	20.65±0.03	107.6±0.04	0.91±0.02	80.118±0.05	3.54±0.02	<0.01
R3	70.18±0.04	40.66±0.04	8.013±0.04	21.02±0.05	120.3±0.03	1.02±0.03	74.735±0.04	3.92±0.02	<0.01
R4	85.51±0.03	39.37±0.02	9.44±0.03	25.94±0.02	89.4±0.03	3.15±0.04	83.054±0.02	15.68±0.01	<0.01
R5	101.23±0.05	18.99±0.03	5.238±0.03	10.73±0.03	90.53±0.01	1.37±0.04	520.231±0.02	11.36±0.03	<0.01

See explanations of the abbreviations of the rivers sampling sites in Table 3

Table 19: Na, Ca, Mg and anions in shallow wells in May 2012.

	(concentration in ppm)								
Sampling Site	Na^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}/HCO_3^-	Cl^-	F^-	SO_4^{2-}	NO_3^-	NO_2^-
SW 1	64.60±0.02	36.63±0.03	2.91±0.02	39.0±0.02	67.45±0.02	1.52±0.03	29.217±0.01	1.89±0.02	<0.01
SW 2	56.40±0.01	34.62±0.02	7.065±0.03	37.5±0.01	56.80±0.01	2.06±0.03	69.544±0.02	2.71±0.03	<0.01
SW 3	74.25±0.03	185.75±0.01	9.325±0.01	26.3±0.02	216.55±0.04	4.06±0.03	214.803±0.03	12.32±0.02	<0.01
SW 4	39.85±0.03	153.13±0.03	7.895±0.03	30.00±0.04	89.93±0.03	3.75±0.02	34.978±0.04	6.78±0.03	<0.01
SW 5	23.50±0.03	14.75±0.02	3.345±0.04	37.5±0.03	92.30±0.01	4.18±0.02	28.805±0.01	2.52±0.03	<0.01

See explanations of the abbreviations of the shallow wells sampling sites in Table 1

Table 20: Na, Ca, Mg and anions in shallow wells in May 2012.

(concentration in ppm)

Sampling Site	Na^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}/HCO_3^-	Cl^-	F^-	SO_4^{2-}	NO_3^-	NO_2^-
BH 1	64.85±0.03	26.63±0.02	4.185±0.03	45±0.02	102.95±0.01	3.87±0.02	60.491±0.01	2.20±0.03	<0.01
BH 2	83.55±0.04	36.00±0.02	6.455±0.05	42.5±0.02	102.95±0.03	2.09±0.03	69.132±0.01	2.21±0.01	<0.01
BH 3	79.00±0.02	22.13±0.03	2.960±0.02	41.5±0.03	67.45±0.02	2.76±0.03	91.353±0.01	1.53±0.01	<0.01
BH 4	71.30±0.02	33.50±0.03	2.820±0.03	25.0±0.03	99.4±0.02	3.21±0.01	16.46±0.02	2.36±0.03	<0.01
BH 5	84.75±0.03	29.50±0.02	3.925±0.02	57.5±0.01	92.3±0.03	3.73±0.04	61.725±0.02	1.74±0.01	<0.01
BH 6	83.75±0.02	26.88±0.01	2.395±0.02	34±0.03	131.35±0.01	7.00±0.04	133.738±0.03	1.52±0.03	<0.01
BH 7	88.60±0.01	29.25±0.03	2.955±0.03	35.5±0.04	145.55±0.02	6.45±0.01	148.552±0.03	4.32±0.02	<0.01
BH 8	36.75±0.04	20.25±0.02	2.840±0.02	30.2±0.03	41.46±0.02	1.84±0.03	13.580±0.04	8.38±0.02	<0.01
BH 9	11.75±0.03	22.63±0.02	4.625±0.02	30±0.03	85.2±0.02	0.28±0.03	11.934±0.03	7.55±0.03	<0.01
BH 10	30.45±0.03	36.63±0.02	5.305±0.02	25±0.03	26.03±0.02	2.62±0.02	16.46±0.02	1.98±0.03	<0.01
BH 11	43.15±0.03	149.38±0.02	10.96±0.01	35±0.02	95.85±0.02	0.78±0.01	39.504±0.01	5.74±0.03	<0.01

See explanations of the abbreviations of the boreholes sampling sites in Table 2

Table 21: Na, Ca, Mg and anions in shallow wells in May 2012.

	(concentration in ppm)								
Sampling Site	Na^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}/HCO_3^-	Cl^-	F^-	SO_4^{2-}	NO_3^-	NO_2^-
R1	102.20±0.02	32.40±0.03	6.615±0.02	6.5±0.04	28.4±0.03	0.28±0.01	481.867±0.02	6.33±0.03	<0.01
R2	73.95±0.02	28.25±0.03	7.245±0.01	16±0.02	99.4±0.04	0.61±0.03	68.309±0.03	2.78±0.03	<0.01
R3	64.45±0.03	37.85±0.02	6.765±0.02	16±0.01	106.5±0.02	0.75±0.03	66.252±0.03	2.96±0.02	<0.01
R4	78.15±0.02	32.10±0.03	7.615±0.02	20±0.04	85.2±0.03	2.80±0.04	74.482±0.01	10.74±0.01	<0.01
R5	95.20±0.02	15.55±0.02	4.83±0.03	8.4±0.03	81.65±0.03	1.02±0.01	493.800±0.03	7.21±0.03	<0.01

See explanations of the abbreviations of the rivers sampling sites in Table 3

4.2.3 Calcium, magnesium and total alkalinity

Tables 16-21 show the results of calcium, magnesium and total alkalinity in both surface and underground water. Figures 28-33 provide a graphical representation of data obtained when calcium, magnesium and total alkalinity were analyzed.

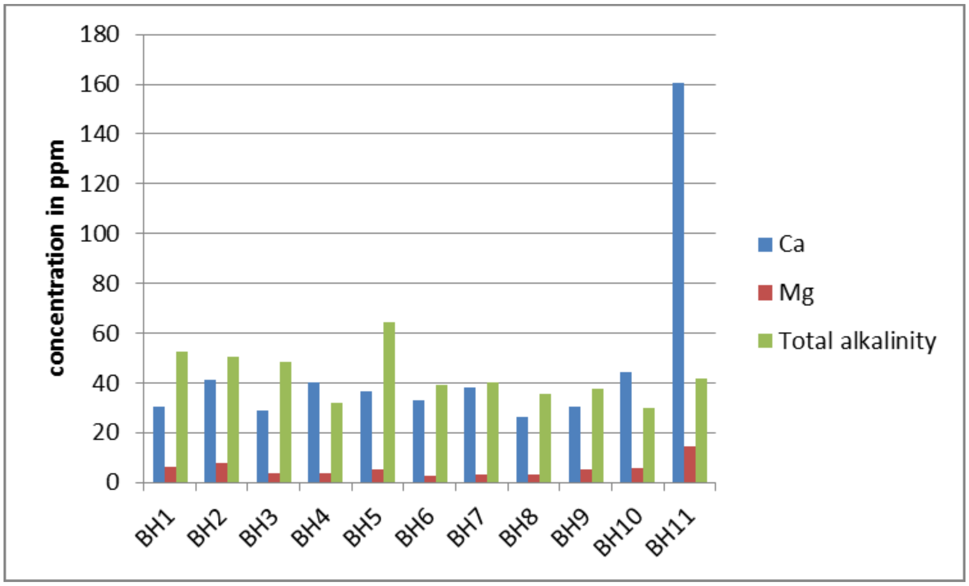

Figure 28: Mg, Ca and total alkalinity levels in boreholes during dry month.

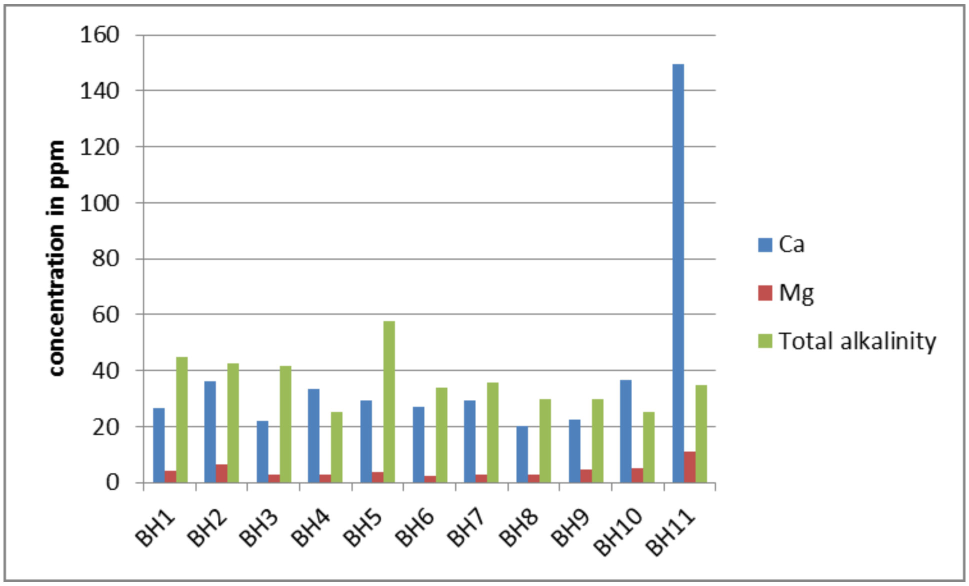

Figure 29: Mg, Ca and total alkalinity levels in boreholes during wet month.

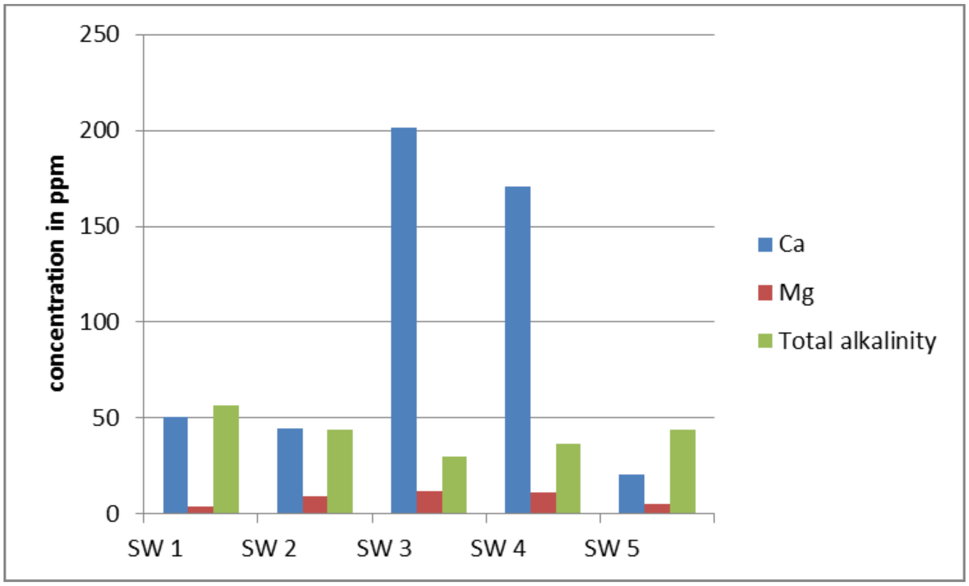

Figure 30: Mg, Ca and total alkalinity levels in shallow wells during dry month.

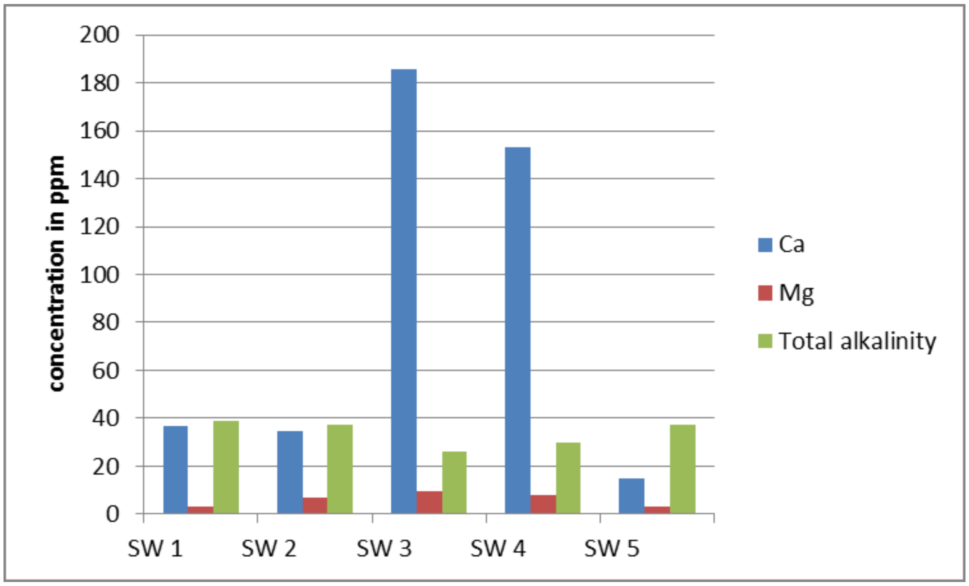

Figure 31: Mg, Ca and total alkalinity levels in shallow wells during wet month.

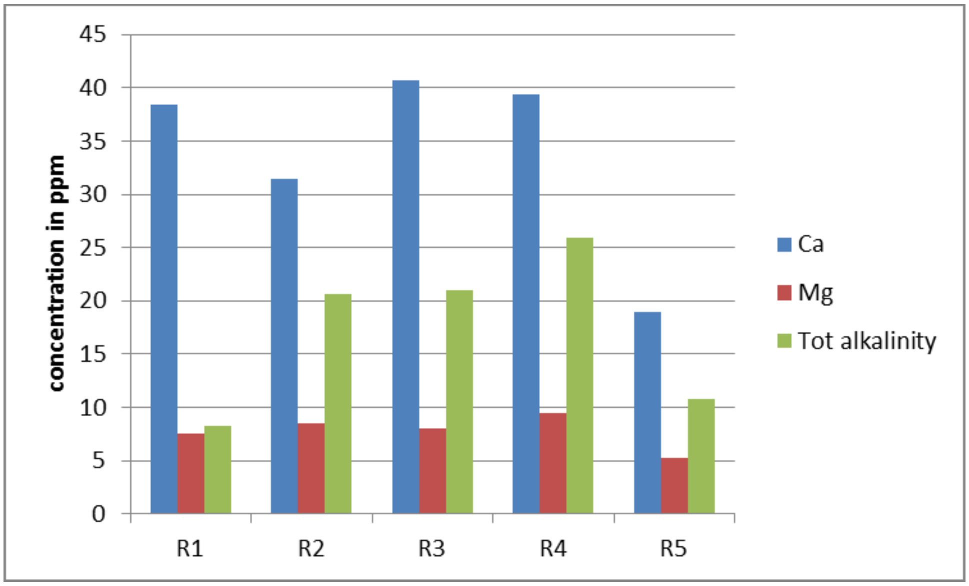

Figure 32: Mg, Ca and total alkalinity levels in river water samples during dry month.

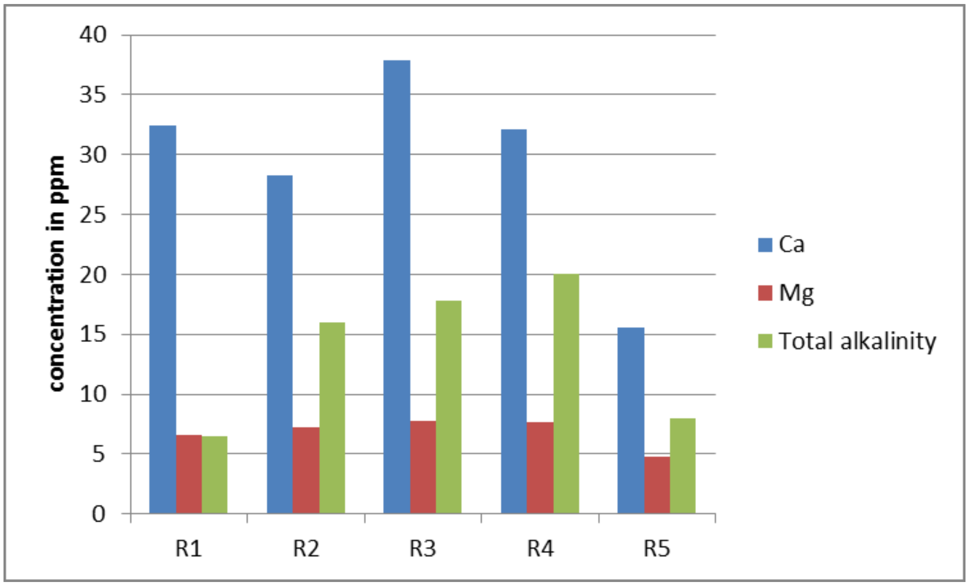

Figure 33: Mg, Ca and total alkalinity levels in river water samples during wet month.

There were higher levels of Calcium in ground water ranging from 20.36±0.03 ppm to 201.29±0.02 ppm at shallow well located near Brookshine School compared to surface which ranged from 15.55±0.03 ppm to 40.66±0.02 ppm. There were higher levels of magnesium in ground water ranging from 2.723±0.03 ppm to 14.385±0.04 ppm in borehole 11 located in Ngong town (Figures 28 and 29). Underground water had higher levels of total alkalinity ranging from 29.656±0.03 ppm to 64.117±0.02 ppm at borehole 5 located at Athi Primary school shown in figures 28 and 29. On the other hand, surface water had total alkalinity ranging from 8.21±0.03 ppm to 25.94±0.02 ppm in sample R4 located at Mbagathi River as shown in figures 32 and 33.

The levels of calcium, magnesium and hydrogen carbonates/carbonates were higher in ground water as compared to surface water. These ions together contribute to alkalinity of water. Area under study contains porous rocks that contain these ions and so the reason for the ground water having alkaline pH. Seasonal variation was noted in that the levels of these ions were higher in dry season compared to wet season indicating that rain contributed due to the dilution effect of these ions. The carbonates and bicarbonates in ground water act as buffer against any acidity in water that may find its way into the underground rocks. [Snoeynik,et al, 1980]

4.2.4 Fluoride, nitrate and nitrite ions

Figures 34, 35 and 36 represent fluoride and nitrate/nitrite data from both surface and underground water samples. Results for fluoride, nitrate and nitrite ions are shown in tables 16-21 for both dry and wet months.

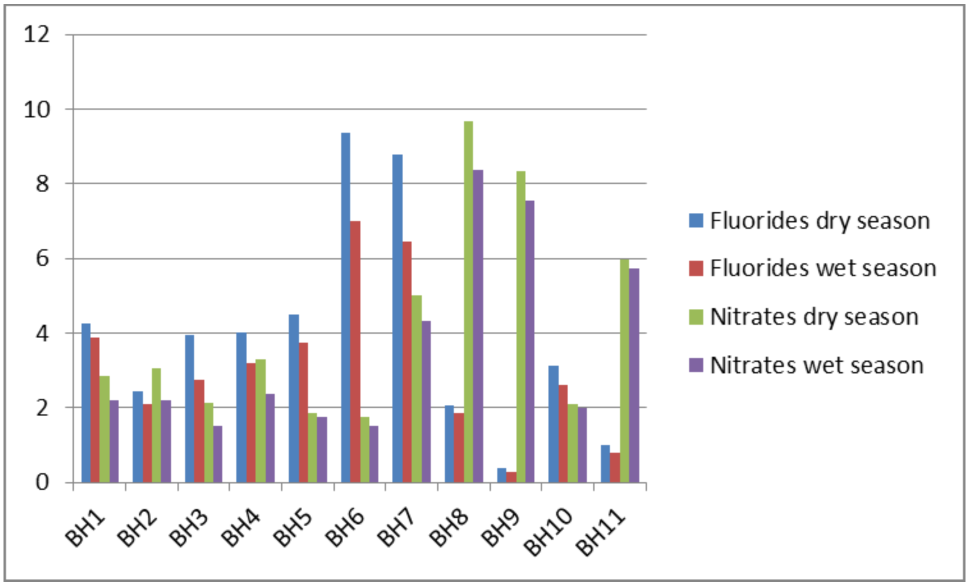

Figure 34: Fluorides and nitrates levels in boreholes water samples in wet and dry months.

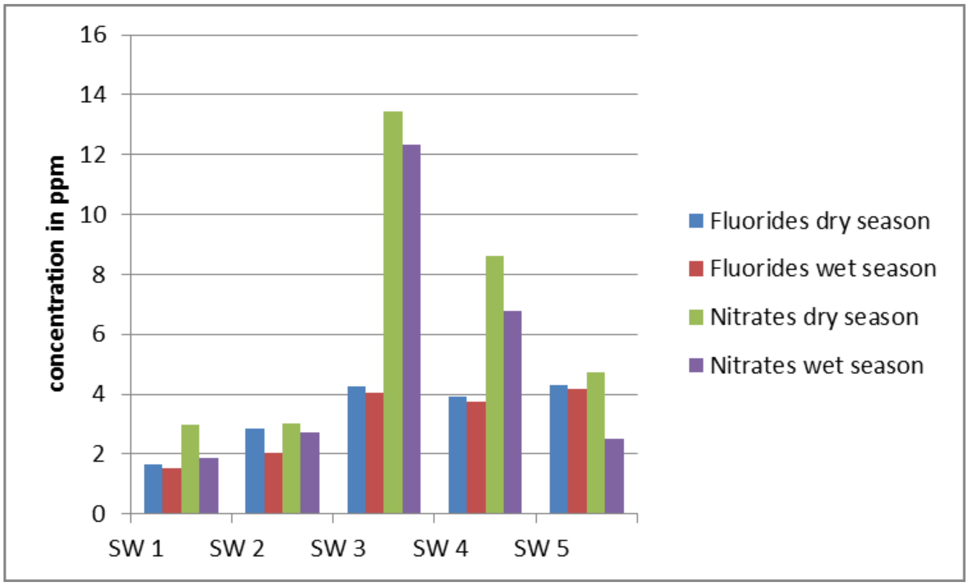

Figure 35 Fluoride and nitrate levels in shallow wells water samples in wet and dry months.

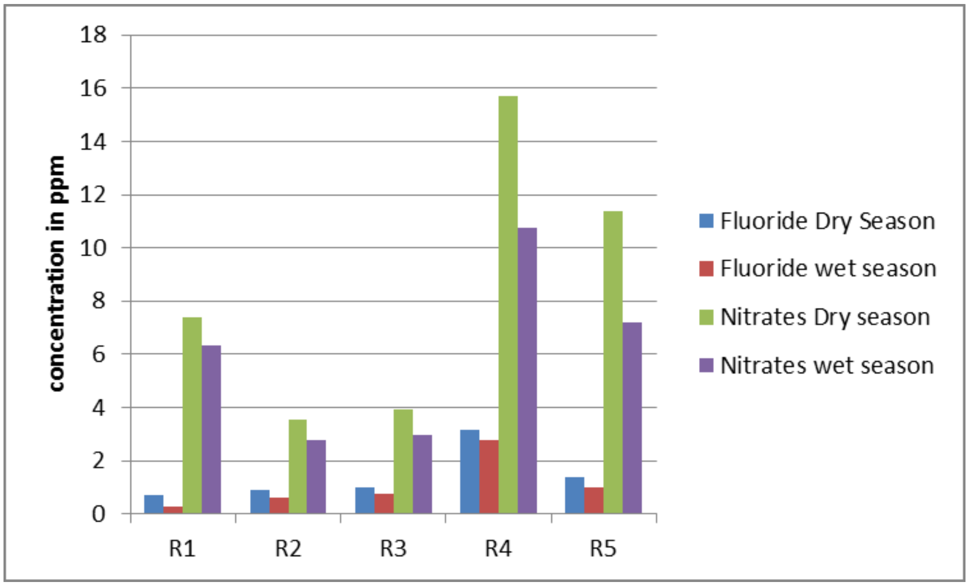

Figure 36: Fluoride and nitrate levels in River water samples in dry and wet months.

Results indicated that there were higher levels of fluoride in ground water ranging from 0.28±0.03 ppm in borehole located at Rongai to 9.36±0.03 ppm in borehole located in Mlolongo compared to surface water which ranged from 0.73±0.03 ppm to 3.15±0.04 ppm. There was also seasonal variation between dry and wet season. There were higher levels of fluoride in water samples collected in dry season as compared to those collected in wet season. Nitrates levels in both surface and ground water were determined as shown in figures 34, 35 and 36. There were higher levels of nitrates in surface water ranging from 3.24±0.03ppm in river sample located at Mombasa Road Bridge to 15.68±0.002 ppm at Mbagathi River near Ongata Rongai. Within ground water systems shallow wells had higher levels of nitrates and compared to boreholes.

Fluoride levels were also found to be higher in ground water because the area under study has fluoride-containing rocks. The levels of fluorides were a major concern. According to WHO drinking water quality guidelines water for domestic use should not exceed 1.5 ppm fluoride levels. In some boreholes, the levels of fluorides were as high as 9.36±0.04 ppm. These levels are way too high to meet drinking water standards. High levels of fluorides were the cause of brown teeth for the community around. Children in this region had brown teeth and with continued use of the only source of water available they may develop diseases such osteomalacia later in their lives characterized with weak bones.

There were higher levels of nitrates in surface water ranging from 3.24±0.03 ppm in river sample located at Mombasa Road Bridge to 15.68±0.002 ppm at Mbagathi River near Ongata Rongai. This could be due to human activities such as discharge of waste water into the river. Within ground water systems shallow wells had higher levels of nitrates and compared to boreholes. This could be due to nitrates from waste water percolating into the pervious rocks and thus finding their way into shallow wells.

4.2.5 SULPHATE IONS

The levels of sulphate ions were determined in both surface and ground water and represented in figures 37, 38 and 39. Results for sulphate ions in boreholes, shallow wells and river water samples are shown in tables 16-21.

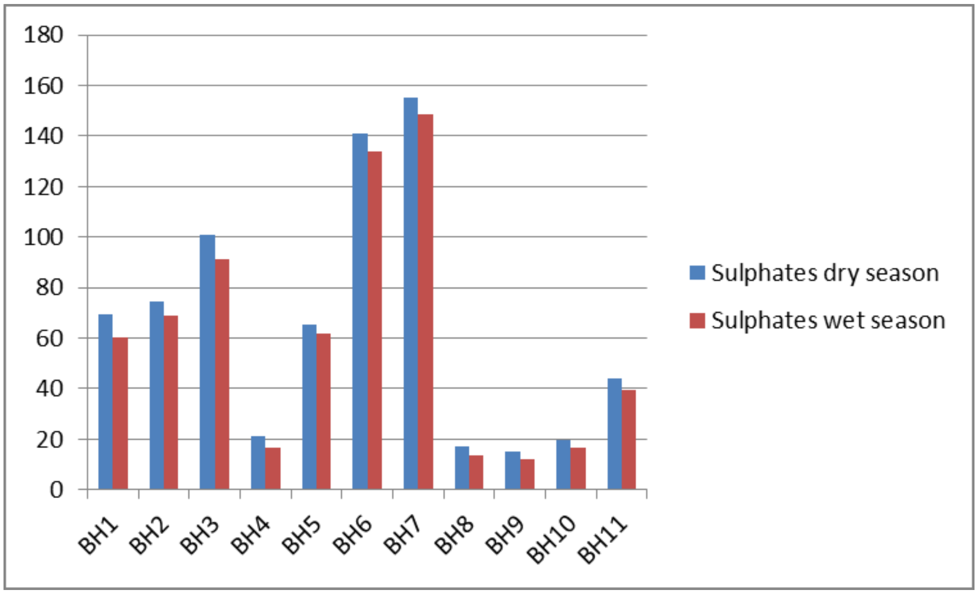

Figure 37: Sulphate levels in boreholes water samples in wet and dry months.

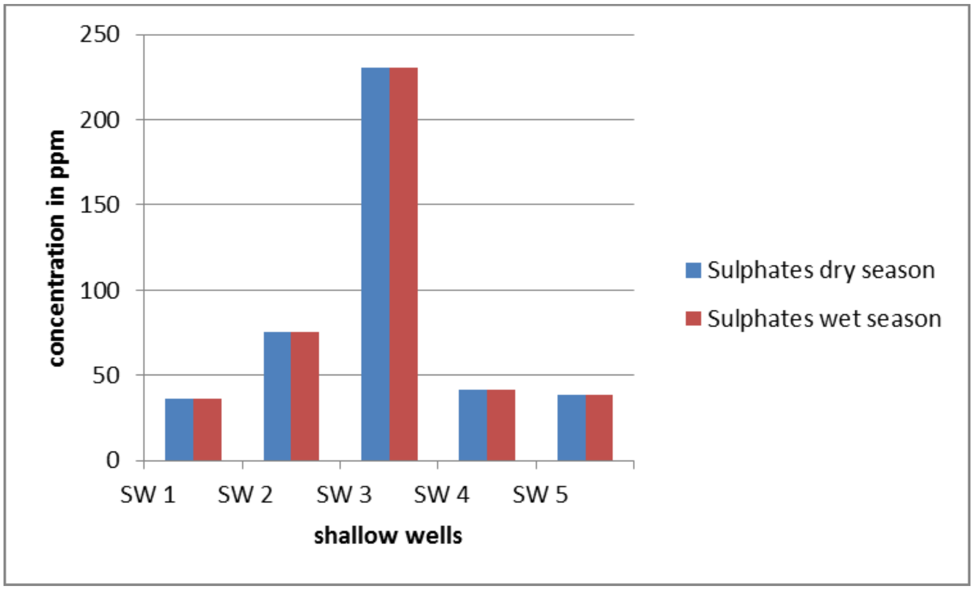

Figure 38: Sulphate levels in shallow wells water samples in wet and dry seasons.

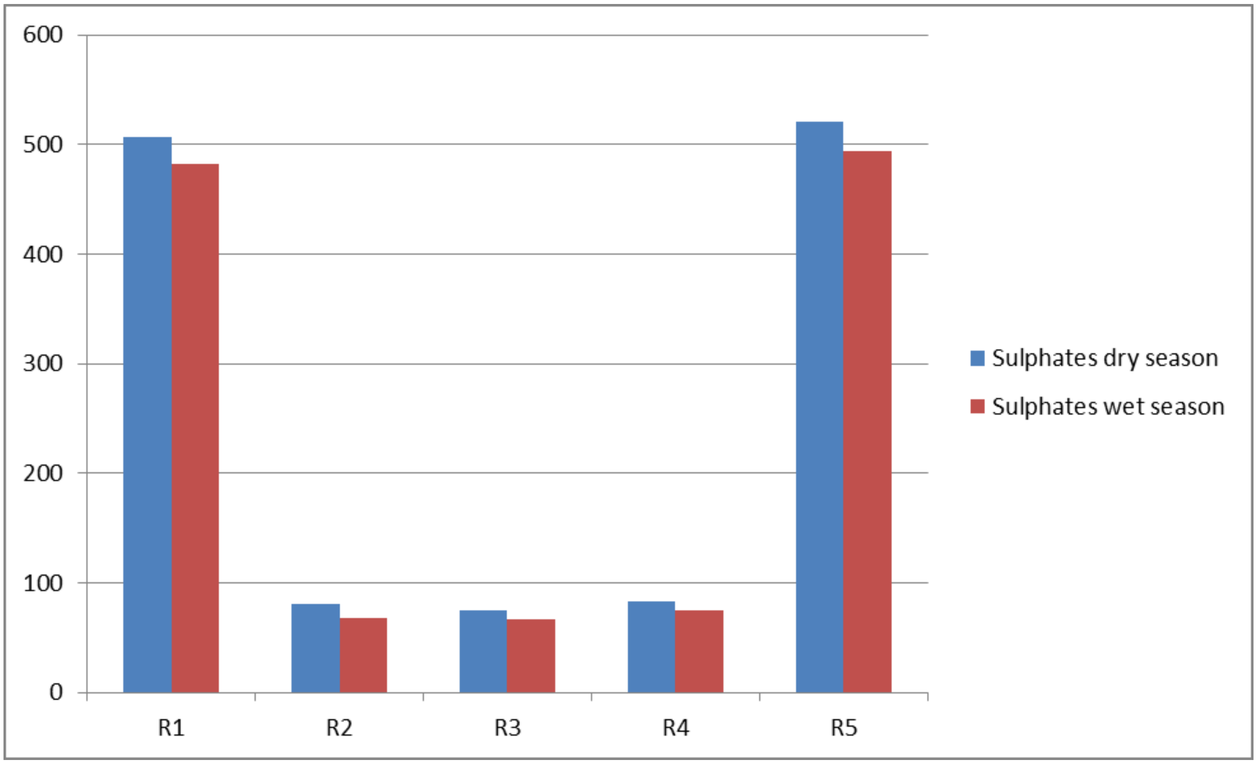

Figure 39: Sulphate levels in River water samples in dry and wet month.

The levels of sulphates were higher in surface water than in ground water. In surface water samples analyzed, levels of sulphates ranged from 74.735±0.04 ppm Mbagathi River near Ongata Rongai to 520.231±0.02 ppm Brookshine School Bridge.

The levels of sulphates were higher in surface water than in ground water. In surface water samples analysed, levels of sulphates ranged from 74.735±0.04 ppm in river sample R4 at Mbagathi River near Ongata Rongai to 520.231±0.02 ppm Brookshine School Bridge. This could be due to discharge of sulfonates containing detergents into river systems by communities living around the rivers.

4.3 CORRELATIONS

Statistical analysis data is shown in tables 22 and 23. From the results, there existed a strong correlation between pH of water and turbidity of water at 0.828 in the month of December 2011. There was also a strong negative correlation between pH and total dissolved solids at -0.707. This indicates that most dissolved ions in water were neutral and did not affect the pH of water.

The results also indicated a very strong correlation between electrical conductivity and total dissolved solids with a correlation of 1.000. This indicated that the dissolved solids were responsible for electrical conductivity of water. There was also a strong correlation between coliforms and turbidity at 0.850. This was because the solid particles provide a conducive environment for coliforms to be embedded and carried into water ways. There also existed a strong correlation between pH and levels of zinc at 0.934. This points to presence of a basic salt of zinc in the water samples collected.

The data also indicated a very strong correlation between electrical conductivity and levels of chromium at 0.946. This pointed at the multivalent nature of chromium in its ability to conduct electricity. There was also a strong correlation between colour of water and levels of manganese ions at 0.817 pointing at the presence of oxidation sates of manganese that produce colour in presence of visible light. However, the strong correlation between colour and zinc ions could not be explained since zinc is known to exist in only one stable oxidation state of 2+.

Table 22: Correlation of December 2011 physical and microbial coliforms parameters with those of May 2012.

		pH December	E.C December	Turbidity December	Colour December	TDS December	Coliforms December	pH May	E.C May	Turbidity May	Colour May	TDS May	Coliforms May
pH December	Pearson Correlation	1	-.710	.828	.263	-.707	.619	-.368	.301	.677	-.368	.301	.298
	Sig. (2-tailed)		.179	.083	.669	.182	.266	.542	.623	.210	.543	.623	.626
	N	5	5	5	5	5	5	5	5	5	5	5	5
eC December	Pearson Correlation	-.710	1	-.239	.251	1.000**	-.780	.395	-.878	-.097	.617	-.878	-.499
	Sig. (2-tailed)	.179		.698	.684	.000	.120	.511	.050	.877	.268	.050	.393
	N	5	5	5	5	5	5	5	5	5	5	5	5
Turbidity December	Pearson Correlation	.828	-.239	1	.568	-.232	.118	-.342	-.255	.960**	.007	-.255	-.168
	Sig. (2-tailed)	.083	.698		.318	.707	.851	.573	.679	.010	.990	.679	.787

	N	5	5	5	5	5	5	5	5	5	5	5	5
Colour December	Pearson Correlation	.263	.251	.568	1	.257	-.373	.491	-.526	.562	.791	-.526	-.515
	Sig. (2-tailed)	.669	.684	.318		.676	.537	.401	.363	.325	.111	.363	.374
	N	5	5	5	5	5	5	5	5	5	5	5	5
TDS December	Pearson Correlation	-.707	1.000**	-.232	.257	1	-.786	.392	-.881*	-.088	.621	-.881*	-.507
	Sig. (2-tailed)	.182	.000	.707	.676		.115	.514	.048	.888	.263	.048	.383
	N	5	5	5	5	5	5	5	5	5	5	5	5
Coliforms December	Pearson Correlation	.619	-.780	.118	-.373	-.786	1	-.177	.724	-.125	-.755	.723	.916*
	Sig. (2-tailed)	.266	.120	.851	.537	.115		.776	.167	.841	.140	.167	.029

	N	5	5	5	5	5	5	5	5	5	5	5	5
pH May	Pearson Correlation	-.368	.395	-.342	.491	.392	-.177	1	-.216	-.427	.682	-.216	-.007
	Sig. (2-tailed)	.542	.511	.573	.401	.514	.776		.727	.474	.204	.727	.991
	N	5	5	5	5	5	5	5	5	5	5	5	5
eC May	Pearson Correlation	.301	-.878	-.255	-.526	-.881*	.724	-.216	1	-.380	-.616	1.000**	.585
	Sig. (2-tailed)	.623	.050	.679	.363	.048	.167	.727		.528	.269	.000	.300
	N	5	5	5	5	5	5	5	5	5	5	5	5
Turbidity May	Pearson Correlation	.677	-.097	.960**	.562	-.088	-.125	-.427	-.380	1	.107	-.379	-.406
	Sig. (2-tailed)	.210	.877	.010	.325	.888	.841	.474	.528		.864	.529	.498
	N	5	5	5	5	5	5	5	5	5	5	5	5

Colour May	Pearson Correlation	-.368	.617	.007	.791	.621	-.755	.682	-.616	.107	1	-.616	-.724
	Sig. (2-tailed)	.543	.268	.990	.111	.263	.140	.204	.269	.864		.269	.166
	N	5	5	5	5	5	5	5	5	5	5	5	5
TDS May	Pearson Correlation	.301	-.878	-.255	-.526	-.881*	.723	-.216	1.000**	-.379	-.616	1	.585
	Sig. (2-tailed)	.623	.050	.679	.363	.048	.167	.727	.000	.529	.269		.300
	N	5	5	5	5	5	5	5	5	5	5	5	5
Coliforms May	Pearson Correlation	.298	-.499	-.168	-.515	-.507	.916*	-.007	.585	-.406	-.724	.585	1
	Sig. (2-tailed)	.626	.393	.787	.374	.383	.029	.991	.300	.498	.166	.300	
	N	5	5	5	5	5	5	5	5	5	5	5	5

**. Correlation is significant at the 0.01 level (2-tailed).

Table 23: Correlation of physical parameters with heavy metals during the month of December 2011.

		pH December	eC December	Turbidity December	Colour December	TDS December	Coliforms December	Cr December	Fe December	Mn December	Zn December
pH December	Pearson Correlation	1	.747	.[a]	.967**	.749	.052	-.539	.369	-.203	.052
	Sig. (2-tailed)		.147	.	.007	.145	.934	.348	.541	.744	.934
	N	5	5	5	5	5	5	5	5	5	5
eC December	Pearson Correlation	.747	1	.[a]	.872	1.000**	.112	-.042	-.179	-.217	.112
	Sig. (2-tailed)	.147		.	.054	.000	.857	.946	.774	.726	.857
	N	5	5	5	5	5	5	5	5	5	5

Turbidity December	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.		.	.	.	.	.	.	.
	N	5	5	5	5	5	5	5	5	5	5
Colour December	Pearson Correlation	.967[**]	.872	.[a]	1	.874	.023	-.325	.262	-.144	.023
	Sig. (2-tailed)	.007	.054	.		.053	.970	.594	.671	.817	.970
	N	5	5	5	5	5	5	5	5	5	5
TDS Decemb	Pearson Correlation	.749	1.000[**]	.[a]	.874	1	.113	-.044	-.176	-.216	.113
	Sig. (2-tailed)	.145	.000	.	.053		.857	.944	.777	.727	.857
	N	5	5	5	5	5	5	5	5	5	5

Coliforms December	Pearson Correlation	.052	.112	.[a]	.023	.113	1	-.250	-.618	.349	1.000**
	Sig. (2-tailed)	.934	.857	.	.970	.857		.685	.267	.565	.000
	N	5	5	5	5	5	5	5	5	5	5
Cr December	Pearson Correlation	-.539	-.042	.[a]	-.325	-.044	-.250	1	-.251	.470	-.250
	Sig. (2-tailed)	.348	.946	.	.594	.944	.685		.684	.425	.685
	N	5	5	5	5	5	5	5	5	5	5
Fe December	Pearson Correlation	.369	-.179	.[a]	.262	-.176	-.618	-.251	1	.029	-.618
	Sig. (2-tailed)	.541	.774	.	.671	.777	.267	.684		.963	.267
	N	5	5	5	5	5	5	5	5	5	5

Mn December	Pearson Correlation	-.203	-.217	.[a]	-.144	-.216	.349	.470	.029	1	.349
	Sig. (2-tailed)	.744	.726	.	.817	.727	.565	.425	.963		.565
	N	5	5	5	5	5	5	5	5	5	5
Zn December	Pearson Correlation	.052	.112	.[a]	.023	.113	1.000**	-.250	-.618	.349	1
	Sig. (2-tailed)	.934	.857	.	.970	.857	.000	.685	.267	.565	
	N	5	5	5	5	5	5	5	5	5	5

**. Correlation is significant at the 0.01 level (2-tailed).

a. Cannot be computed because at least one of the variables is constant.

Correlations

	pH December	eC December	Colour December	TDS December	Coliforms	pH May	eC May

pH December	Pearson Correlation	1	.747	.967**	.749	.052	.351	.181
	Sig. (2-tailed)		.147	.007	.145	.934	.563	.770
	N	5	5	5	5	5	5	5
eC December	Pearson Correlation	.747	1	.872	1.000**	.112	-.311	.327
	Sig. (2-tailed)	.147		.054	.000	.857	.611	.592
	N	5	5	5	5	5	5	5
Colour December	Pearson Correlation	.967**	.872	1	.874	.023	.150	.235
	Sig. (2-tailed)	.007	.054		.053	.970	.809	.703
	N	5	5	5	5	5	5	5
TDS December	Pearson Correlation	.749	1.000**	.874	1	.113	-.308	.327
	Sig. (2-tailed)	.145	.000	.053		.857	.614	.591
	N	5	5	5	5	5	5	5

Coliforms	Pearson Correlation	.052	.112	.023	.113	1	-.418	.892*
	Sig. (2-tailed)	.934	.857	.970	.857		.484	.042
	N	5	5	5	5	5	5	5
pH May	Pearson Correlation	.351	-.311	.150	-.308	-.418	1	-.528
	Sig. (2-tailed)	.563	.611	.809	.614	.484		.360
	N	5	5	5	5	5	5	5
eC May	Pearson Correlation	.181	.327	.235	.327	.892*	-.528	1
	Sig. (2-tailed)	.770	.592	.703	.591	.042	.360	
	N	5	5	5	5	5	5	5
Colour May	Pearson Correlation	.952*	.869	.978**	.870	-.105	.200	.061
	Sig. (2-tailed)	.012	.056	.004	.055	.866	.747	.922
	N	5	5	5	5	5	5	5

TDS May	Pearson Correlation	.181	.326	.235	.327	.893*	-.528	1.000**
	Sig. (2-tailed)	.771	.592	.704	.592	.041	.360	.000
	N	5	5	5	5	5	5	5
Coliforms May	Pearson Correlation	.193	.277	.203	.277	.965**	-.452	.975**
	Sig. (2-tailed)	.755	.652	.743	.651	.008	.445	.005
	N	5	5	5	5	5	5	5

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.4. Upper, middle and lower sections of the study area.

The area under study was also further divided into three sections; namely the upper section which included Ngong/Ongata Rongai/Kiserian and Ngong areas. The middle section comprised of Mlolongo/ Athi River area along Mombasa Road and the lower section comprising of Kamulu/Joska area.

4.4.1 (Upper section) ONGATA RONGAI/KISERIAN/NGONG AREA

Four boreholes and one river water sample were analysed. These were; BH8, BH9, BH10 and BH11 and river water samples R4. Boreholes BH8, BH9, BH10 and BH11 were analysed on levels of dissolved ions and coliform levels. The analysis was done in two different months, that is, December 2011 which was a dry month and May 2012 which was wet month. Iron levels ranged from 0.35±0.002ppm at borehole BH10 to 0.47±0.001ppm at borehole BH8 in December 2011 and 0.520±0.001ppm to 0.725±0.001ppm in May 2012 for BH8 and BH10 respectively. In river water samples, iron levels were 2.11±0.001ppm at R4 in December 2011 and 14.20±0.001ppm in May 2012. Lead levels ranged from <0.001ppm to 0.38±0.002ppm in boreholes BH11 and BH10 respectively. Lead level in R4 was 0.17±0.001ppm. During the wet month of May 2012, lead levels were at <0.01ppm which was below detection limit.

Sodium levels in this area ranged form 45.37±0.04ppm to 51.53±0.04ppm in boreholes BH8 and BH11 respectively in December 2011 and 11.75±0.03ppm to 43.15±0.03ppm in May 2012.

Calcium levels in this area ranged from 26.18±0.01ppm to 160.75±0.04ppm in BH8 and BH11 respectively during the dry month and 20.25±0.02ppm to 149.38±0.02ppm in BH8 and BH11 respectivleyduring the wet month. This area had greatest variation in calcium levels compared with other areas under study.

Magnesium levels in this area 2.96±0.02ppm to 14.39±0.02ppm in BH8 and BH11 respectively in the dry month and 2.84±0.02ppm to 10.96±0.01ppm in during the wet month.

Total alkalinity ranged from 29.66±0.03ppm to 41.57±0.03ppm in BH10 and BH11 respectively in December 2011and 25.00±0.03ppm to 35.00±0.02ppm in the same boreholes during the wet month.

Chloride levels in this area ranged from 30.04±0.02ppm to 99.18±0.02ppm during the dry month and and 26.03±0.02ppm to 95.85±0.02ppm during the wet month for BH6 and BH7 respectively.

Fluoride levels in this area ranged from 0.37±0.03ppm to 3.11±ppm in BH9 and BH10 during the dry month. Fluoride levels during the wet month ranged from 0.28±0.03ppm to 2.62±0.02ppm in BH9 and BH10 respectively. This region had the lowesrt levels of fluroide when compared ith the other two areas.

Sulfate levels ranged from 15.11±0.02ppm to 43.83±0l.03ppm during the dry month in BH10 to BH11 respectively. In the wet month, sulfate levels ranged from 11.93±0.03 to 39.50±0.01ppm in BH9 and BH10 respectively.

Nitrate levels ranged from 2.11±0.01ppm to 9.69±0.01ppm in BH8 and BH10 respectively in dry month and 1.98±0.03ppm to 8.38±0.02ppm in in the same boreholes during the wet month.

4.4.2 Middle section (MLOLONGO/ATHI RIVER AREA)

Two boreholes and 2 river water samples were analysed.These were; Boreholes BH6, BH7 and river water samples R2 and R3. The analysis was done in two different months, that is, December 2011 which was a dry month and May 2012 which was wet month. Boreholes BH6 and BH7 were analysed for levels of dissolved ions and coliforms. BH6 had a higher level of iron at 0.26±0.002ppm compared with 0.14±0.003ppm in BH7 in December 2011 and 0.550±0.003ppm to 1.105±0.003ppm in boreholes BH7 and BH6 respectively in May 2012. Iron levels in river water samples ranged from 4.08±0.004ppm to 4.45±0.003ppm in R3 and R2 respectively in December 2011 and 0.795±004ppm to 3.86±0.002ppm in May 2012. Lead levels in boreholes water ranged from 0.14±0.003ppm to 0.26±0.002ppm in BH6 and BH7 respectively. Lead levels in river water samples ranged from <0.01ppm to 0.33±0.002ppm in R2 and R3 respectively in December 2011. Lead levels in the month of May 2012 were <0.01ppm which was below detection limit of the equipment used.

Sodium levels in this area ranged from 93.65±0.01ppm to 101.29±0.04ppm in BH6 and BH7 respectively in the month of December 2011. Sodium levels in the month of May 2012 ranged from 83.75±0.01ppm to 88.60±0.01ppm in BH6 and BH7 respectively. Calcium levels in this region ranged from 32.97±0.03ppm to 38.21±0.03ppm in BH6 and BH7 respectively in the dry month and 26.88±0.01ppm to 29.25±0.03ppm in BH6 and BH7 respectively during the wet month. Magnesium levels ranged from 2.73±0.04ppm to 3.32±0.03ppm in BH6 and BH7 respectively in dry month and 2.40±0.02ppm to 2.96±0.03ppm during the wet month.

The levels of total alkalinity ranged from 38.98±0.05ppm to 40.44±0.01ppm in BH6 and BH7 during the dry month and 34.00±0.01ppm and 35.50±0.04ppm during the wet month. Chloride levels in this area ranged from 138.58±0.03ppm to 150.11±0.02ppm in dry month and 131.35±0.01ppm to 145.55±0.02ppm during the wet month in BH6 and BH7 respectively. Fluoride levels ranged from 8.79±0.04ppm to 9.36±0.04ppm during the dry month in BH7 and BH6 respectively. Fluoride levels during the wet month ranged from 6.45±0.01ppm and 7.00±0.04ppm in BH6 and BH7 respectively. This region had the highest level of fluoride as compared to the other two regions.

Sulfate levels ranged from 140.80±0.02ppm to 115.34±0.06ppm during the dry month in BH6 and BH7 respectively. During the wet month sulfate levels ranged from 133.74±0.03ppm to 148.55±0.03ppm in the same boreholes. This area had the highest levels of sulfate ions of all the areas studied.

4.4.3. Lower section (KAMULU/ JOSKA AREA)

Five boreholes, five shallow wells and and two river water samples were analysed. These were, boreholes, BH1, BH2, BH3, BH4 and BH5. Shallow wells analysed in this region were SW1, SW2, SW3,SW4 and SW5. River water samples were R1 and R5. Shallow wells were only available in this region and therefore it was impossible to do a comparative study. The analysis was done in two different months, that is, December 2011 which was a dry month and May 2012 which was wet month.

Boreholes BH1, BH2, BH3, BH4 and BH5 were analysed on the levels of dissolved ions and coliforms. Iron levels ranged from 0.03±0.001ppm in BH1 to 1.93±0.003ppm in borehole BH5 during the dry month of December 2011 and 0.915±0.001ppm to 7.535±0.003ppm during the wet month of May 2012. This area had the highest variation of iron levels. River samples R1 and R5 were analysed for this area. Iron levels ranged from 3.43±0.001ppm at R5 and 18.40±0.002ppm at R1 in the month of December 2011 and 3.625±0.001ppm to 5.066±0.001ppm in R1 and R5 respectively in May 2012. Lead levels in this area ranged from <001ppm to 2.64±0.004ppm in boreholes BH5 and BH5 respectively. Lead levels in boreholes in this area ranged from <0.01ppm to 2.64±0.004ppm in boreholes BH4 and BH5 respectively. Lead levels in the month May 2012 were <0.01ppm which was below the detection limit.

Sodium levels in this area ranged from 71.63±0.02ppm to 90.24±0.03ppm in BH1 and BH5 respectively for the month of December 2011 and 64.25±0.03ppm to 84.75±0.03ppm in BH1 and BH5 respectively during the wet month of May 2012. Calcium levels in this area ranged from 28.79±0.04ppm to 41.29±0.02ppm in BH3 and BH2 respectively in December 2011 and 22.13±0..03ppm to 33.50±0.03ppm in BH4 and BH3 respectively in May 2012. Magnesium levels in this area ranged from 3.64±0.02ppm to 7.89±0.03ppm in BH2 and BH4 in the dry month and 2.82±0.03ppm and 6.46±0.05ppm during the wet month of May 2012.

Total alkalinity in this area ranged from 31.73±0.01ppm to 52.33±0.01ppm in BH4 and BH1 respectively in dry month and 25.00±0.03ppm to 57.50±0.01ppm in BH4 and BH5 during the wet month. The level of chloride ions in this area ranged from 70.84±0.02ppm to 111.75±0.05ppm in BH3 and BH1 respectively during the dry month and 67.45±0.02ppm and 102.95±0.01ppm in the same boreholes during the wet month. Fluoride levels ranged from 2.45±0.03ppm to 4.51±0.04ppm in BH2 and BH5 ranged during the dry month and 2.09±0.03ppm and 3.81±0.02ppm during the wet month ni BH2 and BH1 respectively.

Sulfate levels in this area ranged from 21.40±0.03ppm to 101.14±0.04ppm in BH4 and BH3 during the dry month and 16.46±0.02ppm and 91.35±0.01ppm in the same boreholes during the wet month. Nitrate levels ranged from 1.86±0.01ppm to 3.29±0.04ppm during the dry month in BH5 and BH4 respectively. During the wet month, the levels ranged from 1.53±0.03ppm to 2.21±0.01ppm in BH3 and BH2 respectively. Nitrate levels in this area ranged from 1.77±0.03ppm to 5.01±0.03ppm during the dry month in BH6 and BH7 respectively. Nitrate levels in wet month ranged from 1.52±0.03ppm to 4.32±0.02ppm in BH6 and BH7 respectively.

CHAPTER FIVE CONCLUSION AND RECOMMENDATION

5.0 Conclusion

Ground water is weakly alkaline due to the presence of carbonates and hydrogen carbonates present in most rock structure in the area studied. The results also indicated that ground water had high electrical conductivity due to the large amounts of total dissolved solids present. It was however noted that ground water had low turbidity since as the water percolates into the underground rocks, the rocks act as filters [Arjen van der Wal,2008] trapping any solid particles. The colour of underground water was generally low due to the fact that the area under study only had traces of coloured transition elements.

The number of coliforms and *E. coli* was very low in ground water as compared to surface water. Most surface run-offs had high numbers of total coliforms and *E. coli.* From the results, boreholes recorded lower levels of coliforms than shallow wells since most boreholes are well sealed unlike shallow wells where water is extracted using manual methods of pulley system meaning that the wells are not always protected and are prone to flooding from surface run-off as well as contamination by containers used to draw water from the wells.

Results showed that iron levels were the highest in ground water tested followed by zinc and only traces of other heavy metals. The results indicate that the underground rocks have high levels of iron and zinc. The levels of sodium in ground water were very high and since levels of sodium combines with chlorides the water becomes unpalatable due to its salty taste. The levels of calcium and magnesium were high meaning that the water is hard. Hard water affects the amount of soap used during laundry work due to the scam formed.

The levels of fluorides were a major concern. According to WHO (2011) drinking water quality guidelines water for domestic use should not exceed 1.5 ppm fluoride levels. (KEBS, 2015). In Borehole BH6 located at Athi Primary school had the highest levels of fluoride ions at 9.36±0.04ppm which was way above the 1.5ppm limit set by WHO for drinking water. Children in this study area had brown teeth and with continued use of the only source of water available they may develop diseases such osteomalacia later in their lives. Results showed that levels of nitrates in ground water were generally low. Borehole BH4 at Brookshine School had the highest levels of lead at 2.64±0.04ppm while sodium and iron levels were highest in river water sample R1 situated at Mbagathi River at Mombasa Road bridge with levels of 116.65±0.02ppm and 18.40±0.35ppm respectively.

Sampling site SW3 located at Ngund'u had the highest levels of calcium, magnesium and chloride. The analysis showed 201.29±0.04ppm calcium ions, 11.563±0.02ppm of magnesium ions and 226.49±0.04ppm of chloride ions. Levels of carbonates and bicarbonates ions were highest in borehole sample BH5 located at Athi Primary School whose levels were 64.117±ppm. High levels of sulphates were found river sample R5 located at Brookshine bridge near Brookshine school while river sample R4 located at Ongata Rongai bridge had the highest level of nitrates at 15.68±0.01ppm. *E coli* and faecal coliforms were highest in river water sample located at Mombasa road Dam wall 309±3.41MPN.

5.1 Recommendations

1. The County governments of Machakos, Nairobi and Kajiado to develop a long term plan to provide comminities living in this area with safe drinking water.
2. Cheap water desalinizers and ion exchange equipment should be developed to assist the local communites to remove excess sodium and flouride ions in water.
3. Private and public water supply companies to install water treatment plants that reduce most of these dissolved ions to safe standards.
4. Local communites to be encouraged to invest in rain water harvesting facilites to reduce over-reliance on ground water especially for drinking and cooking purposes.
5. More studies on BOD, COD and ammonium levels need to be conducted to ascertain reasons for low microbial organisms in ground water

APPENDICES

APPENDIX A

Table1a: Results obtained in the study of ground water in the Baringo-Bogoria basin.

Parameter	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	WHO Standards 1996 (ppm)
pH	2.50	13.70	8.09	6.50-8.50
F^-	0.20	1690.00	25.77	1.50
K	1.00	98.00	11.92	No standard
Mg	>0.1	415.00	15.97	100
Na	2.00	8016.00	385.97	200.00
Ca	0.80	183.00	21.58	250.00
NO_3^-	0.01	94.00	8.55	-
Cl^-	0.05	16938.00	384.03	250.00
SO_4^{2-}	0.25	5376.00	248.00	250.00
HCO_3^-	4.00	3708.00	537.14	-

Source, Marietta Mutonga MSc Geology thesis, 2007, University of Nairobi

Appendix B: Photographs of sampling sites and coliforms analysis

Appendix B1: phtograph of sampling site R4 (Mbagathi River)

Appendix B2: photograph of shallow well sampling site SW 2 (Joska)

Appendix B3: photograph of Athi River at Mombasa Road sampling site (R2)

Appendix B4: photograph of samples in Mackonkey's broth for coliform and *E.coli* assessment.

Appendix B5: photograph of samples in Mackonkey’s broth after incubating for 24 hours

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