UNIVERSITY OF NAIROBI

ASSESSMENT OF WATER QUALITY FOR DOMESTIC USE IN ONGATA RONGAI AREA

BY

MACHUMA DENIS OYUNGE

F16/2312/2009

DEPARTMENT OF CIVIL AND CONSTRUCTION ENGINEERING

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SUPERVISOR: PROF. P. M. A. ODIRA

A project report submitted as a partial fulfillment for the requirement for the award of the degree of

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Declaration

I declare that the work presented in this project report is my original work. I also affirm that this work has not been presented in this, or any other university for examination, or for any other purposes.

Denis Oyunge Machuma,
April 2014.

Abstract

This report has been prepared after a successful assessment of water quality from various resources within Ongata Rongai and its environs. The study's primary objective was to assess water quality for domestic use within Ongata Rongai.

The study involved collection of data from the various water resources identified that provide water for domestic use. These involved boreholes, river water, rain water and dam water. Historical water quality information was obtained from WRMA and WASREB databases. Sampling of water from the various water resources was done and later the samples were taken to the laboratory for examination where key physical, chemical and biological parameters of the water were tested.

The analysis of the results was done based on the acceptable limits specified by the Kenya Standards for Drinking water (KS 459-1: 2007) and the determined values compared with the historical values.

Out of all the tests carried out on the samples, most of the results obtained were within the recommended value in the KS and WHO Standards. Fluorides levels however stood out as 6 out of the 16 tested samples had fluorides levels higher than the recommended values. Fluorides had the least safe value of 10/16.

Management of the indicators of pollution in groundwater is of great importance especially if the water is used for drinking. There is also a need for continued and regulated monitoring of water quality from this various resources studied. Under the leadership of WASREB, this can easily be affected. For the resources, WRMA should also strive to involve users in conservation of water resources to ensure sustainable use.

Dedication

To my family and close friends. Thank you for all the support you have given me towards the successful completion of this project.

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An undertaking of this magnitude cannot be successfully achieved by the efforts of one individual. I would wish to express my sincere gratitude to the following:

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List of Abbreviations

ANC	Acid Neutralizing Capacity
APHA	American Public Health Association
AWWA	American Water Works Association
CBS	Central Bureau of Statistics
DO	Dissolved Oxygen
EDTA	Ethylenediamine Tetraacetic Acid
EC	Electrical Conductivity
FTU	Formazin Turbidity Unit
GAC	Granular activated carbon
GPS	Global Positioning Service
KS	Kenya Standards
NRC	National Research Council
NTU	Nephelometric Turbidity Units
pH	Pondus Hydrogenium
ppm	parts per million
TCU	Total Colour Units
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UNESCO	United Nations Educational, Scientific and Cultural Organization
USEPA	United States Environmental Protection Agency
USPHS	United States Public Health Service
WHO	World Health Organization
WRMA	Water Resources Management Authority
WASREB	Water Services Regulatory Board
WSPs	Water Service Providers

List of Symbols

µg/L	Microgram per litre
µm	Micrometre
µS/cm	Microsiemens per centimetre or micromhos per centimetre
CO_2	Carbon dioxide
g, gm	Grams
L, l	Litre
mg $CaCO_3$/L	Calcium Carbonate in milligrams per litre
mg Cl/L	Chloride in milligrams per litre
mg CO_2/L	Carbon Dioxide in milligrams per litre
mg F/L	Fluoride in milligrams per litre
mg Fe/L	Iron in milligrams per litre
mg N/L	Nitrogen as milligrams per litre
mg O_2/L	Dissolved Oxygen in milligrams per litre
mg TSS/L	Total Suspended Solids in milligrams per litre
mg TDS/L	Total Dissolved Solids in milligrams per litre

CHAPTER 1: INTRODUCTION

1.1 Introduction

1.1.1 Background Information

Surface water and groundwater are both important sources for community water supply needs. Groundwater is a common source for single homes and small towns, and rivers and lakes are the usual sources for large cities. Although 98% of liquid fresh water exists as groundwater, much of it occurs very deep in the earth. This makes pumping very expensive preventing the full development and use of all groundwater resources.

Water quality is a term used to describe the chemical, physical and biological characteristics of water, usually in respect to its suitability for a particular purpose. The development of water quality standards has made it easier to measure and determine water quality and gauge the different levels of consumption. Before water can be put to some of its uses especially domestic and industrial, it is necessary to know its quality. Therefore physical, chemical and bacteriological properties of the water are defined and in order to do this accurately, appropriate tests are carried to examine the water. In Kenya, fairly consistent data is contained in various reports which show the natural groundwater quality is good and meets the drinking water stands for most constituents, except for fluoride which often exceeds 1mg/L.

Groundwater is susceptible to quality degradation that can result from poor environmental sanitation. In the rural areas, shallow wells are particularly threatened by indiscriminate solid waste disposal as well as seepage of untreated sewage from septic tanks and pit latrines. The risk of shallow well contamination in urban areas is bound to increase in proportion with the increase of human population in the informal settlements where sanitation coverage is lowest. In urban areas groundwater is equally under threat of contamination from solid waste leaches, raw sewage and industrial effluent discharges seeping into the ground and reaching water bearing rock formations. (African Boreholes Initiative Paper 2005)

Water is in constant circulation, powered by the energy from sunlight and gravity in a natural process called hydrologic cycle. Water evaporates from large masses like oceans and land surfaces, is held temporary as vapour in the atmosphere, and falls back to the Earth's surface as precipitation and melted snow, called runoff. Where the average rate of precipitation exceeds the rate at which runoff seeps into the soil, it evaporates, or is absorbed by vegetation, bodies of surface waters such as streams, rivers, and lakes are formed. Water that infiltrates the Earth’s surface becomes groundwater, slowly seeping downward into extensive layers of porous soil and rock called aquifers. Under the pull of gravity, groundwater flows slowly and steadily through the aquifer. In low areas it emerges in springs and streams. Both surface water and surface water eventually return into the ocean.

1.1.2 Surface water sources

The total land area that contributes surface runoff to a river or lake is called a watershed. The volume of water available for supply depends mostly on the amount of rainfall.it also depends on the size of the watershed, the slope of the ground, the type of soil and vegetation, and the type of land use.

The discharge of a river varies with time. When the average discharge of a river is not enough for a dependable supply of water, a conservation reservoir may be built. The flow of water is blocked by a dam, allowing an artificial lake to be formed. Conservation reservoirs store water from wet weather periods for use during times of drought and low stream flow. A water intake structure is built within the reservoir, with inlet ports and valves at several depths. Since the quality of water in a reservoir varies seasonally with depth, a multilevel intake allows water of best quality to be withdrawn. Sometimes it is worthwhile, for economic reasons, to provide a multipurpose reservoir which is designed to satisfy a combination of community water needs. In addition to drinking water, the reservoir may also provide flood control measures, hydroelectric power, and recreation besides other benefits.

1.1.3 Ground water sources

Groundwater is one of the most valuable natural resources possessed by many developed and developing nations. It is reliable in dry seasons or droughts because of the large storage, is cheaper to develop, since, if unpolluted, it requires little or no treatment and it can often be tapped where it is needed, on a stage by stage basis. As a result, groundwater has become important for human water supply in urban and rural areas in developed and developing nations alike. Groundwater is an important element of the overall Ongata Rongai water supply through the large number of privately operated boreholes. However, a gloomy picture hangs over the use of groundwater in certain regions. Studies have shown that ground water contains contaminants that are deleterious to human health in certain regions.

1.2 Problem Statement

Fresh water is a finite resource, essential for agriculture, industry and even human existence. However, indiscriminate exploitation and unplanned use of various water resources for various purposes diminishes in qualitative and quantitative terms. The health of a community is generally affected by the water they consume and use.

Rapid increase in population and industrialization together with lack of wisdom to live in harmony with nature has led to deterioration of quality of water thus resulting in water ‘pollution’. Demand for fresh water within the region of this study i.e. Ongata Rongai is raising, a consequence of the fast growing population within the region. Therefore ‘pollution’ of water resources needs a serious and immediate attention to understand the importance and control of water quality, so as to ensure the checks and balances are within the accepted boundaries as put down in the Water Act.

1.3 Objectives of the study

The principal objectives of this study are to:

1. To investigate into the various water quality parameters such as Turbidity, colour, taste and Odour, pH, chloride, conductivity, iron, hardness, conductivity, fluoride, total alkalinity and biological characteristics
2. Make recommendations based on the findings of the assessment which will thus be applied to the current case study area and regions whose waters have similar characteristics to those of Ongata Rongai.
3. Determine the presence or absence of water pollution.

1.4 Significance of the study

The quality of both surface and groundwater in some parts of the country is changing, particularly shallow aquifers groundwater and shallow water wells. This is largely associated with human activities. Groundwater is less susceptible to pollution from bacteria because the soil and rocks through which groundwater flows screens out most bacteria. However bacteria occasionally find their way into the groundwater and sometimes could be in high concentration. There are various dissolved organic and mineral constituents found in surface waters and groundwater in varying concentration. Otherwise, at high concentrations they may render the water unsuitable for human consumption and may require treatment before consumption.

Most surface and groundwater supplies are consumed directly by the public or pumped into water distribution systems with minimal treatment. Due to the high potential for pollution scenario that exists in a fast growing environment like Ongata Rongai, it is important to monitor consistency in water quality to ensure that the water for domestic use is safe.

This study seeks to investigate and give a record of the current state of water quality for domestic use in Ongata Rongai region. This study will, therefore, help in making better decisions when it comes to planning, managing and operating of the various water resources that will be looked into and determining the water quality majorly for domestic use in Ongata Rongai area.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Water quality refers to the physical, chemical, radiological and bacteriological characteristics of water. Water quality assessment refers to the overall process of evaluation of the physical, chemical, radiological and biological nature of water in relation to natural quality, human effects and intended uses, particularly uses which may affect human health and the health of the aquatic system. Water quality analysis therefore falls into four broad categories, namely:

- Physical analysis;
- Chemical analysis;
- Bacteriological analysis;
- Radiological analysis.

Physical analysis is primarily involved with the appearance, colour, taste and odour, solids, temperature, and turbidity of water, which are majorly used to define the aesthetic properties of water.

2.2 Chemical characteristics

In chemical analysis, substances of health concern with effects on the taste, odour or appearance of drinking water that would normally lead to rejection of water at concentrations significantly lower than the existing standards for proper health, are investigated. These investigations help to establish health-based summary statements and guideline values. These summary statements and guideline values for each substance, upon adoption by water authorities, aid in the provision and usage of water which is satisfactory aesthetically and has uniform quality (UNESCO and WHO, 1996).

Bacteriological water analysis is a method of analyzing water to estimate the numbers of bacteria present and, if needed, to find out what sort of bacteria they are. The importance of bacteriological analysis of drinking water helps to determine the presence of potential water-borne pathogens. It suffices here to say that bacteriological analysis of water provides the most sensitive quality parameter.

Nonetheless, the need for radiological analysis of water has grown with the prolific transformations that have taken place in the late 20th and early 21st century. The emergence of nuclear power plants and warfare, for example, has had serious impacts on water sources e.g. death of human beings, and the flora and fauna in the aquatic environment. Radiological analyses thus help in assessing the level of contamination of a given water body by radioactive pollutants.

2.2.1 pH in water

2.2.1.1 Introduction

pH (pondus Hydrogenium), is a measure of the acidity or basicity of an aqueous solution or simply as the measure of hydrogen ion concentration of a solution. It is defined as the cologarithm of the activity of dissolved hydrogen ions (H+). By virtue of its logarithmic nature, pH is a dimensionless quantity. Technically, it can be represented as:

$$\boldsymbol{pH = -\log_{10} aH = \log_{10} \frac{1}{aH}} \qquad \text{(Equation 1)}$$

Where:

aH is the (dimensionless) activity of hydrogen ions.

pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body and all other processes associated with water supply and treatment. Pure water, for example, has a pH around 7 (neutral); the exact values depend on temperature. When an acid is dissolved in water pH will be less than 7 and when a base, or alkali is dissolved in water the pH will be greater than 7.

The pH of most natural waters ranges from 6 to 8.5, though lower values can occur in dilute waters high in organic content and higher values of eutrophic waters, ground water brines and salt lakes The pH of clean water depends on several factors, including the types of rocks and vegetation within the watershed.(UNESCO and WHO, 1996).

The pH is a very important factor, because certain chemical processes geared towards improving water quality can only take place when water has a certain pH. For instance, chlorine reactions only take place when the pH has a value of between 6.5 and 8.

2.2.1.2 Causes of pH in water

The main causes of pH variations in water are: industrial effluent i.e. dumping pollutants directly into water, and acid rain from atmospheric depositions. Fluctuations in pH can be caused by photosynthesis and respiration of algae in eutrophic waters. During photosynthesis plants take up carbon dioxide from the water. This consequently accounts for a raise in pH. Since plants do photosynthesis when there is sunlight, the pH of the water will be highest during the middle of the afternoon and lowest just before sunrise. (UNESCO and WHO, 1996).

Extreme values of pH can result from accidental spills, treatment breakdowns and insufficiently cured cement mortar pipe linings or cement mortar linings applied when the alkalinity of the water is low.

2.2.1.3 Effects of pH on the usability of water

Although pH has no direct impact on consumers, it is one of the most important operational water quality parameters. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. Low pH values, (less than 4), indicate that the water is corrosive and that it will tend to dissolve heavy metals such as lead and chromium and other substances that it contacts. These heavy metals and other dissolved substances tend to become toxic when dissolved in water. High values of pH, (greater than 8.5), indicate that the water is alkaline, and that on heating, it will tend to form scale (Pedro et. al., 2007).

pH affects aquatic life. Stream or pond water with a pH value less than 5.5 is too acidic for fish to survive. A change in stream water pH can also affect aquatic life indirectly by altering other aspects of water chemistry. For example, low pH levels can increase the solubility of certain heavy metals. These allow the metals to be more easily absorbed by aquatic organisms.

2.2.1.4 Management of levels of pH and guideline values

pH adjustment in water is achieved through the use of: calcium carbonate, carbon dioxide, hydrochloric acid, lime (quicklime and hydrated lime), sodium carbonate, sodium hydroxide, sulphuric acid (AWWA, 1971).

The minimum and maximum allowable range of pH for potability as issued by the WHO (in 1984), the Safe Drinking Water Act and the European Community is 6.5-8.5. The Kenya standard (KS 459-1, 2007), however, has adopted a minimum value of 4 for carbonated waters.

2.2.2 Alkalinity in water

2.2.2.1 Introduction

Alkalinity is a measure of the ability of a solution to neutralize acids to the equivalence point of carbonate or bicarbonate. Alkalinity is loosely related to the Acid Neutralizing Capacity (ANC) of a solution and ANC is often incorrectly used to refer to alkalinity (Edmunds and Shand, 2008).

Only three types of alkalinity can be determined from water analysis namely: hydroxide OH^-, carbonate $CO_3^{=}$, and bicarbonate HCO_3^- alkalinity. These subdivisions are useful in the softening process and in the boiler water analysis. Waters of low alkalinity have a low buffering capacity and can be susceptible to alterations in pH. The amount of strong acid needed to lower the pH of a sample to 8.3 gives the free alkalinity (Caustic alkalinity), and to a pH of 4 gives the total alkalinity (APHA, 1999). Most of the natural alkalinity in waters is due to HCO_3^- produced by the action of ground water on limestone or chalk. The amount of alkalinity present is expressed in terms of $CaCO_3$.

2.2.2.2 Sources of Alkalinity in water

Alkalinity in drinking water emanates from bicarbonates, carbonates, and hydroxide ions components in raw or treated water supplies. Bicarbonates are the major components because of carbon dioxide action on basic materials of soil; borates, silicates, and phosphates may be minor components. Alkalinity of raw water may also come from salts formed from organic acids, such as humic acids (De Zuane, 1997).

2.2.2.3 Effects of Alkalinity on the utility of water

High levels of alkalinity have been shown to cause corrosion of boilers and boiler sittings (Taylor, 1958). Evidence from research further shows that high levels of alkalinity may render water unfit for many industrial and agricultural processes e.g. irrigation (Pedro et al., 2007). Fluctuations in alkalinity levels have also been found to interfere with water treatment processes (AWWA, 1971).

2.2.2.4 Management of levels of Alkalinity and guideline values

There are no recommended guideline values for alkalinity in drinking water, however, from the potability viewpoint; alkalinity is not a significant parameter. Variations of concentration from 5 to 125 mg/L are expected, and the extremes of these values are tolerated in water supplies (John De Zuane, 1997).

2.2.3 Chloride in water

2.2.3.1 Introduction

Chlorides are compounds of chlorine which occur as chloride ions (Cl^-) in solution. Chlorides are soluble in water and are unaffected by biological processes, hence, reducible by dilution. Almost all natural waters contain chloride ions. Their concentrations vary considerably according to the mineral content of the earth in any given area. Small quantities of chlorides of calcium and magnesium are found in many waters. This characteristic adds palatability to the water thus is desirable for consumption. The concentration of chloride in natural waters is commonly less than 10 mg/L in humid regions and pristine freshwaters. Tidal streams contain increasing amounts of chloride (as much as 19,000 mg/L) as the bay or ocean is approached. Sea water contains chloride levels of about 19,300 mg/L, while brines may have levels as high as 200,000 mg/L (Pedro et al., 2007).

2.2.3.2 Sources of Chloride in water

Chloride is introduced in water through the leaching process of chlorides from sedimentary rocks (e.g. evaporites, rock salt deposits) and soils. Salt water intrusion through ocean tides in coastal areas and tidal estuaries is also a major source of chloride in sea water (Pedro et al., 2007). Higher concentrations of chloride can occur near sewage and other waste outlets, irrigation drains, salt water intrusions, in arid areas and in wet coastal areas.

Chloride may get into surface water from several sources including; wastewater from industries and municipalities, wastewater from water softening, road salting, produced water from gas and oil wells. In addition, atmospheric deposition of oceanic aerosols introduces chloride in surface waters when carried inland in minute crystals or droplets. Chloride is also introduced into water as a result of agricultural runoff, especially when fertilizers containing chlorides are washed into water bodies (Spellman, 2003).

The use of de-icing salt on roads during winter periods in temperate lands has been known to result in seasonal fluctuations in levels of chloride in ground water, streams and reservoirs adjacent to the road when carried as runoff (UNESCO and WHO, 1996). Industrial effluent (galvanizing plants, water-softening plants, oil wells, refineries, and paper works) may also leach into groundwater or streams leading to increased levels of chloride in water.

2.2.3.3 Effects of Chloride on the utility of water

High concentrations of chloride can make waters unpalatable and, therefore, unfit for drinking or livestock watering. Chloride in excess of 100 mg/L, for example, imparts a salty taste to water and beverages. Excessive chloride concentrations increase rates of corrosion of metals in the distribution system, depending on the alkalinity of the water. This can lead to increased concentrations of metals in the supply (UNESCO and WHO, 1996). Chlorides also contribute to the total mineral content of water.

High levels of chloride in water also create problems for certain industries. Food processing industries, for example, usually require chloride levels lower than 250 mg/L. Some industries like textile industries, processing plants, paper manufacture and synthetic rubber manufacturing, require chloride levels of less than 100 mg/L (Pedro et al., 2007). High concentration of chloride has been shown to cause physiological damage to both human and plant cells. The effects of high levels of chloride are catastrophic to individuals who are affected by heart and kidney diseases (De Zuane, 1997).

2.2.3.4 Management of levels of Chloride and guideline values

Chloride in water is not removed by conventional treatment. Levels of chloride in water, however, can be lowered by the process of dechloridation which is achieved by the use of agents like: activated carbon, aluminum ammonium sulphate, ion-exchange resins, sodium bi-sulphite (sodium pyrosulphate), sodium sulphite, and sulphur dioxide. Pollution control and dilution can also be used to reduce chloride concentration. The actual removal of chloride, however, can be accomplished through a demineralization process (which includes reverse osmosis or electrodialysis) (De Zuane, 1997).

The WHO (1963) listed 200 mg/L as a guideline value for chloride as a maximum acceptable value, and 600 mg/L as a maximum allowable value. On the other hand, The European Community (1980) used 250 mg/L as a guideline value and 200 mg/L as a level over which effects may be registered. The USEPA (1979 and 1981) issued a secondary drinking water standard for chloride at 250 mg/L. The WHO (1984) listed a guideline value of 250 mg/L (De Zuane, 1997). The Kenya standard (KS 459-1, 2007) has adopted 250 mg/L as the standard for chloride in drinking water.

2.2.4 Iron in water

2.2.4.1 Introduction

Iron is a white, malleable, ductile, metallic chemical element, vital to animal and plant life. Iron is the fourth most abundant element by weight in the earth's crust and occurs in water at two levels of oxidation; either as bivalent ferrous iron, or as trivalent ferric iron. Under reducing conditions, iron in water will tend to be in the ferrous state. Elemental iron ions $Fe^{2+}$and Fe^{3+} readily combine with oxygen and sulphur containing compounds to form oxides, hydroxides, carbonates, and sulphides.

The concentration of iron in natural fully aerated waters is generally below 0.5 mg/L. Groundwater having a pH less than 8.0 may contain 10 mg/L of iron; but it is not rare for values as much as 50 mg/L to occur in extreme cases. Acid waters from thermal springs, mine wastes and industries may contain more than 6000 mg/L (Pedro et. al., 2007).

2.2.4.2 Sources of Iron in water

The presence of iron in groundwater is often attributed to the solution of rocks and minerals, chiefly oxides, sulphides, carbonates and silicates. Iron occurs in the silicate minerals of igneous rocks, pyroxenes amphiboles and micas. Iron also occurs in oxides such as magnetite (Fe_3O_4), hematite (Fe_2O_4) and limonite ($2Fe_2O_3.3H_2O$). The sulphide and carbonate minerals, pyrite (FeS_2) and siderite ($FeCO_3$) are also important sources of iron in water (Pedro et al., 2007).

2.2.4.3 Effects of Iron on the utility of water

The presence of iron in drinking water is objectionable primarily because the precipitation of iron changes the appearance of the water turning it turbid yellow-brown to black. In addition, the deposition of iron precipitate causes staining of plumbing fixtures and laundry. Another condition which has been associated with iron in water supplies is the growth of micro-organisms in distribution systems. Accumulation of microbial growth leads to a reduction in pipeline carrying capacity and clogging of meters and valves. Sloughing of the accumulations often leads to adverse consumer reactions including complaints of tastes and odours. (AWWA, 1971).

Iron imparts an inky flavour to water when present in large amounts. This flavour tends to make the affected waters objectionable thus making people reject the water (Taylor, 1958). Various iron salts are used as coagulants in water treatment, therefore the precipitation of iron may cause difficulty in water treatment processes such as ion exchange. As a result, owners of individual household treatment units become aggravated.

2.2.4.4 Management of levels of Iron and guideline values

There are three general methods used for the control of iron in water supplies. The primary method involves precipitation followed by filtration. The second method involves ion-exchange, and the third method involves stabilization of the iron in suspension using dispersing agents to prevent the deposition of iron (AWWA, 1971).

In 1963 the WHO adopted a 0.3 mg/L as a maximum acceptable level and 1.0 mg/L as a maximum allowable level. The European Community adopted, in 1980, a guide of 0.05 mg/L and a maximum of 0.20 mg/L. WHO (1984) recorded a guideline of 0.3 mg/L. The Kenya standard (KS 459-1, 2007) adopts 0.3mg/L as a standard for iron in drinking water.

2.2.5 Conductivity in water

2.2.5.1 Introduction

Conductivity is a measurement of the ability of an aqueous solution to carry an electrical current. Specific conductance, on the other hand, is a measure of the electric current in a given water sample by ionized substances. Conductivity is expressed as microsiemens per centimetre (μS/Cm).

The electrical conductivity of water estimates the total amount of solids dissolved in water (TDS). This is measured in parts per million (ppm) or mg/l.

The electrical conductivity of water depends on the water temperature: the higher the temperature, the higher the electrical conductivity would be. The electrical conductivity of water increases by 2-3% for an increase of 1 degree Celsius of water temperature.

Since electrical conductivity is a measure of the capacity of water to conduct electrical current, it is directly related to the concentration of salts dissolved in water, and therefore to the total dissolved solids (TDS). Salts dissolve into positively charged ions and negatively charged ions, which conduct electricity. Since it is difficult to measure the TDS in the field, the EC of water is used as a measure.

Chemically pure water in liquid form has a very low electrical conductance. The presence of dissociated ions in solution, however, renders the solution conductive. The most important factors in determining how well a given solution will conduct an electrical current are: variations in dissolved solids (mostly mineral salts), the number and kinds of ions present, the degree to which dissolved minerals dissociate into ions, their relative charge of ions and their mobility and the temperature of the solution (Hem, 1967). The conductivity of most freshwaters ranges from 10 to 1,000 μS/Cm. Higher values, greater than 1000 μS/Cm, can be observed in polluted waters, or those waters which receive large quantities of land run-off (Pedro et al., 2007).

2.2.5.2 Causes of Conductivity in water

Conductivity arises from dissolved mineral matter in water. Free carbon dioxide and ammonia also impart conductivity in water, though their effect is negligible, except in waters of very low salinity.

2.2.5.3 Effects of Conductivity on the utility of water

Since the conductivity of water is directly proportional to the presence of dissolved mineral matter and temperature; waters with very high conductivity may possess repugnant tastes and thus less attractive to consumers.

2.2.5.4 Management of levels of Conductivity and guideline values

No known method has been proposed for the management of the levels of conductivity in water, and no guideline values has been proposed for conductivity in drinking waters.

2.2.6 Fluoride in Water

2.2.6.1 Introduction

Fluorine is a pale greenish-yellow noxious gas that is highly reactive. It is the most electronegative element. Fluorine constitutes about 0.08% of the earth’s crust thus making it the thirteenth most abundant element in the earth’s crust.

Fluorine is not found in a free state in nature, as it is a gas. It is always found in combination with chemical radicals or other elements as fluoride compounds. When these compounds dissolve in water, they dissociate into ions to form fluorides (De Zuane, 1997).

Fluoride concentration in water depends on pH and the presence of complexing agents, however, it has been observed that fluoride in water increases with salinity (Weinstein and Davison, 2004). The mobility of fluoride in water depends to a large extent on the calcium ion content of the water. This is due to the fact that fluoride forms low solubility ions with divalent cations.

Fluoride concentration in natural waters varies from 0.05 to 100 mg/L, although in most situations it is less than 0.1 mg/L. Fluoride concentration in groundwater is often as high as 10 mg/L. Very high concentrations of fluoride, far exceeding the WHO guideline value of 1.5 mg/L, are encountered in volcanic aquifers and lakes in the East African Rift system and in Hawaii. Localized occurrences of high fluoride in groundwater associated with sedimentary and metamorphic rocks are also reported from Ohio, Sri Lanka, India, Malawi and Tanzania (Howard and Bartram, 2003).

2.2.6.2 Sources of Fluoride in Water

Fluoride is found in almost all water sources and supplies. Some sources contain too much, most contain too little, while a few contain just the right amount of fluoride for optimum dental health. Sources of fluoride in water can be divided into two broad categories, namely:

i. Natural sources

ii. Artificial sources

2.2.6.2.1 Natural sources of Fluoride in water

Fluoride is widely distributed in the earth’s lithosphere and hydrosphere. It is found in solid form in fluoride-containing minerals in igneous and sedimentary rocks such as fluorspar, amphiboles (hornblende), fluorite, mica, cryolite and apatite. Fluoride originates from the weathering of these minerals which subsequently enter the surface waters with the runoff. In ground water, fluoride results from direct contact between the ground water and the fluoride-containing rocks.

2.2.6.2.2 Artificial sources of Fluoride in water

In public water supplies of developed countries like the USA, fluoride is found in drinking water as an additive intended to provide public health protection from dental caries during the process of artificial water fluoridation. Run-off from agricultural lands using phosphoric fertilizers; and from industries, does contribute to increased levels of fluoride in water bodies. Furthermore, liquid and gas emissions from certain industrial processes (such as metal-and chemical-based manufacturing) have also been shown to contribute to the origin of fluoride ions (F^{-}) to water bodies (Letterman et al., 1999).

2.2.6.3 Effects of Fluoride on the utility of Water

2.2.6.3.1 Medical effects of Fluoride

Fluoride in concentrations between 0.6-1.7 mg/L in drinking water has a beneficial effect on the structure and resistance to decay on children's teeth as it helps to control dental caries. Nevertheless, fluoride in excess of 1.5 mg/L in some waters causes 'mottled enamel' in children's teeth. The recommended optimal fluoride intake for children to maximize caries prevention and minimize the occurrence of enamel fluorosis is stated to be 0.05-0.07 mg/kg/day (NRC 2006a).

Fluoride in excess of 6.0 mg/L has been observed to cause prolonged mottling and disfiguration of teeth (Pedro et al., 2007). An acute overdose (20-200 mg/L) can result in nausea, diarrhoea, abdominal pain, headache and dizziness. Long-term exposure to high levels of fluoride, for example, has been attributed to dental fluorosis. In its mildest form, dental fluorosis is characterized by very slight opaque, whitish areas on some posterior teeth. As the defect becomes more severe, discolouration is more widespread and changes in colour range from shades of grey to black. In most severe cases, gross calcification defects occur, resulting in pitting of the enamel. In some of the latter cases, teeth are subjected to such severe attrition that they wear down to the gum line, and complete dentures may be obtained (Letterman et al., 1999). This condition is permanent after it develops in children during tooth formation, a period ranging from birth until about the age of 8.

On the other hand, skeletal fluorosis is a bone and joint condition associated with prolonged exposure to high levels of fluoride. Fluoride appears to worsen the growth of osteophytes present in the bone and joints, resulting in joint stiffness and pain. Epidemiological studies of fluoride and bone fracture have indicated that there is an increased risk of bone fracture in populations exposed to fluoride at 4 mg/L. A few human studies have also suggested that high concentrations of fluoride exposure might be associated with alteration in reproductive hormones, thus having an overall effect on fertility and development outcomes (NRC, 2006a).

The chief endocrine effects of fluoride exposures in experimental animals and in humans include decreased thyroid function, increased calcitonin activity, increased parathyroid hormone activity, secondary hyperparathyroidism and impaired glucose tolerance. Case reports and in vitro and animal studies have indicated that exposure to fluoride at concentrations greater than 4 mg/L can be irritating to the gastrointestinal system, affect renal tissues and function, and alter hepatic and immunologic parameters (NRC, 2006b).

2.2.6.3.2 Industrial effects of Fluoride

The concentration of fluoride in water intended for industrial use is a critical factor for consideration in industry. Several industries like: the baking industry, confectionery, sugar manufacturing industry, dairy industry, power generating industry, paper and pulp industry, iron and steel industry and the petroleum industry are not affected by the level of fluoride in water. However, the concentration of fluoride becomes a critical factor for consideration when it comes to the operations of industries like: carbonated beverages industry, food processing industry and brewing industry.

Typical levels of fluoride recommended for use in some of these industries are illustrated in table 2.0

Table 2.0: Levels of fluoride recommended.

Type of Industry	Recommended levels of Fluoride (mg/L)
Carbonated beverages	0.2-1.0
Food processing and canning	< 1.0
Brewing	<1.0

(Source: Pedro et al., 2007)

2.2.6.4 Management of levels of Fluoride in drinking water

Depending on the area under consideration, the levels of fluoride in water can be managed by two distinct methods, namely:

- Defluoridation: a process in which the concentration of fluoride is reduced/ lowered in waters with high levels of fluoride.
- Fluoridation: a process in which fluoride is added to water with low levels of fluoride.

These two distinct processes are discussed below.

2.2.6.4.1 Defluoridation

Defluoridation refers to a scientific process used to reduce the concentration of fluorides in a given water supply/body. Defluoridation can be achieved by chemical precipitation, adsorption, or by membrane separation processes (Twort, 2000). Adsorption media successfully used are granular activated carbon (GAC), bone char, serpentinite, activated bauxite and activated alumina. All these processes, with the exception of activated alumina, have limitations which would make the process uneconomical.

Activated alumina has been used successfully in several full-scale plants. Activated alumina is an excellent medium for fluoride removal and it normally comes from several aluminium manufacturers in various mesh sizes of granules and degrees of purity. For defluoridation, it is used in mesh sizes between 28 and 48 (AWWA, 1971). Activated alumina is highly selective to fluorides in the presence of sulphates when compared to synthetic ion-exchange resins. In the presence of bicarbonates, although the fluoride level is reduced, the adsorption capacity shows a major decline (Twort, 2000). One major limitation of the activated alumina is the problem of disposal of the generated waste which comes out after the treatment of large volumes of water as the aluminium becomes saturated with fluoride and must be regenerated. This problem has also been found to affect the process of defluoridation by the use of bone char (Hem, 1967).

Silica is also known with the adsorption of fluoride. The adsorption process is best carried out under slightly acidic conditions (pH 5-7); the lower the pH, the more effective the removal. Reverse osmosis and electrodialysis, which are membrane type desalinisation processes, can be used to remove fluoride along with other ions. Membranes exhibit anion and cation rejections in the range 95-99%. For these processes to be successful the feed water must be pre-treated to prevent membrane fouling and scaling (Twort, 2000). Other substances used in defluoridation are tricalcium phosphate and anion exchange resins (De Zuane, 1997). The modified lime softening process has also been used in certain areas for defluoridation (AWWA, 1971).

The use of water filtration and purification systems has been shown to reduce fluoride concentration in community water by 13%-99%, depending on the type of system. Distillation, for example can remove nearly all the fluoride (NRC 2006b). Aluminium sulphate coagulation is known to reduce fluoride levels by 10-60% but the pH must be kept in the optimum range for coagulation to ensure residual aluminium levels are low; the aluminium sulphate dose required could be as high as 750 mg/L. In the 'Nalgoda process' the combined use of lime and aluminium sulphate has reduced fluoride levels to below 1.5mg/L, but the chemical doses required are substantial.

2.2.6.4.1 Fluoridation

Fluoridation is the deliberate adjustment of the fluoride concentration of a public water supply in accordance with the scientific and medical guidelines (Letterman et al, 1999). The goal in water fluoridation, as it always has been, is to obtain the lowest rate of tooth decay with the least amount of dental fluorosis.

Fluoridation has been achieved by the use of chemicals like: ammonium silicofluoride, fluorspar (CaF_2), hydrofluoric acid, hydrofluosilicic acid, sodium fluoride, and sodium silicofluoride (NRC, 2006b). Sodium fluoride is the only compound used at present for the fluoridation of municipal water supplies and it is manufactured from hydrofluoric acid (AWWA, 1971).

2.2.6.5 Water Quality Guidelines for Fluoride in drinking water

2.2.6.5.1 History of Fluoride guideline development

The 1958 and 1963 WHO International Standards for Drinking-water referred to fluoride, stating that concentrations in drinking-water in excess of 1.0–1.5mg/Litre of fluoride may give rise to dental fluorosis in some children, and much higher concentrations may eventually result in skeletal damage in both children and adults.

To prevent the development of dental caries in children, a number of communal water supplies were fluoridated to bring the fluoride concentration to 1.0mg/litre. The 1971 International Standards recommended control limits for fluoride in drinking-water for various ranges of the annual average of maximum daily air temperatures; control limits ranged from 0.6–0.8 mg/litre for temperatures of 26.3–32.6°C to 0.9–1.7 mg/litre for temperatures of 10–12°C. In the first edition of the Guidelines for Drinking- water Quality, published in 1984, a guideline value of 1.5 mg/litre was established for fluoride, as mottling of teeth has been reported very occasionally at higher levels. It was also noted that local application of the guideline value must take into account climatic conditions and higher levels of water intake. The 1993 guidelines concluded that there was no evidence to suggest that the guideline value of 1.5 mg/litre set in 1984 needed to be revised. It was also recognized that in areas with high natural fluoride levels, the guideline value may be difficult to achieve in some circumstances with the treatment technology available. It was also emphasized that in setting national standards for fluoride, it is particularly important to consider climatic conditions, volume of water intake and the intake of fluoride from other sources.

2.2.6.5.2 Guideline values for Fluoride

The optimal fluoride level in water is the level that produces the greatest protection against caries with the least risk of fluorosis. The guideline value for fluoride has been based on the climatic conditions of the area under consideration, and the quantity/volume of water consumed; and not health-based assessments as has been the norm (Gray, 2008).

The WHO guideline value for fluoride in water is 1.5 mg/L but this value may change depending on climatic conditions and water consumption. Other organizations that have developed guideline values for fluoride include: USPHS (1942) 1.0 mg/L; USPHS (1946) 1.5 mg/L; and the European community 0.7-1.5 mg/L (related to temperature) (De Zuane, 1997). The Kenya Standard (KS 459-01, 2007) adopts 1.5 mg/L as a standard for fluoride in drinking water.

2.2.7 Hardness in water

2.2.7.1 Introduction

This is the property of water which prevents lather formation with soap and produces limescale in kettles and hot water systems. Hardness may be considered as a physical or chemical parameter of water. It is determined by the concentration of multivalent cations in water. It represents the total concentration of calcium (Ca^{++}) and magnesium (Mg^{++}) ions in water although (Fe^{++}) and (Sr^{++}) are also responsible (Tebbutt, 2003). Water hardness is categorized as:

- Carbonate hardness: this is also referred to as temporary hardness (hardness that can be removed by boiling or addition of lime). It is caused by the presence of dissolved carbonate and bicarbonate salts of calcium and magnesium. When dissolved these minerals yield calcium and magnesium cations (Ca^{2+}, Mg^{2+}) and carbonate and bicarbonate anions (CO_3^{2-}, HCO_3^{-})

- Non-carbonate hardness, also referred to as permanent hardness (hardness that cannot be removed by boiling), is represented by any salts of calcium and magnesium (such as sulphates and chlorides) ($SO_4^{=}$, CL^{-}, NO_3^{-}).

Non-carbonate hardness = Total hardness ─ alkalinity.

Total hardness is defined as the sum of the calcium and magnesium concentrations, both expressed as calcium carbonate, in milligrams per litre.

If concentrations of Na and K salts are present, the non-carbonate hardness may be negative since such salts could form alkalinity without producing hardness (Tebbutt, 2003)

The degree of hardness can be represented as shown in tables 2.1 and 2.2.

Table 2.1: Degree of Hardness

Concentration mg/L	Degree of hardness
0 – 50	Soft
50 – 100	Moderately soft
100 – 150	Slightly hard
150 – 250	Moderately hard
250 – 350	Hard
350+	Excessively hard

(Source: Gray, 2008)

Table 2.2: Degree of Hardness

Concentration mg/L	Degree of hardness
0 – 75	Soft
75 – 150	Moderately hard
150 – 300	Hard
300+	Very hard

(Source: Gray, 2008)

2.2.7.2 Causes of Hardness in water

Hardness in water is primarily caused by the presence of minerals mainly calcium and magnesium in it. The minerals get into the water if it passes through soft rock like chalk or limestone. If water passes through hard rocks, like granite or through peaty soils, it does not pick up these minerals therefore remains soft.

2.2.7.3 Effects of Hardness on the usability of water

Depending on the interaction of other factors, such as pH and alkalinity, water with hardness above 200 mg/L may cause scale deposition in the distribution system and pipework and tanks within buildings. High levels of hardness will also result in excessive soap consumption and subsequent "scum" formation. On heating, hard waters form deposits of calcium carbonate scale. Soft water, with a hardness of less than 100 mg/L, may, on the other hand, have a low buffering capacity and so be more corrosive for water pipes.

2.2.7.4 Management of levels of Hardness and guideline values

High levels of hardness (greater than 150 mg/L) can be managed by the use of precipitation softening or cation exchange. No guideline value has been proposed for hardness since it does not cause a health concern at levels found in drinking water (Vigil, 2003).

2.2.8 Nitrites and Nitrates

Nitrites represent the first product of oxidation of free ammonia by biochemical activity. Unpolluted natural waters contain practically no nitrites. The nitrite concentration present is due to the organic matter in the soils. Concentrations exceeding the very low value of 0.001mg/L are of sanitary significance.

Nitrates represent the final stage of oxidation of ammonia and mineralization of nitrogen from organic matter. This oxidation is achieved by nitrifying bacteria and can also occur in a well oxygenated environment. Excessive levels of nitrate may cause serious illness and sometimes death in infants (Twort, 1962)

Microbiological measures

The most important microbiological measure of drinking-water quality is a group of bacteria called coliforms. Coliform bacteria normally are not pathogenic, but they are always present in the intestinal tract of humans and are excreted in very large numbers with human waste. Water contaminated with human waste always contains coliforms, and it is also likely to contain pathogens excreted by infected individuals in the community. Since it is easier to test for the presence of coliforms rather than for specific types of pathogens, coliforms are used as indicator organisms for measuring the biological quality of water. If coliforms are not found in the water, it can be assumed that the water is also free of pathogens. The coliform count thus reflects the chance of pathogens being present; the lower the coliform count, the less likely it is that pathogens are in the water.

2.3 Physical characteristics

The physical characteristics of water are those that are apparent to the senses of taste, smell, sight and touch. Colour, taste, and odour are physical characteristics of drinking water that are important for aesthetic reasons rather than for health reasons. Colour in water may be caused by decaying leaves or by algae, giving it a brownish yellow hue. Taste and odour may be caused by naturally occurring dissolved organics or gases. Some well-water supplies, for example, have a rotten-egg odour that is caused by hydrogen sulfide gas. Chemical impurities associated with the aesthetic quality of drinking water include iron, manganese, copper, zinc, and chloride. Dissolved metals impart a bitter taste to water and may stain laundry and plumbing fixtures. Excessive chlorides give the water an objectionable salty taste.

2.3.1 Colour

Pure water is colourless. Presence of colour in water is due to foreign substances such as organic matter from soils, vegetation, minerals and aquatic organisms. Colour in water is classified as either true colour or apparent colour. Water whose colour is partly due to dissolved solids that remain after removal of suspended matter is known as true colour. Colour contributed by suspended matter is said to have apparent colour. During treatment, true colour is the most difficult to remove.

Colour is a physical parameter that is not necessarily related to toxicity or pathogenic contamination of water. Nevertheless the colour of water has a profound impact on its marketability for both domestic and industrial use. Coloured water can create psychological rejection and fear to consumers (Spellman, 2003)

The Kenya Standards (KS) and World Health Organization (WHO) guidelines specify 15 Total Colour Units (TCU) as the acceptable level of colour in water. The WHO guidelines are based on acceptance of the fact that at 15 TCU no colour is detected visually and therefore consumers' acceptance is expected. Table 2.3 shows different colour problems encountered in water and their possible causes.

Table 2.3: Colour problems and causes

Colour	Possible Cause
Milky	Precipitation of carbonates, excess air, Suspended solids
Blackish tint	Reaction with manganese and possibly iron
Yellowish tint	Presence of humic compounds
Reddish tint	Presence of dissolved precipitated iron

2.3.2 Temperature

The temperature of water is important in terms of its intended use, its treatment and its transport. Water temperature affects other water properties for example chemical reactions, solubility of gases and solids, amplification of taste and odours. Water temperature is important especially when designing water structures and pipes (Tebbutt, 2003)

Water temperature also depends on the source of water. Groundwater temperature will vary depending on the depth and the characteristics of the aquifer from which the water is drawn (Linsley, 1979)

Surface waters are subject to great temperature variations. Temperature increments in water tends to affect the solubility of oxygen in water, the rate of bacterial activity, and the rate at which gases are transferred to and from the water. (Spellman, 2003)

2.3.3 Taste and Odour

Water with a bad taste and odour, is not attractive to consumers as the consumers automatically associate the water with contamination. Tastes and odours in water are mainly due to the presence of a variety of substances for example algae growth which secretes an oily substance that may produce taste and odour, phenols and chlorophenols, or metals and salts from the soil. Some odours are indicative of increased biological activity in water. When water has a taste but not accompanying odour, the cause is usually inorganic contamination. Water that tastes bitter is usually alkaline, while salty water is commonly the result of metallic salts. (Tebbutt, 2003)

When water has both taste and odour, the likely cause is organic materials. Tastes and odour producing liquids and gases in water are produced by biological decomposition of organics e.g. hydrogen sulphide. When certain substances combine, such as organics and chlorine, the effect is taste and odour (Spellman, 2003)

Taste and odour can be neutralized by oxidizing the materials that cause the problem. Oxidants such as potassium permanganate and chlorine are used. Another method is to feed powdered activated carbon before the filter. The activated carbon has numerous small openings that absorb the components that cause the odour and tastes. These contained spaces must then be positively vented to wet chemical scrubbers to prevent the build-up of toxic concentrations of gas. (Spellman, 2003)

The KS and WHO guidelines specify that the taste and odour of water should should not be offensive to consumers. Table 2.4 and table 2.5 below, list various odour and taste problems respectively and their likely causes

Table 2.4: Odour Problems and Causes

Odour	Possible Cause
Oily smell	Gasoline or oil contamination or persistent bacteria
Rotten egg odour	Hydrogen sulphide
Methane gas	Organic decomposition or presence of gas in aquifer
Phenolic	Industrial or gasoline contamination
Chemical	Organic chemicals

(L. Leonard, 1973)

Table 2.5: Taste Problems and Causes

Taste	Possible Cause
Alkali Taste	High hardness, total dissolved solids, high alkalinity
Metallic taste	Low pH, high metal content, corrosive water, presence of iron

(L. Leonard, 1973)

2.3.4 Turbidity

Turbidity is defined as the dispersion and interference of light passage due to the presence of suspended organic matter like silt, clay and other finely divided organic or inorganic particles in water. Both the size and surface characteristics of the suspended material influence absorption and scattering. Most turbidity is related to the smaller inorganic components of the suspended solids burden, primarily the clay particles, microorganisms and vegetable material. The colloidal material associated with turbidity provides absorption sites for microorganisms and chemicals that may be harmful or cause undesirable tastes and odours. Moreover, the adsorptive characteristics many colloids work to provide protection sites for microorganisms impending, the disinfection process. (Spellman, 2003)

The degree of turbidity of water is often taken to be an approximate measure of the extent of pollution. However it is not the only measure when determining presence or absence of pollution. This is because water may be clear but is contaminated by acids, toxic metals or other substances that do not cause turbidity. Following rainfall, variation in colour of water may indicate contamination due to surface runoff and may lead to the need of treatment prior to use especially for public supplies. (Spellman, 2003)

The KS and WHO guidelines value for turbidity is 5 FTU and above this value water can be objected for aesthetic value. Turbidity above 5 NTU may be discernible to consumers.

2.4 Biological Characteristics

Water may serve as a medium in which thousands of biological species spend part, if not all of their life cycles. All members of the biological community constitute water quality parameters. This is because their presence or absence may indicate in general terms the characteristics of a given body of water. Pathogens are of primary importance to water specialists. Pathogens are organisms that are capable of infecting or transmitting diseases in humans and animals. These organisms are not native to aquatic systems and usually require an animal host for growth and reproduction. They can however, be transported by natural water systems. These water borne pathogens include species of bacteria, viruses, protozoa, and parasitic worms (Spellman, 2003)

2.4.1 Bacteria

Bacteria are single celled microscopic organisms that multiply by binary fission. In order to multiply they need carbon dioxide if they are autotrophs or organic compounds if they are heterotrophs. Their energy comes either from sunlight if they are photosynthetic or from chemical reaction if they are chemosynthetic. Bacteria are present in air, water, earth, rotting vegetation, and the intestines of animals (Spellman, 2003)

Human and animal wastes are the primary sources of bacteria in water. These sources of bacterial contamination include runoff from feedlots, pastures, and other lands where animal wastes are deposited. Additional sources include seepage or discharge from septic tanks and sewage treatment facilities. Bacteria from these sources can enter wells that are either open at the land surface or do not have watertight casings or caps. (Spellman, 2003)

2.4.2 Protozoa

Protozoa are mobile, single-celled, complete self-contained organisms that can be free living or parasitic, pathogenic, or microscopic, or macroscopic. They are highly adaptable and widely distributed in natural waters, although only a few are parasitic. Most protozoa are harmless, only a few cause illness in human beings e.g. Entamoeba histolytica (amebiasis) and Giardia lamblia (giardiasis). (Spellman, 2003)

2.4.3 Viruses

Viruses are obligate parasites that require a host in which to live. They are the smallest biological structures known, and can only be seen by use of an electron microscope. Waterborne viral infections are usually indicated by disorders in the nervous system rather than of gastrointestinal tract. Viruses that are excreted by human beings may become a major health hazard to public health. Waterborne viral pathogens are known to cause poliomyelitis and infectious hepatitis. Testing for viruses in water is difficult because:

- They are small and low concentrations in natural waters
- They are of numerous varieties and unstable

- There are limited identification methods available

2.4.4 Worms

Worms are the normal inhabitants in organic mud and organic slime. They have aerobic requirements, but can metabolize solid organic matter not readily degraded by other microorganisms. Water contamination may result from human and animal wastes that contain worms. Worms pose hazards primarily to those persons who come into contact with untreated water. (Spellman, 2003)

2.4.5 Indicator Organisms

Indicator organisms are used as indicators of bacteriological water quality due to the technical and economic difficulty in isolating and identifying each pathogens relative to other microorganisms in water can also be very small, and thus, requiring a large sample volume. An ideal indicator should meet the following general criteria:

- Be easily detected by simple, inexpensive laboratory tests in the shortest time with accurate results
- Respond to natural environmental conditions and to treatment processes in a manner similar to the pathogens of interest
- Be present when the pathogenic organism is present and absent in clean, uncontaminated water
- Be present in faecal matter in large numbers
- Have a high indicator/pathogen ratio
- Be stable and non-pathogenic
- Be suitable for all types of drinking water (Cohn R, 2004)

Examples of indicator organisms include

2.4.5.1Total Coliform

Total coliforms are a group of closely related bacteria. They are defined as aerobic and facultatively anaerobic, gram negative, non-spore forming, and rod-shaped bacteria. Examples of the total coliform group include most species of the genera Citrobacter, Enterobacter, Klebsiella, and Escherichia coli and some species of Serratia and other genera. (Cohn R, 2006)

Total coliforms are used to access water treatment effectiveness and the integrity of the distribution system. They are also used as a screening test for recent faecal contamination. Shortcomings to using total coliforms as a useful indicator of the microbial quality of drinking water include:

- They are only marginally adequate for predicting the potential presence of pathogenic protozoan cysts/oocysts and some viruses, because total coliforms are less resistant to disinfection than these other organisms.
- They may proliferate in the bio-films of water distribution systems, clouding their uses as an indicator of external contamination.
- Coliforms are also often not of faecal origin (Cohn R, 2004)

2.4.5.2 Faecal Coliforms and E.coli

Faecal coliforms are a subset of the total coliform group while E.coli are the major subset of the faecal coliform group. They are distinguished in the laboratory by their ability to grow at elevated temperatures (44.5°C) and their ability to produce the enzyme glucuronidase. Under the total coliform rule, all total coliform positive samples must be tested for either faecal coliforms or E.coli (Cohn R, 2004)

Both faecal coliforms and E.coli are better indicators for the presence of recent faecal contamination than total coliforms. However, they do not distinguish between human and animal contamination. Their densities are also much lower than those for total coliforms, and thus are not used as an indicator for treatment effectiveness and post-treatment contamination. E.coli are also a more specific indicator of faecal contamination than is the faecal coliform group. (Cohn R, 2004)

CHAPTER 3: METHODOLOGY

3.1 Introduction

The main objective of the project is to assess water quality for domestic use within Ongata Rongai from the various water resources used within the region and thereafter make necessary recommendations as concerns the water resources within Ongata Rongai area. From the set objectives, the study approach employed so as to achieve the set objectives involves the following four mainstream stages, namely:

- Reconnaissance stage.
- Feasibility studies stage.
- Fieldwork stage.
- Challenges faced.

The specifics of each of the mainstream stages are outlined below:

3.2 Reconnaissance Stage

Field visits were made to the study area. Initial trips were purposefully made for reconnaissance purposes. Reconnaissance/planning involved the following activities:

- *Statement of the project objectives*: the objectives of this study were defined. The objectives of this study have been given in the literature review section.
- *Identification of parameters*: Parameters to be studied were identified during this stage. These parameters include: chemical analysis i.e. pH, alkalinity, chloride, iron, conductivity, fluoride, hardness, nitrates, physical characteristics i.e. colour, temperature, taste and odour, turbidity, and biological characteristics i.e. bacteria, worms, indicator organisms.
- *Acquisition of topographical m*aps: topographical maps to be used to provide prior information with regards to the possible location of the various water resources and the relief of the study area, etc.
- A *general survey of the study area*: this survey was accomplished and was of great importance especially in familiarization with the study area well. Information gathered during this survey was of help during the planning on how the fieldwork was to be conducted, for example, the order in which the sampling process was conducted.
- *Familiarization with the authorities*: at this stage, several authorities and organizations e.g. local/community water providers, councils, water authorities etc., were contacted,

and a notification of the study to be undertaken was given prior. These authorities and organizations were of great relevance especially during data collection in a bid to achieve the comprehensive objectives stated in chapter two of this report.

- *Determination of equipment needed*: all equipment which were to be used for this study were identified and arrangements for easy access were put in place. Some of this equipment included the hand-held Global Positioning Service (GPS) receiver, thermometer and sampling containers.

Table 3.0: A schematic representation of the institutional framework for the water sector under the Water Act 2002

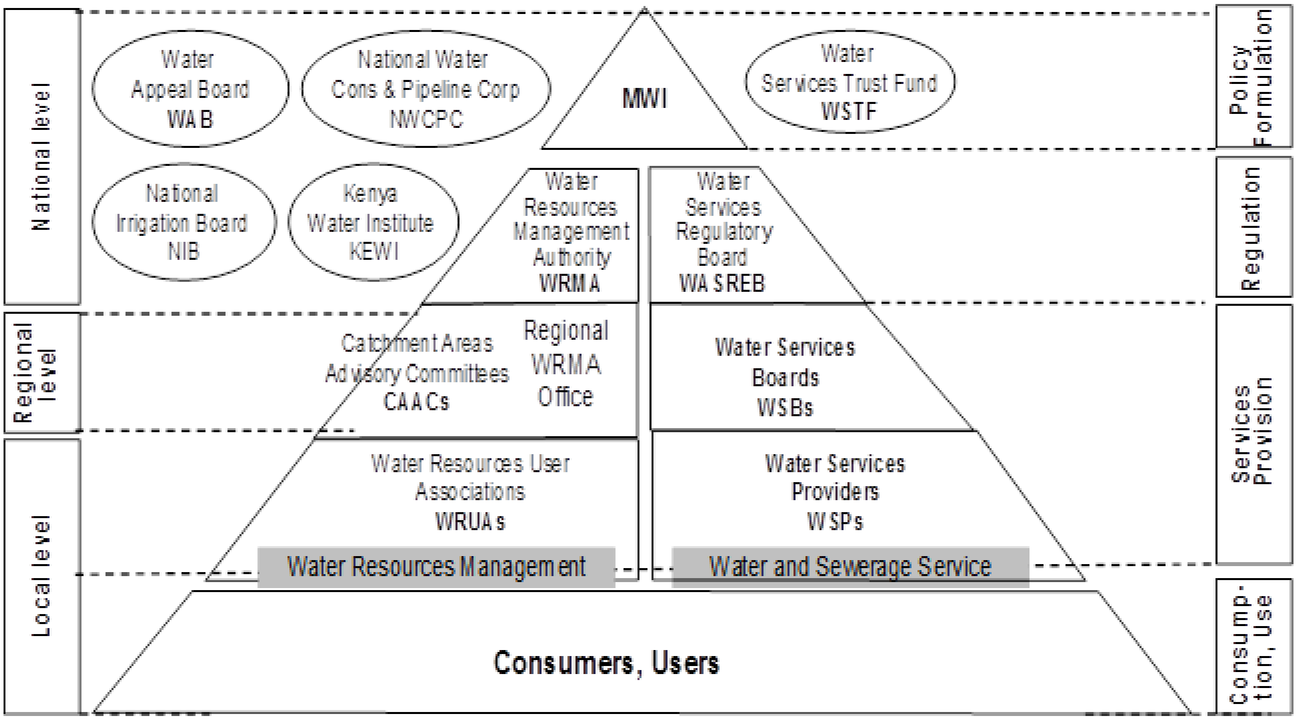

Table 3.1: The roles and responsibilities of these institutions:-

Institution		**Roles and responsibilities**
1.	Ministry of Water and Irrigation (MWI)	• Development of legislation, policy and strategy formulation, sector coordination and guidance,

		and monitoring and evaluation • Overall sector investments planning and resource mobilization
2.	Water Services Regulatory Board (WASREB)	• Regulation and monitoring of service provision (Water Services Boards and Providers) • Issuing of licenses to Water Services Boards • Setting standards for provision of water services • Developing guidelines (water tariffs etc.)
3.	Water Services Boards (WSBs)	• Efficient and economical provision of water services • Developing water and sewer facilities, investment planning and implementation • Rehabilitation and replacement of infrastructure • Applying regulations on water services and tariffs • Procuring and leasing water and sewerage facilities • Contracting Water Service Providers (WSPs)
4.	Water Service Providers (WSPs)	• Provision of water and sanitation services, ensuring good customer relation and sensitization, adequate maintenance of assets and reaching a performance level set by regulation
5.	Water Services Trust Fund (WSTF)	• Financing provision of water and sanitation to disadvantaged groups (pro-poor) as water poverty fund

6.	The Water Appeals Board (WAB)	• Arbitration of water related disputes and conflicts between institutions and organizations
7.	National Water Conservation and Pipeline Corporation (NWCPC)	• Construction of dams and drilling of boreholes
8.	Kenya Water Institute (KEWI)	• Training and research

3.3 Feasibility Studies Stage

Feasibility studies involved the following activities:

- *Determination of the resource requirements*: the actual financial costs to be incurred during this study were calculated. Other resources such as time required to undertake this study, costs of extra equipment, etc. were also estimated.

- *Risk assessment*: all risks, such as accidents, conflict with locals etc., that could arise as a result of conducting a study in this area were identified and assessed. All the necessary and prior mitigation and control measures were evaluated and subsequently adopted.

- *Design of the data collection techniques*: data collection sheets were prepared and a camera was acquired. The methodology for the testing of samples; and the schedule for data collection was designed at this stage.

3.4 Fieldwork Stage

Actual field operations, involving data collection and sampling, began on the 31st of January 2014. Sampling processes were done as per the rules stated in “Standard Methods for the Examination of Waters and Wastewaters” and the “Water Quality Sampling Manual”. (Appendix A). Samples from boreholes, dam, stored rain water and a river flowing through Ongata Rongai Area were taken in two-litre plastic containers, packed and then transported to the Laboratory for testing. On-site data like: the exact water resource location, weather conditions at the time of sampling, the type of soil, presence of possible sources of pollution and indicators of contamination or pollution were recorded. Some on-site data obtained from this study are given in appendix C. Laboratory tests were undertaken as specified in "Standard Methods for the Examination of Waters and Wastewaters". A brief description and detailed account of the actual laboratory tests undertaken are given in appendix B. Parameters tested in the laboratory included the following: pH, fluoride, conductivity, chloride, iron, total hardness, calcium hardness, total alkalinity, total dissolved and suspended solids, dissolved oxygen and the bacteriological parameters. Some raw, unanalyzed laboratory tests results are attached in appendix D. Actual field operations, involving data collection and sampling processes were done at this stage. Care was taken to ensure the samples were truly representative of the existing conditions and handled in such a way that no contamination occurred before testing. Testing was conducted at the University of Nairobi Environmental Health Engineering laboratory and also at the Kiserian Dam & water supply testing laboratory. The water samples collected were tested using standard methods for examination of water

The following precautions were considered when handling the samples:

- Before filling the sample bottle, it was be rinsed at least twice with the water being collected.
- Each sample was treated individually with regard to the substances to be determined and other conditions that may influence the results. A record of every sample collected has been kept and well labelled.
- Enough quantity of water was collected to ensure it's enough for all the tests to be carried out.
- Minimum time interval between collection and analysis was maintained so as to ensure the results obtained are reliable. All samples that had to wait for testing were refrigerated.

3.5 Challenges experienced

Several limitations were encountered during this study. They include the following:

- Some borehole operators refused access to the sample collection points.
- There were insufficient records of the initial water quality from the WRMA's records which would be used as a basis for assessment.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The objective of the project was to assess the water quality from various resources within Ongata Rongai and hence determine whether or not the water is suitable to be employed and put into use for various domestic uses. Following the set objectives, sampling of water from various resources was conducted and laboratory examinations were conducted and thereafter result obtained for assessment. Key parameters were investigated to assist in drawing accurate conclusions and thus make relevant recommendations.

4.2 Analysis of Results

The quality of water from the various resources was assessed in terms of its physical, chemical and bacteriological characteristics. These were determined using standard methods of laboratory examinations as prescribed in Standard Methods for the Examination of Water and Wastewater (see Appendix B). The following parameters were assessed:

Table 4.0: Parameters assessed.

Physical	Chemical	Biological
Turbidity, Colour, Total Dissolved Solids, Total Suspended Solids.	pH, Electrical conductivity, iron, Total Hardness, Calcium Hardness, Total Alkalinity, Chlorides, Fluorides, Nitrates, Dissolved Oxygen.	Total Coliform Count, E.Coli Count

Analysis of the results entailed the consideration of the historical values from previous investigations and the quality requirement for the intended beneficial use as specified by the WHO Standards and also the KBS (KS-1:2007) Standards. From the field investigations carried out, it was ascertained that most of the water used for domestic use comes from boreholes and thus more emphasis on boreholes was prioritized. Rain water collected and also river water are equally employed for domestic use at a lower scale as compared to borehole water.

The historical values obtained from initial tests conducted from the various boreholes, did not include the boreholes that were sampled. As a result, it was not possible to do a parallel comparison using the available values.

4.2.1 Chemical Characteristics

Testing was done in order to determine and establish the levels of chemical constituents occurring naturally in water or foreign constituents that may have been introduced through acts of pollution.

4.2.1.1 pH Value

pH in water indicates its acidity or alkalinity. From laboratory tests conducted, pH values were determined to range from a minimum of 5.99 to a maximum of 9.20 with a mean of 7.53. The historical values of the available data range from 6.4 – 8.17 (Appendix E). Figure 4-0 illustrates the variation of determined pH values from the 16 different sampled points.

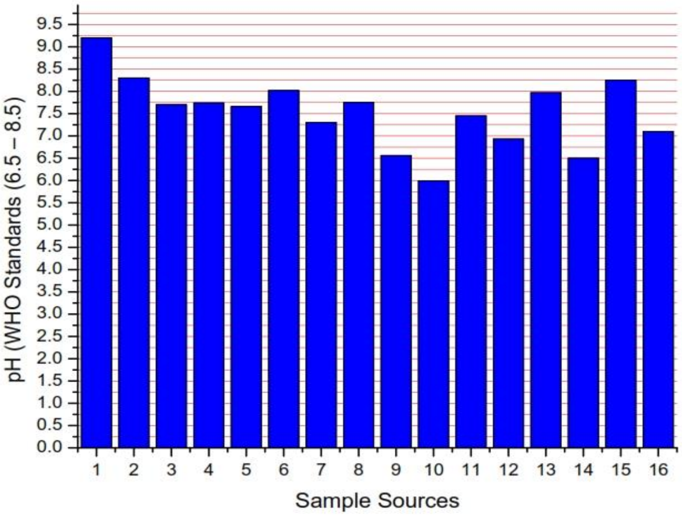

Figure 1: **pH variation over the different sampled points**

The values indicate minimal variation; with 12 sampled points recording a pH of above 7 thus it can be inferred that water from these points is alkaline in nature. The sample which recorded the lowest pH value of 5.99 was from collected from rain water. This indicates slightly acidic, which is brought about by presence of mineral acids, free carbon dioxide, sulphates or nitrogen oxides. As for the changing and rising pH values of samples collected from boreholes, this could have been caused as a result of water percolating through limestone in the rock stratum and more ions dissolving in the water with time.

4.2.1.2 Total Alkalinity

Total Alkalinity values determined from the laboratory ranged from a minimum of 40 mg/L to a maximum of 401 mg/L; with a mean value of 216 mg/L. The historical data available had values ranging from a minimum value of 8 mg/L to 340 mg/L. (Appendix E). Figure 4-1 illustrates the variation of determined total alkalinity values from the 16 different sampled points.

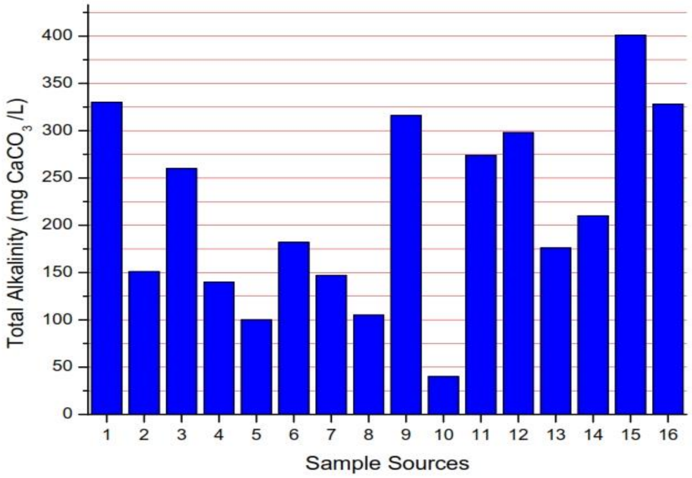

Figure 2: **Total Alkalinity variations over the different sampled points**

Alkalinity is a function of bicarbonate, carbonate and hydroxyl ions which have dissolved from chemical compounds from rocks and soils. Out of all the samples collected, sample 1 and 2 had bicarbonate alkalinity. This is further confirmed in their pH values which are above 8.3. Sample 7, which was from collected rain water had the lowest value of 40 mg/L while sample 15 which was collected from a borehole had the highest value of 401 mg/L. Alkalinity in water has no health significance but high levels makes water unpalatable and may affect the efficiency of certain water treatment processes such coagulation where treatment is needed. According to the set standards, all the tested samples fall within range and satisfy alkalinity requirements.

4.2.1.3 Chlorides

Chloride level fluctuated between 27 mg/L and 289 mg/L; with an average value of 138mg/L. The upper value is above the maximum value recommended by WHO Standards of 250 mg/L. From the past information available, the chloride values ranged between 0 mg/L to 145 mg/L. (Appendix E). Figure 4-2, illustrates the variation of the determined chloride levels from the different sampled water

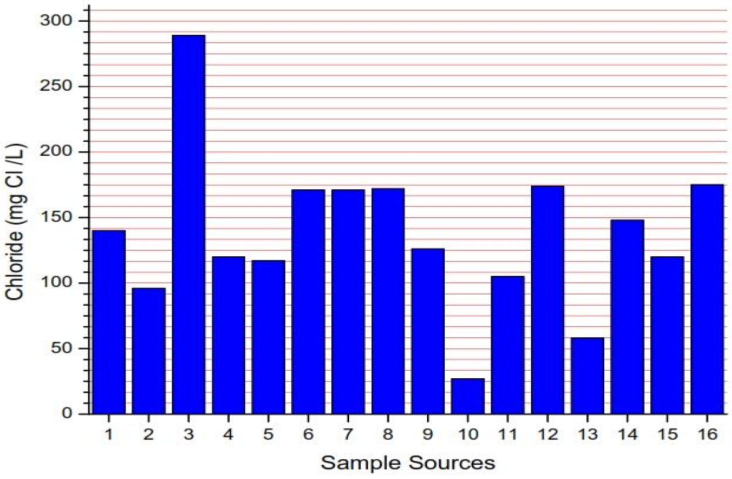

Figure 3: **Chloride levels obtained from the sampled water**

Sample 3 had the highest levels of Chlorides present of 289mg/L while sample 10 recorded the lowest value of 27 mg/L. These samples were collected from a borehole and rain water tank respectively. Chlorides in groundwater result from leaching of chlorides from rocks and soils and are associated with sodium in drinking water. The levels of chlorides as displayed on the chart fall within acceptable limits as guided by the WHO Standards and the KS-1:2007.

4.2.1.4 Iron

The levels of Iron in the sampled water varied from a minimum of 0.05 mg/L to a maximum of 1.6 mg/L. The mean Iron level was calculated as 0.356 mg/L. Using the past information gathered, Iron present in the sampled water as at then varied from a minimum of 0.01 mg/L to a maximum of 1.6 mg/L. (Appendix E). Figure 4-3 illustrates well the variation of the Iron levels in the different 16 sampled points.

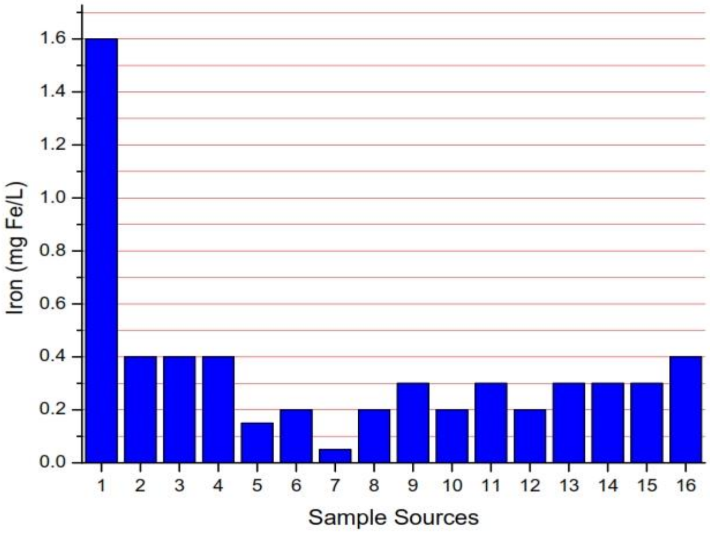

Figure 4: **Iron levels on the sampled waters**

Sample point 7 which recorded the lowest value of Iron present, i. e 0.05 mg/L was collected from treated water in one of the treatment plants in Ongata Rongai, while sample 1, which recorded the highest value of 1.6 mg/L, was collected from a borehole. This was more than the value given as a guideline from WHO Standards of 0.3 mg/L. Excess Iron in water gives it an unpleasant metallic taste, affects the colour to brownish which makes the water less attractive to consumers, and also lowers the pH, making the water corrosive to distribution pipes. According to the total sampled points, 31.25% samples have Iron levels higher than the recommended value from KS and WHO Standards.

4.2.1.5 Electrical Conductivity

Electrical Conductivity in the sampled water varied from 23µS/Cm to 825µS/Cm. The mean conductivity of the samples was 474µS/Cm. The historical study that had been conducted had values ranging from 25.9µS/Cm to 1191µS/Cm. (Appendix E). Figure 4-4 illustrates the variation of the determined Electrical Conductivity values from the different sample points.

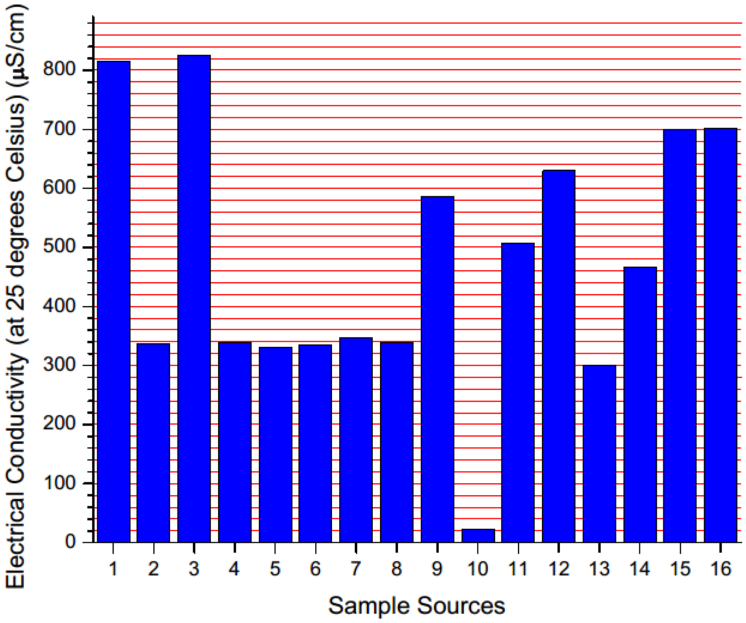

Figure 5: **Electrical Conductivity values obtained**

Pure water is a poor conductor of electricity. Conductivity is dependent upon the presence of ions and thus an indicator of TDS in water. As the concentration of dissolved salts, usually salts of sodium, calcium and magnesium, bicarbonate, chloride and sulphate, increases in water, electrical conductivity increases. Electrical Conductivity also relates to salinity of water, and this was confirmed from samples 1, 2, 15 and 16 which had a saline taste. The guidelines given in WHO Standards is a maximum of 2500 µS/Cm, thus all the tested sampled were within range.

4.2.1.6 Fluorides

Fluorides ranged from a minimum value of 0.25 mg/L to a maximum value of 1.85 mg/L. The mean fluoride level was calculated as 1.17 mg/L. Using the historical values obtained from the past study, the fluorides values ranged from a minimum of 0.23 mg/L to a maximum of 6.78 mg/L.(Appendix E). Figure 4-5 illustrates the fluoride levels in water from the different sample points.

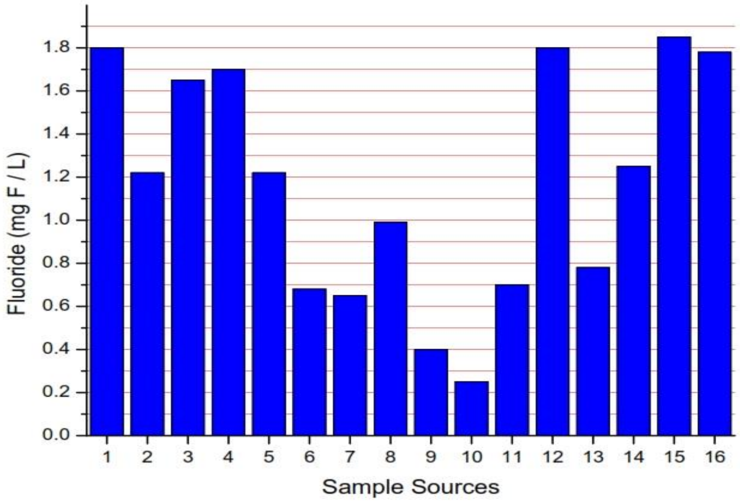

Figure 6: **Fluoride levels in water sampled from the different points**

A total of 6 out of the 16 sampled points had levels of fluorides higher than the recommended value in the KS and the WHO Standards of 1.5 mg/L. The high levels of fluorides make water unsafe for drinking. Issues of teeth discolouration and dental fluorosis may arise to people who consume the water regularly without any form of management measures applied to the water. Fluoride, a natural element, exists in combination with other elements as fluoride compound and is found as a constituent of minerals in rocks and soil. When the water passes through and over soil and rock formations containing fluoride it dissolves these compounds, resulting in the small amounts of soluble fluoride present in water. This explains the reason as to why most of the water collected from boreholes had high levels of fluorides.

4.2.1.7 Total Hardness

Total hardness ranged from a minimum of 29 mg/L to a maximum of 352 mg/L, expressed in terms of calcium carbonate. The mean total hardness of the sampled water was found to be 175 mg/L. From the past study that had been conducted, the Total Hardness values ranged between 4mg/L and 290 mg/L (Appendix E). Figure 4-6 illustrates the variation of determined Total Hardness values from the different sample points.

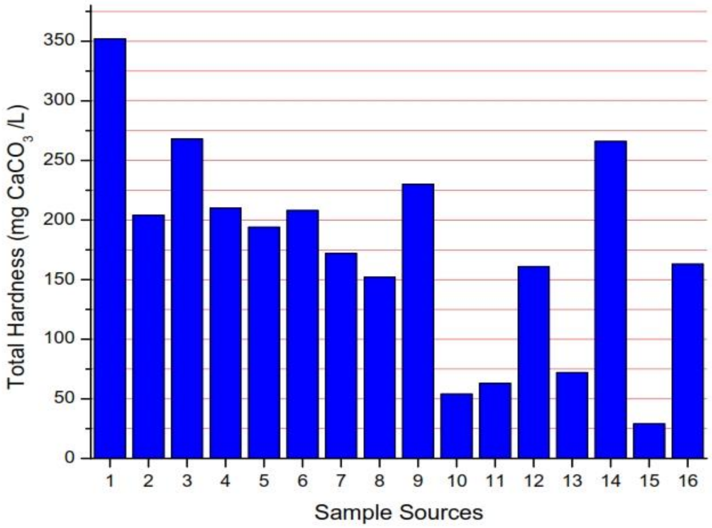

Figure 7: **Total Hardness values obtained from the different water samples**

Hardness is the soap consuming capacity of water; that is, the more soap required to produce lather, the harder the water. From the determined values it can be inferred that the sampled water was generally soft as there was only one sample which surpassed advised value of 300 mg/L in the KS Standards. This was sample 1 which recorded a value of 352 mg/L.

4.2.1.8 Calcium Hardness

Calcium hardness ranged from a minimum value of 6 mg/L to a maximum value of 178 mg/L expressed in terms of calcium carbonate. The mean Calcium hardness of the sampled water was calculated to be 74 mg/L. Figure 4-7 illustrates the variation of determined Calcium Hardness values from the different sample points.

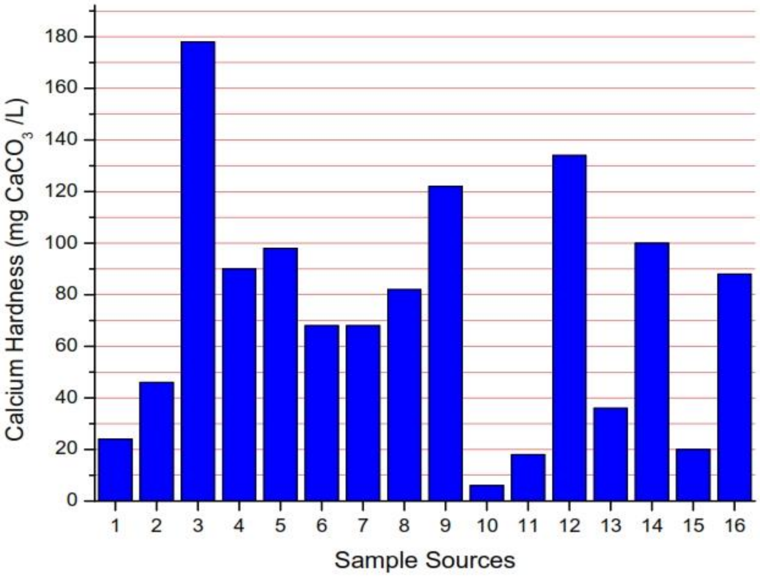

Figure 8: **Calcium Hardness values obtained from the different water samples**

Sample 10 which was collected from rain water tank, recorded the lowest the lowest value of Calcium Hardness. This means that it formed lather easily when used for various domestic uses. Water collected from sample point 3, recorded the highest level of Calcium Hardness. Generally, all the samples recorded values within the advised WHO Standard value of 500 mg/L.

4.2.1.9 Nitrates

Nitrate level determined from the various sample points ranged from a minimum value of 1 mg/L to a maximum value of 8 mg/L. This was well within the Standards advised by WHO and KS standards. From the past studies conducted within the Ongata Rongai indicated values which ranged between a minimum value of 0.56 mg/L and a maximum value of 7.05 mg/L. (Appendix E). Figure 4-8 illustrates the Nitrate levels in the water sampled from the various sample points.

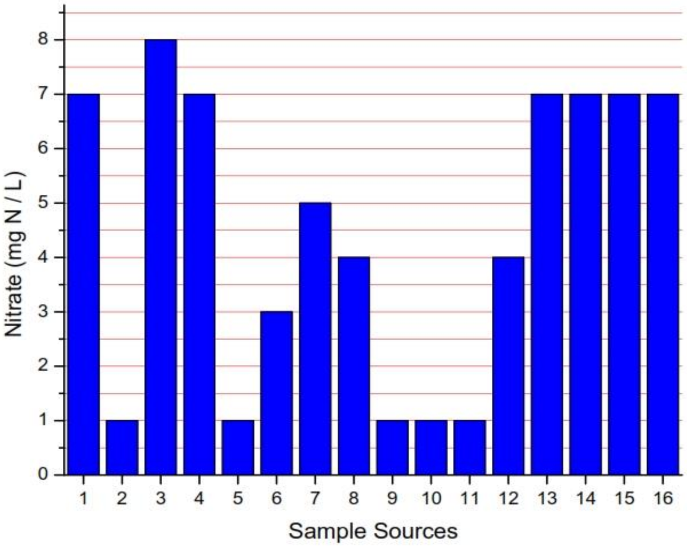

Figure 9: **Nitrate levels in the different water samples tested**

High Nitrate levels may indicate pollution from fertilizers, feedlots or sewage. This applies to water collected from boreholes. Nitrate in water interfers with the body’s capacity to absorb oxygen. However, the concentration of Nitrates in the sampled water was found to be within the acceptable limits of a Maximum value of 10, as specified by the KS and WHO Standards.

4.2.2 Physical Characteristics

These parameters of water quality are important because they affect the acceptability of the water to consumers. These key parameters affect the appearance and taste of the water.

4.2.2.1 Colour

The Colour obtained from the water analysis tests ranged from a minimum value of 5 Hazens to a maximum value of 50 Hazens. From previous studies that had been conducted in the area, the Colour values ranged between 5 Degrees Hazen and 60 Degrees Hazen. The variations in Colour are as illustrated in figure 4-9.

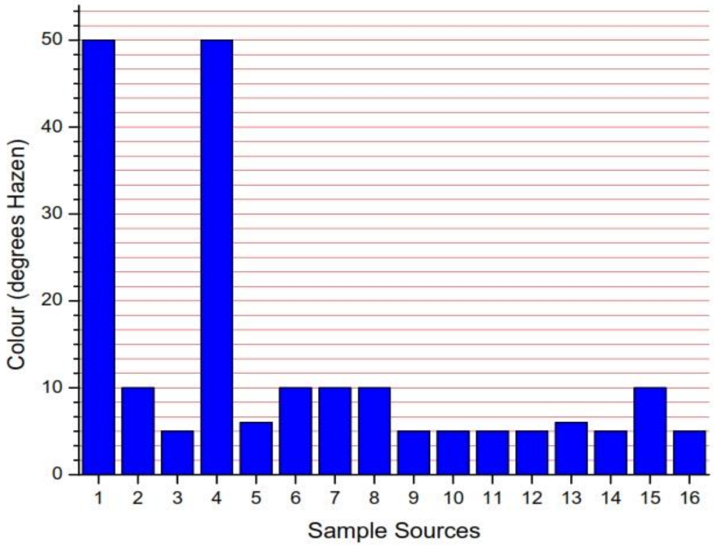

Figure 10: **Colour variations in the water sampled**

The sampled points 1 and 4 recorded the highest values of 50 degree hazens. These waters were brownish in colour and it can be concluded that water in these sources were polluted; however colour cannot be used as an indicator of pathogenic or toxic contaminants. A total of 14 samples recorded values within the stated value of a maximum of 15 Degrees Hazens in the WHO and KS Standards.

4.2.2.2 Taste and Odour

Samples from points 4 and 6 were raw water from Mbagathi River and raw water that feeds Kiserian Dam. They had an Odour because of the waste materials and sewage contamination. This was an indication of pollution that had taken place. All the other 14 sampled points had no taste or odour thus fit for various domestic uses. For drinking water, the WHO Standards advise a guideline of ‘Unobjectionable’.

4.2.2.3 Turbidity

The Turbidity values were determined to range from 0.4 NTU to 7.2 NTU as illustrated in figure 4-10. From the previous investigations conducted, the Turbidity ranged between a minimum of 0.4 NTU and a maximum of 47.1 NTU.

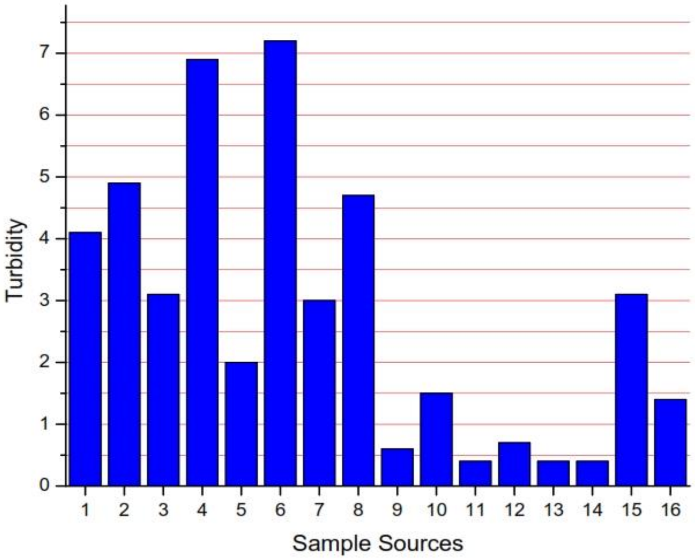

Figure 11: **Turbidity level variations in the different samples tested**

Samples 4 and 6 recorded values of 6.9 and 7.2 respectively which are higher than the recommended value by WHO and KS Standards. The rest of the samples recorded values within the advised range of 5NTU. The high levels of turbidity in sample 4 and 6 indicate presence of increased colloidal material in water whose source could be possibly contaminated from surface run-off or from suspended solids, microorganisms and vegetable material in the ground. A majority of the samples which had Turbidity levels within the advised WHO and KS Standards were clear an indication of little or no suspended materials.

4.2.2.4 Total Dissolved Solids

The TDS values obtained from the tested samples ranged between a minimum value of 8 mg/L and a maximum value of 408 mg/L. The mean TDS of the sampled water was calculated to be 255 mg/L. Figure 4-11 illustrates the variation of the determined values of TDS from the different sample points.

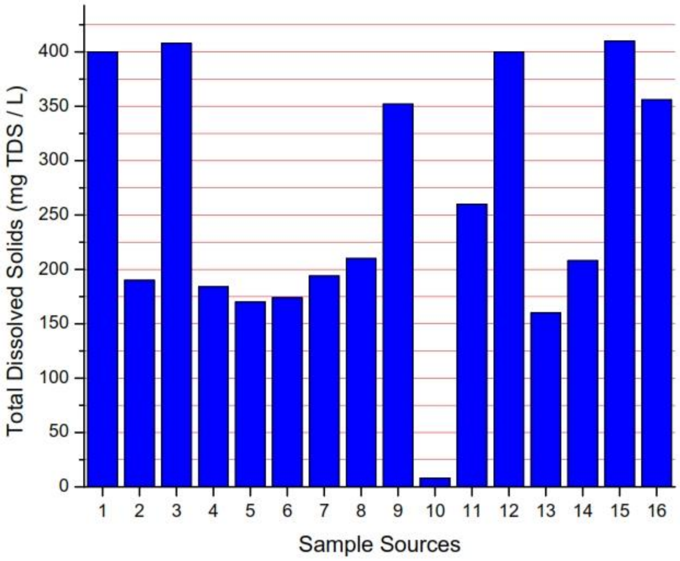

Figure 12: **Total Dissolved Solids in the sampled water**

Total Dissolved Solids (TDS), is the total amount of mobile charged ions including minerals, salts or metals dissolved in a given volume of water. TDS thus includes anything present in water other than the pure water molecules and suspended solids. TDS concentration is thus generally the sum of the cations and anions in water. Some dissolved solids come from organic sources such as leaves, silt and industrial waste and sewage. Other sources come from runoff of fertilizers and pesticides used on farms along some of the sources where sampling was done. Dissolved solids also come from inorganic materials such as rocks and air that may contain calcium bicarbonate, nitrogen, iron phosphorus, sulfur, and other minerals. Sample 10 had the least of the TDS. This was rain water which had not come into contact with the ground surface thus explains the low levels of TDS.

4.2.2.5 Total Suspended Solids

The Total Suspended Solids (TSS) values obtained from the tested samples ranged between a minimum value of 0 mg/L and a maximum value of 45 mg/L. The mean TSS of the sampled water was calculated to be 5 mg/L. Suspended solids are insoluble in water and settle out with enough time. Figure 4-12 illustrates the variation of the determined values of TSS from the different sample points.

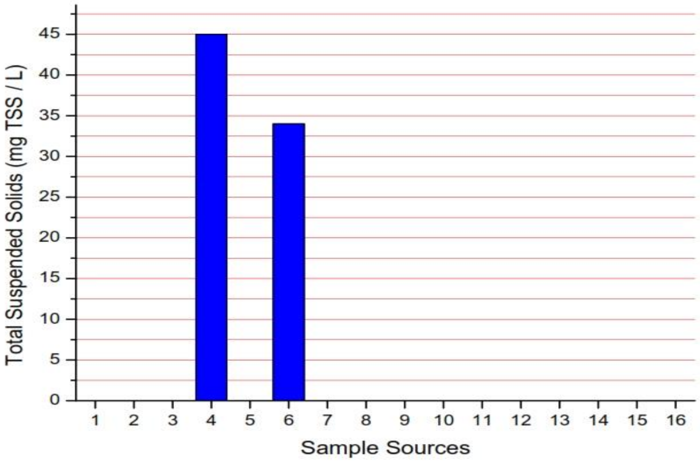

Figure 13: **Total Suspended Solids in the water samples tested**

Total Suspended Solids (TSS) and Turbidity are distinct measurements that provide similar assessment of the water quality. TSS is a measure of the mass of solids found in a volume of water and describes particulates of varied origin, including soils, metals, organic materials and debris that are suspended in water. Only two samples had suspended solids present. These samples were collected from raw water that feeds Kiserian dam and the other sample was collected from Mbagathi River. This was also an indication of pollution present. There is no guideline provided by the WHO and KS Standards. The presence of TSS in water makes it less aesthetically enjoyable.

4.3.3 Biological Characteristics

Microbiological parameters can have an immediate and significant impact on human health and must therefore be analyzed more frequently. For bacteriological tests, coliform tests were used to show the presence of bacteria. Upon confirmation, a faecal coliform test was carried out to check for feacal contamination.

Thus for this study, biological characteristics were determined by carrying out tests on the water samples with a special emphasis on Total Coliforms and E.Coli.

4.3.3.1 Total Coliform Count

Total Coliforms were detected in 2 sample points as shown in the figure 4-13. 14 out of the 16 tested samples had a most probable number index (M.P.N) of zero. According to the KS guidelines, coliforms should not be detected in water.

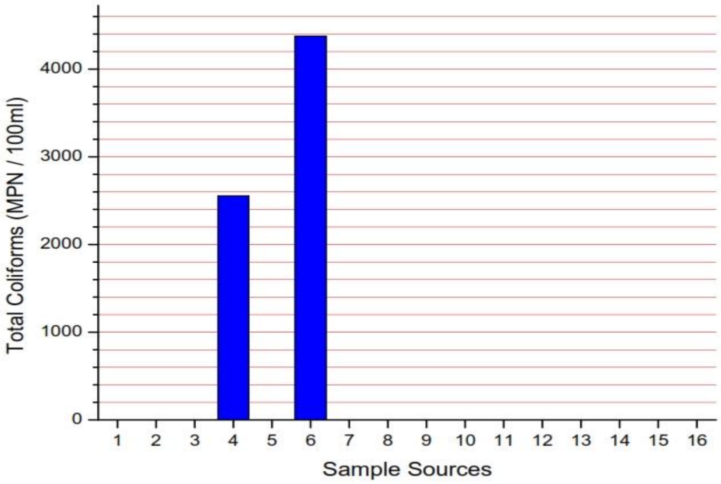

Figure 14: **Determined Total Coliforms counts**

Samples 4 and 6 were collected from raw water in Kiserian dam and water from Mbagathi River. It can thus be concluded that this water was polluted by wastes and sewage. Generally, most of the sampled points tested negative, thus we can conclude that the water is safe for use in various domestic purposes. Some of the reasons that lead to the satisfactory results observed could have been adequate disinfection at the treatment works.

4.3.3.2 E Coli Counts

All total coliform positive samples were tested for both faecal coliforms and E Coli. Two samples from sample points 4 and 6, tested positive for the presence of E Coli as illustrated in figure 4-14.

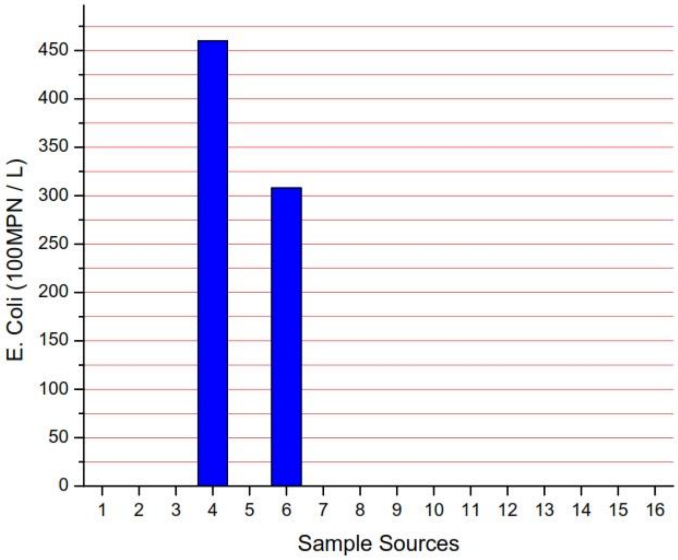

Figure 15: **Determined E. Coli counts**

4.3 Discussion of Results

4.3.1 Biological Characteristics

The presence of Total Coliforms indicates potential presence of pathogenic protozoan cysts and some viruses in the various sources where the samples were picked from. E Coli tests which turned out positive confirmed presence of feacal contamination.

4.3.2 Physical Characteristics

A majority of these characteristics were within safe limits and acceptable levels in terms of colour, turbidity, taste and odour, total dissolved solids and total suspended solids.

Out of all the 16 sampled points, 2 sampled points had slightly higher colour levels. This may have been caused by presence of minerals such as iron or by substances of vegetable origin such as weeds and algae.

Turbidity levels of two sampled point was much higher than the recommended levels. This was because of the suspended solids and colloidal matter present in these samples.

Two samples collected from raw water feeding Kiserian dam and another sample from Mbagathi River had odour. This is associated with presence of living organisms or decaying matter including weeds, algae or wastes containing hydrocarbons or ammonia.

An aesthetic objective of less than 500 mg/L has been established for total dissolved solids (TDS), in drinking water. At higher levels, excessive hardness, unpalability, mineral deposition and corrosion may occur. At low levels, however, TDS contributes to the palatability of water. Sample collected from point 10 had the lowest TDS, thus we can conclude it was the most palatable.

Only two samples out of the sixteen collected had suspended solids. These samples again were collected from raw water; from Mbagathi River and that which feeds Kiserian dam. A high concentration of total solids will make drinking water unpalatable and might have an adverse effect on people who are not used to drinking such water. Total solids also affect the clarity of water, which is the most probable case in samples from points 4 and 6.

4.3.3 Chemical Characteristics

The pH of one sampled point; that is point 1, was above the recommended standards by WHO and the KS. It was too alkaline which may result to formation of precipitates that can foul water system appurtenances.

Iron was found in objectionable quantities in five sampled points. High concentrations of Iron may affect the taste and appearance of water, causes staining of laundry, utensils and glassware, cause plugging of the water pipes and cause the presence of Iron bacteria which feeds on iron in water and form red brown slime which clogs water systems.

40% of the sampled water had Fluoride levels higher than the prescribed guideline value for fluoride in drinking water; which is set at 1.5 mg/L. The high levels cause the browning of teeth. Fluoride in excess of 1.5 mg/L in waters causes ‘mottled enamel’ especially in children’s teeth.

Both total and calcium hardness levels of the sampled water were found to be within the limits advised by WHO Standards and KS-1:2007 limits. This thus means that this sampled water was fit for various domestic uses for example laundry.

Chlorides levels were above normal advised levels in one of the sampled point.

Nitrates, alkalinity and electrical conductivity levels were 100% within the advised and acceptable limits specified by the KS-1:2007.

CHAPTER 5: CONCLUSIONS AND RECCOMMENDATIONS

5.1 Conclusions

In accordance with the set objectives for this project, the quality of water from the various resources within Ongata Rongai was assessed in the laboratory and the results analyzed both on the historical values accessed from WRMA and WASREB databases. The following conclusions can be drawn from this investigation.

1. All the water from the sampled boreholes and rain water tanks was good aesthetically; that is, the water quality was good with reference to aesthetic quality parameters like colour, turbidity, conductivity, total suspended solids and total dissolved solids apart from source point one which was a borehole that was not well maintained thus most of the tested parameters were not within the recommended specifications.
2. It was established that continuous monitoring of the boreholes, was done in 6 out of the 9 sampled boreholes. This was a good sign of good management of the boreholes though some of the records were missing. This is contributed by bad governance and negligence.
3. Water from Kiserian dam was well monitored and some parameters like pH, colour and electrical conductivity were monitored daily so as to ensure before the water is pumped to consumers, all parameters are within the KS-1:2007. This dam supplies a total of 1,228m^3/ day for Ongata Rongai population.
4. For the piped water, it can be concluded that there is no sewage or waste water pollution along the distribution system. Apart from the piped water, all other sources which contained water ready for distribution had no signs to indicate any pollution.

5.2 Recommendations

With current issues of climate change and global warming, the future of water resources depends on how well these resources are managed to ensure there is conservation of quality. The following measures should be taken to ensure sustainable and safe use of the water resources within Ongata Rongai:

1. An efficient, accessible, retrievable and well managed water quality database that incorporates the use of GIS should be developed and maintained. This database may be used to

provide baseline data that may be used to model water quality in Ongata Rongai area. The data system may also help while undertaking studies like change-detection analysis and water quality monitoring.

2. Since the water resources sampled; that is ground water, surface water and rain water, in this area are not highly polluted, watershed and water catchment protection measures should be employed by WRMA and encouraged, to preserve if not improve the quality of the water. This can be done through public awareness.
3. Water Services Regulatory Board (WASREB) should come up with clear-cut and tight measures of ensuring that people who abstract water from boreholes have complied with the standards specified in the Kenya Drinking water quality standards
4. Apart from Oloolaiser Water and Sewerage Company which supplies water to a bigger population in Ongata Rongai, more Water Service Providers (WSPs) should be incorporated into the system. Thereafter there mandate and duties should be laid down more clearly e.g. they should be given the mandate to inspect borehole water, river water along different points on its course and report its findings to higher authorities like the Water Services Regulatory Board (WASREB).
5. There is need to manage the quality of water especially groundwater in terms of reducing fluoride levels where they have exceeded 1.5 mg/L. This is so as to safeguard human health and in such cases, private operators who rely solely on groundwater supply, should defluoridate their water if they desire to supply it for drinking purposes.

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ii. http://www.nema.go.ke/

iii. http://www.epa.gov/safewater/contaminants/index.html

APPENDIX A: SAMPLING PROCEDURES ADOPTED

The rationale for the collection of water samples was undertaken following the guidelines in the following reference texts:

i. Standard Methods for the Examination of Water and Wastewaters, Volume 20, Section. 1060, parts A, B, and C., and Section 3030. Parts A, and B.

ii. Water Quality Sampling Manual, 3rd Edition.

iii. The Essential Handbook of Groundwater Sampling.

iv. Water Quality Assessments-A Guide to Use of Biota, Sediments and Water in Environmental Monitoring, 2nd Edition. Appendix 10.1.

v. Practise Manual for Water Supply Services in Kenya, Section 3.5.

APPENDIX B: LABORATORY TESTS PROCEDURES

The Laboratory tests were performed according to the procedures prescribed in Standard Methods for the Examination of Water and Wastewater under the following sub-sections:

- Alkalinity: 2320 (# 29) 2320. B
- Appearance: 2110 (# 6)
- Chloride: 4500. B
- Colour: 2120 (# 7)
- Conductivity: 2510 (# 35)
- Dissolved Oxygen: 4500-O. C (# 70)
- Fluoride: 4500 F^-C.
- Hardness: 2340 (# 31)
- Iron: 3500 (# 107)
- Nitrate: 4500 (# 60)
- pH: 4500 (# 42)
- Solids: 2540 (# 43)
- Temperature: 2550 (# 49). 2550. B.
- Turbidity: 2130 (# 15) .2130.B.

APPENDIX C: FIELD DATA COLLECTION SHEET

Source Name/Number	
Source location	
Date and time of sampling	
Weather at the time of sampling	
Possible source of pollution in the vicinity	
Temperature of the water	
The mode of Source construction and its covering	
Characteristic changes caused in the water during heavy rains	
Character of the surroundings	
Nature of soil	
Miscellaneous	

Table C1: Field Data Collection Sheet

Source Name/Number: Borehole water	OR/001/14
Source location	37 0251171; UTM 9845671
Date and time of sampling	31st January 2014 at 1030hrs
Weather at the time of sampling	Partially sunny with some cloud cover
Possible source of pollution in the vicinity	Pit latrine within a radius of 40m.
Temperature of the water	27°C
The mode of borehole construction and its covering	Steel cased but not well protected from human interference on the earth's surface.
Character of the surroundings	Borehole is not fenced and exposed to a small swampy area.
Nature of soil	Black cotton soil
Miscellaneous	The borehole water is not sold to the public, i.e. private domestic use.

Table C2: Field Data

Source Name/Number: Piped water	OR/002/14
Source location	37 0247783; UTM 9846979
Date and time of sampling	31st January 2014 at 1039hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	This was piped water from a Hospital
Temperature of the water	25.5°C
Characteristic changes caused in the water during heavy rains	The colour of the water changes during the rainy season
Character of the surroundings	There are other buildings and a good existing piped system.
Miscellaneous	The water is supplied from one of the main water supplying companies in Ongata Rongai.

Table C3: Field Data

Source Name/Number	OR/003/14
Source location	37 0247783; UTM 9846979
Date and time of sampling	31st January 2014 at 1130hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	No possible sources of pollution.
Temperature of the water	26°C
The mode of borehole construction and its covering	Steel cased and also protected from human interference on the earth's surface.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	Construction activities are on-going within a radius of 100m from the borehole
Nature of soil	Black cotton soil
Miscellaneous	The borehole water is sold to the public.

Table C4: Field Data

Source Name/Number: Raw Dam Water	OR/004/14
Source location	37 0249471; UTM 9845394
Date and time of sampling	10th February 2014 at 1014hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	Sewage disposal into the feeding rivers and farming chemicals that may be drained into the flowing rivers.
Temperature of the water	24°C
Characteristic changes caused in the water during heavy rains	Colour changes experienced mostly.
Character of the surroundings	Construction and mining activities are present at a radius of 100m from the reservoir.
Nature of soil	Black cotton soil
Miscellaneous	After treatment, the water is supplied to the public.

Table C5: Field Data

Source Name/Number: Treated Dam Water.	OR/005/14
Source location	36 0249448; UTM 9845224
Date and time of sampling	10th February 2014 at 1020hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	No possible sources of pollution.
Temperature of the water	25°C
The mode of storage tanks construction and its covering	Well-constructed and covered so as to avoid any forms of possible contamination from humans and earth surface.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	Construction and mining activities are present at a radius of 200m from the storage tank.
Nature of soil	Black cotton soil
Miscellaneous	The water is supplied to the public.

Table C6: Field Data

Source Name/Number: Raw River water	OR/006/14
Source location	37 0251993; UTM 9845090
Date and time of sampling	13th February 2014 at 1405hrs
Weather at the time of sampling	Rainy
Possible source of pollution in the vicinity	A private greenhouse upstream
Temperature of the water	24°C
Characteristic changes caused in the water during heavy rains	Colour changes to the water to deep brown.
Character of the surroundings	Residential area
Nature of soil	Black cotton soil
Miscellaneous	The water accessible to use by the public for outdoor domestic activities.

Table C7: Field Data

Source Name/Number: Treated River Water.	OR/007/14
Source location	37 0251993; UTM 9845090
Date and time of sampling	13th February 2014 at 1415hrs
Weather at the time of sampling	Rainy
Possible source of pollution in the vicinity	A private greenhouse operated 100m away from the collection point.
Temperature of the water	28°C
The mode of collecting tank and its covering	The collecting is well covered and elevated to protect the water from human interference.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	Residential area
Nature of soil	Black cotton soil
Miscellaneous	The water is distributed to the public.

Table C8: Field Data

Source Name/Number: Borehole water	OR/008/14
Source location	37 0247783; UTM 9846979
Date and time of sampling	10th February 2014 at 1448hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	A dumping site nearby.
Temperature of the water	26°C
The mode of borehole construction and its covering	Steel cased and also protected from human interference on the earth's surface.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	Residential area and a market centre
Nature of soil	Black cotton soil
Miscellaneous	The borehole water is sold to the public.

Table C9: Field Data

Source Name/Number: Borehole water	OR/009/14
Source location	36 0242821; UTM 9842783
Date and time of sampling	10th February 2014 at 1515hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	No possible sources of pollution
Temperature of the water	26°C
The mode of borehole construction and its covering	Steel cased and also protected from human interference on the earth's surface.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	Office blocks and Residential houses.
Nature of soil	Black cotton soil
Miscellaneous	The borehole water is only for use within the institution.

Table C10: Field Data

Source Name/Number: Rain water	OR/010/14
Source location	37 0251171; UTM 9845671
Date and time of sampling	10th February 2014 at 1145hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	No possible sources of pollution
Temperature of the water	23°C
The mode of collecting area and its covering	Water is collected into a concrete tank and also protected from human interference.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	A churchyard and a school are in the vicinity.
Nature of soil	Black cotton soil
Miscellaneous	The collected water is used within the institution.

Table C11: Field Data

Source Name/Number: Borehole	OR/011/14
Borehole location	37 0249791; UTM 9846004
Date and time of sampling	17th January 2014 at 1228hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	No possible sources of pollution
Temperature of the water	29°C
The mode of borehole construction and its covering	Steel cased but not protected from human interference on the earth's surface.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	There is a market, and a churchyard nearby (about 35 metres from the borehole)
Nature soil	Black cotton soil
Miscellaneous	Constructed in 2005 The borehole water is sold to the public.

Table C12: Field Data

Source Name/Number: Borehole water	OR/012/14
Source location	37 0251171; UTM 9845671
Date and time of sampling	17th February 2009 at 1526hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	No possible source of pollution
Temperature of the water	27°C
The mode of borehole construction and its covering	Steel cased and also protected from human interference on the earth's surface.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	Residential area
Nature soil	Black cotton soil
Miscellaneous	The borehole water is only used within the institution.

Table C13: Field Data

Source Name/Number: Borehole water	OR/013/14
Source location	37 0244685; UTM 9849032
Date and time of sampling	17th February 2014 at 1234hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	A toilet block is 60 metres from the borehole location
Temperature of the water	29°C
The mode of borehole construction and its covering	Steel cased and also protected from human interference on the earth's surface.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	Residential area and a market within the vicinity.
Nature soil	Black cotton soil
Miscellaneous	The borehole water is sold to the public.

Table C14: Field Data

Source Name/Number: Borehole water	OR/014/14

Source location	36 0242821; UTM 9842783
Date and time of sampling	17th February 2014 at 1310hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	No possible sources of pollution
Temperature of the water	25°C
The mode of borehole construction and its covering	Steel cased and also protected from human interference on the earth's surface.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	Office Blocks
Nature soil	Black cotton soil
Miscellaneous	The borehole water is only used within the institution.

Table C15: Field Data

Source Name/Number: Borehole water	OR/015/14

Source location	37 0252220; UTM 9845772
Date and time of sampling	17th February 2014 at 1335hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	No possible sources of pollution
Temperature of the water	27°C
The mode of borehole construction and its covering	Steel cased and also protected from human interference on the earth's surface.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	Residential area
Nature soil	Black cotton soil
Miscellaneous	The borehole water is sold to the public.

Table C16: Field Data

Source Name/Number: Borehole water	OR/016/14
Source location	37 0252214; UTM 9845777

Date and time of sampling	17th February 2014 at 1405hrs
Weather at the time of sampling	Sunny
Possible source of pollution in the vicinity	The borehole area is not fenced thus exposed to human interference and vandalism.
Temperature of the water	28°C
The mode of borehole construction and its covering	Steel cased and also protected from human interference on the earth's surface.
Characteristic changes caused in the water during heavy rains	Not affected by heavy rains
Character of the surroundings	A market centre exists in the vicinity.
Nature soil	Black cotton soil
Miscellaneous	The borehole water is sold to the public.

Table C17: Field Data

APPENDIX D: LABORATORY RESULTS

LABORATORY REPORT

Sample Number: OR/001/14 **Date of Sampling 31st January 2014**

Source: Ongata Rongai **Date Received 05th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	9.2	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	50	Max 15	Max 15
Turbidity	NTU	4.1	Max 5	Max 5
Conductivity (25^oC)	µS/cm	815	Max 2500	-
Iron	mg Fe/L	1.6	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	352	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	24	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	330	Max 500	-
Chloride	mg Cl/L	140	Max 250	Max 250
Fluoride	mg F/L	1.8	Max 1.5	Max 1.5
Nitrate	mg N/L	7.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L			
Dissolved Oxygen	mg O_2/L	9.2	-	-
Total Dissolved Solids	mg TDS/L	400	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D1: Laboratory tests results

<u>LABORATORY REPORT</u>

Sample Number: OR/002/14 **Date of Sampling 31st January 2014**

Source: Ongata Rongai **Date Received 05th February 2014**

Purpose of Sampling: Research/Study Submitted by: Machuma D.O.

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	8.3	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	10	Max 15	Max 15
Turbidity	NTU	4.9	Max 5	Max 5
Conductivity (25^oC)	µS/cm	337	Max 2500	-
Iron	mg Fe/L	0.4	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	204	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	46	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	151	Max 500	-
Chloride	mg Cl/L	96	Max 250	Max 250
Fluoride	mg F/L	1.22	Max 1.5	Max 1.5
Nitrate	mg N/L	1.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	0	-	-
Dissolved Oxygen	mg O_2/L	9.0	-	-
Total Dissolved Solids	mg TDS/L	190	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D2: Laboratory tests results

<u>LABORATORY REPORT</u>

Sample Number: OR/003/14 Date of Sampling 31st January 2014

Source: Ongata Rongai Date Received 05th February 2014

Purpose of Sampling: Research/Study Submitted by: Machuma D.O.

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	7.7	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	5.0	Max 15	Max 15
Turbidity	NTU	3.1	Max 5	Max 5
Conductivity (25°C)	µS/cm	825	Max 2500	-
Iron	mg Fe/L	0.4	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	268	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	178	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	260	Max 500	-
Chloride	mg Cl/L	289	Max 250	Max 250
Fluoride	mg F/L	1.65	Max 1.5	Max 1.5
Nitrate	mg N/L	8.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	0	-	-
Dissolved Oxygen	mg O_2/L	7.8	-	-
Total Dissolved Solids	mg TDS/L	408	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D3: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/004/14 **Date of Sampling 10th February 2014**

Source: Ongata Rongai **Date Received 13th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	7.74	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	50	Max 15	Max 15
Turbidity	NTU	6.9	Max 5	Max 5
Conductivity (25°C)	µS/cm	338	Max 2500	-
Iron	mg Fe/L	0.4	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	210	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	90	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	140	Max 500	-
Chloride	mg Cl/L	120	Max 250	Max 250
Fluoride	mg F/L	1.7	Max 1.5	Max 1.5
Nitrate	mg N/L	7.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	45	-	-
Dissolved Oxygen	mg O_2/L	6.2	-	-
Total Dissolved Solids	mg TDS/L	184	Max 1500	Max 1000
Total Coliforms	MPN/100ml	2553		
E. Coli	MPN/100ml	460		

Table D4: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/005/14 **Date of Sampling 10th February 2014**

Source: Ongata Rongai **Date Received 13th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	7.66	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	6	Max 15	Max 15
Turbidity	NTU	2.0	Max 5	Max 5
Conductivity (25^{o}C)	µS/cm	331	Max 2500	-
Iron	mg Fe/L	0.15	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	194	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	98	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	100	Max 500	-
Chloride	mg Cl/L	117	Max 250	Max 250
Fluoride	mg F/L	1.22	Max 1.5	Max 1.5
Nitrate	mg N/L	1.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	0	-	-
Dissolved Oxygen	mg O_2/L	7.1	-	-
Total Dissolved Solids	mg TDS/L	170	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D5: Laboratory tests results

<u>LABORATORY REPORT</u>

Sample Number: OR/006/14	**Date of Sampling 10th February 2014**
Source: Ongata Rongai	**Date Received 13th February 2014**
Purpose of Sampling: Research/Study	**Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	8.02	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	10	Max 15	Max 15
Turbidity	NTU	7.2	Max 5	Max 5
Conductivity (25^oC)	µS/cm	335	Max 2500	-
Iron	mg Fe/L	0.2	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	208	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	68	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	182	Max 500	-
Chloride	mg Cl/L	171	Max 250	Max 250
Fluoride	mg F/L	0.68	Max 1.5	Max 1.5
Nitrate	mg N/L	3.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	34	-	-
Dissolved Oxygen	mg O_2/L	6.8	-	-
Total Dissolved Solids	mg TDS/L	174	Max 1500	Max 1000
Total Coliforms	MPN/100ml	4376		
E. Coli	MPN/100ml	308		

Table D6: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/007/14 **Date of Sampling 10th February 2014**

Source: Ongata Rongai **Date Received 13th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	7.30	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	10	Max 15	Max 15
Turbidity	NTU	3.0	Max 5	Max 5
Conductivity (25°C)	µS/cm	347	Max 2500	-
Iron	mg Fe/L	0.05	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	172	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	68	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	147	Max 500	-
Chloride	mg Cl/L	171	Max 250	Max 250
Fluoride	mg F/L	0.65	Max 1.5	Max 1.5
Nitrate	mg N/L	5.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L		-	-
Dissolved Oxygen	mg O_2/L	7.3	-	-
Total Dissolved Solids	mg TDS/L	194	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D7: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/008/14	**Date of Sampling 17th February 2014**
Source: Ongata Rongai	**Date Received 19th February 2014**
Purpose of Sampling: Research/Study	**Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	7.75	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	10	Max 15	Max 15
Turbidity	NTU	4.7	Max 5	Max 5
Conductivity (25°C)	µS/cm	339	Max 2500	-
Iron	mg Fe/L	0.2	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	152	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	82	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	105	Max 500	-
Chloride	mg Cl/L	172	Max 250	Max 250
Fluoride	mg F/L	0.99	Max 1.5	Max 1.5
Nitrate	mg N/L	4.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L		-	-
Dissolved Oxygen	mg O_2/L	7.3	-	-
Total Dissolved Solids	mg TDS/L	210	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D8: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/009/14 **Date of Sampling 17th February 2014**

Source: Ongata Rongai **Date Received 19th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	6.56	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	5	Max 15	Max 15
Turbidity	NTU	0.6	Max 5	Max 5
Conductivity (25°C)	µS/cm	586	Max 2500	-
Iron	mg Fe/L	0.3	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	230	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	122	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	316	Max 500	-
Chloride	mg Cl/L	126	Max 250	Max 250
Fluoride	mg F/L	0.4	Max 1.5	Max 1.5
Nitrate	mg N/L	1.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L		-	-
Dissolved Oxygen	mg O_2/L	7.6	-	-
Total Dissolved Solids	mg TDS/L	352	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D9: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/010/14 **Date of Sampling 17th February 2014**

Source: Ongata Rongai **Date Received 19th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	5.99	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	5.0	Max 15	Max 15
Turbidity	NTU	1.5	Max 5	Max 5
Conductivity (25°C)	µS/cm	23	Max 2500	-
Iron	mg Fe/L	0.2	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	54	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	6	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	40	Max 500	-
Chloride	mg Cl/L	27	Max 250	Max 250
Fluoride	mg F/L	0.25	Max 1.5	Max 1.5
Nitrate	mg N/L	1.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	0	-	-
Dissolved Oxygen	mg O_2/L	7.8	-	-
Total Dissolved Solids	mg TDS/L	08	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D10: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/011/14 **Date of Sampling 17th January 2014**

Source: Ongata Rongai **Date Received 19th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	7.45	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	5.0	Max 15	Max 15
Turbidity	NTU	0.4	Max 5	Max 5
Conductivity (25^{o}C)	µS/cm	508	Max 2500	-
Iron	mg Fe/L	0.3	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	63	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	18	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	274	Max 500	-
Chloride	mg Cl/L	105	Max 250	Max 250
Fluoride	mg F/L	0.7	Max 1.5	Max 1.5
Nitrate	mg N/L	1.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	0	-	-
Dissolved Oxygen	mg O_2/L	6.9	-	-
Total Dissolved Solids	mg TDS/L	260	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D11: Table: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/012/14 **Date of Sampling 17th February 2014**

Source: Ongata Rongai **Date Received 19th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	6.93	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	5.0	Max 15	Max 15
Turbidity	NTU	0.7	Max 5	Max 5
Conductivity (25^{o}C)	µS/cm	630	Max 2500	-
Iron	mg Fe/L	0.2	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	161	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	134	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	298	Max 500	-
Chloride	mg Cl/L	174	Max 250	Max 250
Fluoride	mg F/L	1.8	Max 1.5	Max 1.5
Nitrate	mg N/L	4.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	0	-	-
Dissolved Oxygen	mg O_2/L	7.8	-	-
Total Dissolved Solids	mg TDS/L	400	Max 1500	Max 1000
Total Coliforms	MPN/100	Nil		
E. Coli	MPN/100	Nil		

Table D12: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/013/14 **Date of Sampling 17th February 2014**

Source: Ongata Rongai **Date Received 19th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	7.97	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	6.0	Max 15	Max 15
Turbidity	NTU	0.4	Max 5	Max 5
Conductivity (25°C)	µS/cm	301	Max 2500	-
Iron	mg Fe/L	0.3	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	72	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	36	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	176	Max 500	-
Chloride	mg Cl/L	58	Max 250	Max 250
Fluoride	mg F/L	0.78	Max 1.5	Max 1.5
Nitrate	mg N/L	7.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	0	-	-
Dissolved Oxygen	mg O_2/L	6.8	-	-
Total Dissolved Solids	mg TDS/L	160	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D13: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/014/14 **Date of Sampling 17th February 2014**

Source: Ongata Rongai **Date Received 19th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	6.50	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	5.0	Max 15	Max 15
Turbidity	NTU	0.4	Max 5	Max 5
Conductivity (25^oC)	µS/cm	467	Max 2500	-
Iron	mg Fe/L	0.3	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	266	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	100	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	210	Max 500	-
Chloride	mg Cl/L	148	Max 250	Max 250
Fluoride	mg F/L	1.25	Max 1.5	Max 1.5
Nitrate	mg N/L	7.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	0	-	-
Dissolved Oxygen	mg O_2/L	7.1	-	-
Total Dissolved Solids	mg TDS/L	208	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D14: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/015/14 **Date of Sampling 17th February 2014**

Source: Ongata Rongai **Date Received 19th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	8.25	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	10.0	Max 15	Max 15
Turbidity	NTU	3.1	Max 5	Max 5
Conductivity (25^oC)	µS/cm	700	Max 2500	-
Iron	mg Fe/L	0.3	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	29	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	20	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	401	Max 500	-
Chloride	mg Cl/L	120	Max 250	Max 250
Fluoride	mg F/L	1.85	Max 1.5	Max 1.5
Nitrate	mg N/L	7.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	0	-	-
Dissolved Oxygen	mg O_2/L	7.7	-	-
Total Dissolved Solids	mg TDS/L	410	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D15: Laboratory tests results

LABORATORY REPORT

Sample Number: OR/016/14 **Date of Sampling 17th February 2014**

Source: Ongata Rongai **Date Received 19th February 2014**

Purpose of Sampling: Research/Study **Submitted by: Machuma D.O.**

Parameters	Unit	Results	WHO Standards	KBS(KS-1:2007 Standards
pH	pH scale	7.10	6.5 – 8.5	6.5 – 8.5
Colour	Degrees Hazen	5.0	Max 15	Max 15
Turbidity	NTU	1.4	Max 5	Max 5
Conductivity (25^{o}C)	µS/cm	702	Max 2500	-
Iron	mg Fe/L	0.4	Max 0.3	Max 0.3
Total Hardness	mg $CaCO_3$/L	163	Max 500	Max 300
Calcium Hardness	mg $CaCO_3$/L	88	Max 500	-
Total Alkalinity	mg $CaCO_3$/L	328	Max 500	-
Chloride	mg Cl/L	175	Max 250	Max 250
Fluoride	mg F/L	1.78	Max 1.5	Max 1.5
Nitrate	mg N/L	7.0	Max 10	Max 10
Total Suspended Solids	mg TSS/L	0	-	-
Dissolved Oxygen	mg O_2/L	7.2	-	-
Total Dissolved Solids	mg TDS/L	356	Max 1500	Max 1000
Total Coliforms	MPN/100ml	Nil		
E. Coli	MPN/100ml	Nil		

Table D16: Laboratory tests results

APPENDIX E: WRMA PREVIOUS STUDY RESULTS

APPENDIX F: PLATES

Plate 1: Borehole OR/001/14

Plate 2: Borehole OR/003/14

Plate 3: Kiserian Dam Raw Water

Plate 4: Kiserian Dam Clear Water

Plate 5: Mbagathi River Raw Water

Plate 6: Oloolaiser Water Treatment Plant Clear Water Tank.

Plate 7: Borehole OR/008/14

Plate 8: Borehole OR/009/14

Plate 9: Rain Water Tank OR/010/14

Plate 10: Borehole OR/011/14

Plate 11: Borehole OR/012/14

Plate 12: Borehole OR/013/14

Plate 13: Borehole OR/014/14

Plate 14: Borehole OR/015/14

Plate 15: Borehole OR/016/14

APPENDIX G: WATER QUALITY GUIDELINES

WHO and EU Water Quality Guidelines

Table G1: WHO and EU Water Quality guidelines

Chemical	**WHO (Guidelines)** (mg/L)	**EU Guidelines** (mg/L)
Acryl amide	0.0005	0.0001
Alachlor	0.02	
Aldicarb	0.01	
Aldin and dieldrin	0.00003	
Aluminium	0.2	0.2
Ammonium		0.5

Antimony	0.02	0.005
Arsenic	0.01	0.01
Atrazine	0.002	
Barium	0.7	
Benzene	0.001	0.01
Benzo [a] pyrene	0.0007	0.00001
Boron	0.5	1.0
Bromate	0.01	0.01
Bromodichloromethane	0.06	
Bromoform	0.1	

Source: Gray, 2008

Table G2: WHO and EU Water Quality guidelines

Chemical	**WHO (Guidelines)** (mg/L)	**EU Guidelines** (mg/L)
Cadmium	0.003	0.005
Carbofuran	0.007	
Carbon tetrachloride	0.004	
Chloral hydrate	0.01	
Chlorate	0.7	2.0
Chlordane	0.0002	
Chloride	250	250

Chlorine	5	
Chlorite	0.2	
Chloroform	0.7	
Chlorotoluron	0.03	
Chlorpyfiros	0.03	
Chromium	0.05	0.05
Copper	2	
Cyanazine	0.0006	
Cyanide	0.07	0.05
Cyanogens Chloride	0.07	

Source: Gray, 2008

Table G3: WHO and EU Water Quality guidelines

Chemical	**WHO (Guidelines)** (mg/L)	**EU Guidelines** (mg/L)
2,4-D(2,4-dichlorophenolxy acetic acid)	0.001	
2,4-DB	0.09	
DDT and metabolites	0.03	
Di(2- ethylhexyl)phthalate	0.1	
Dibromoacetonitrile	0.07	
Dibromochloromethane	0.008	

1,2-Dibromoacetonitrile	0.07	
Dibromochloromethane	0.1	
1,2-Dibromo-3-Chloro propane	0.001	
1,2-Dibromoethane	0.0004	
Dichloroacetate	0.05	
Dichloroacetonitrile	0.02	
Dichlorobenzene 1,2	1	
Dichlorobenzene 1,4	0.3	
Dichloroethane 1,2	0.03	
Dichloroethene 1,1	0.03	

Source: Gray, 2008

Table G4: WHO and EU Water Quality guidelines

Chemical	**WHO (Guidelines)** (mg/L)	**EU Guidelines** (mg/L)
Dichloroethene 1,2	0.006	0.003
Dichloromethane	0.02	
1,2-Dichloropropene	0.04	
1,3-Dichloropropene	0.02	
Dichlorprop	0.1	
Dimethoate	0.006	

Edetic acid (EDTA)	0.6	
Endrin	0.0006	
Epichlorohydrin	0.0004	0.0001
Ethylbenzene	0.3	
Fenoprop	0.009	
Fluoride	1.5	1.5
Formaldehyde	0.9	
Hexachlorobutidiene	0.0006	
Isoproturon	0.009	
Lead	0.001	0.01
Lindane	0.002	

Source: Gray, 2008

Table G5: WHO and EU Water Quality guidelines

Chemical	**WHO (Guidelines)** (mg/L)	**EU Guidelines** (mg/L)
Manganese	0.4	
MCPA	0.002	
Mecoprop	0.01	
Mercury	0.001	0.001
Methoxychlor	0.02	
Metolachlor	0.01	

Microcystin-LR	0.001	
Molinate	0.006	
Molybdenum	0.07	
Monochloramine	3	
Monochloroacetate	0.02	
Nickel	0.02	0.02
Nitrate (as NO_3)	50	50
Nitrilotriacetic Acid (NTA)	0.2	
Nitrite (as NO_2)	3 (short-term exposure) 0.2 (short term exposure)	0.85
Pendimethalin	0.02	

Source: Gray, 2008

Table G6: WHO and EU Water Quality guidelines

Chemical	**WHO (Guidelines)** (mg/L)	**EU Guidelines** (mg/L)
Pentachlorophenol	0.009	
Pesticides Pesticides (Total)		0.0001 0.0005
Polycyclic aromatic hydrocarbons		0.0001
Pyriproxyfen	0.3	

Selenium	0.01	0.01
Simazine	0.002	
Styrene	0.02	
2,4,5-T	0.009	
Terbuthylazine	0.007	
Tetrachloroethene	0.04	0.01
Toluene	0.7	
Trichloroacetate	0.2	
Trichloroethene	0.07	
Trichlorophenol, 2,4,6	0.2	
Trifluralin	0.02	
Trihalomethanes		0.1

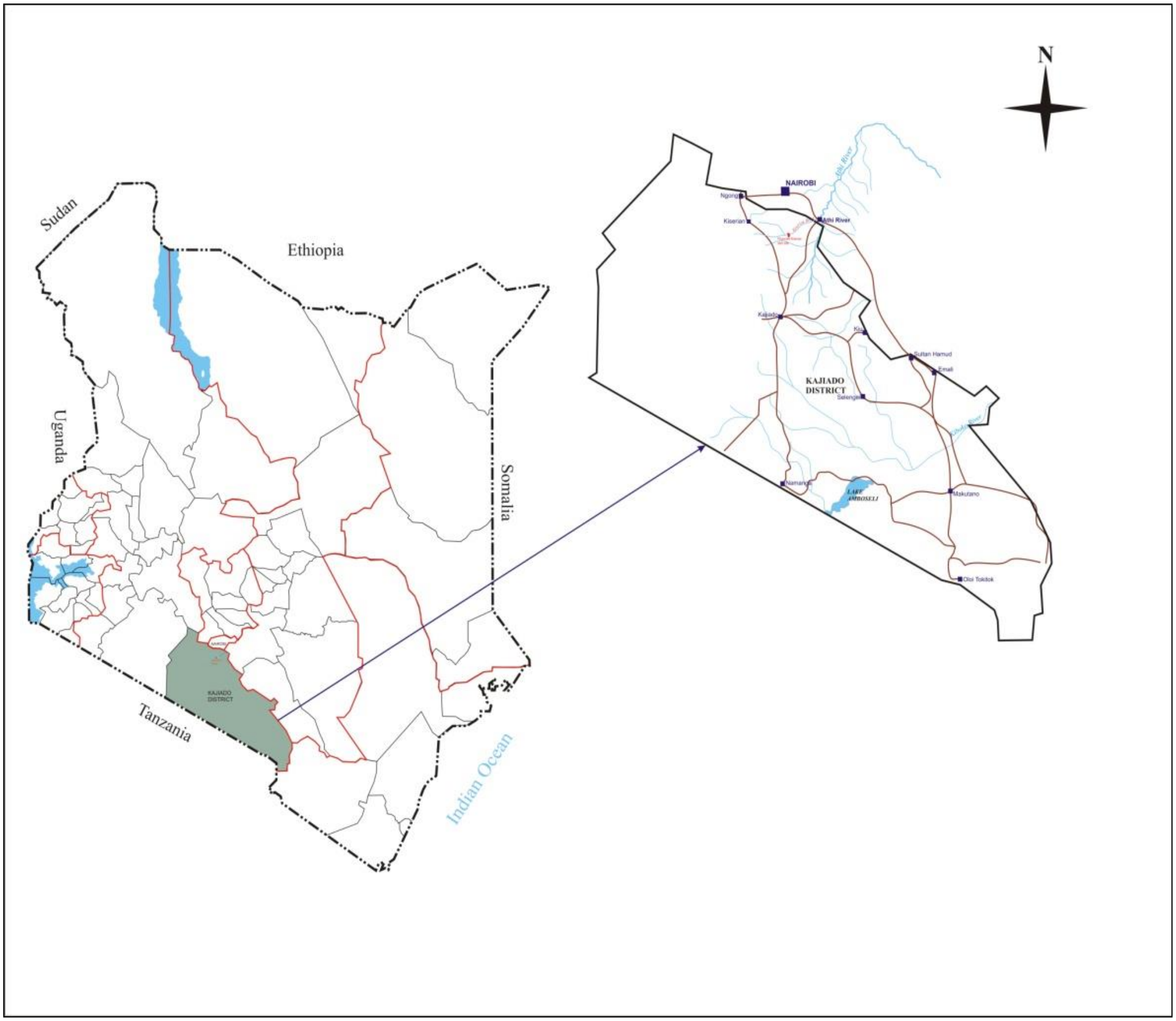
Source: Gray, 2008.

Table G7: WHO and EU Water Quality guidelines

Uranium	0.015	
Vinyl chloride	0.0003	0.005
Xylenes	0.5	

Source: Gray, 2008.

APPENDIX H: MAPS



Map 1: Showing the district in which Ongata Rongai lies.