SEASONAL ASSESSMENT OF GROUNDWATER QUALITY IN RUIRU KIAMBU COUNTY, KENYA

By

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DECLARATION

This thesis is my original work and has not been presented for a degree or any other award in any other university.

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DEDICATION

This research work is dedicated to my family. My husband John, my daughters Lucy, Lencia and son Louis for being my greatest blessing and source of encouragement throughout the research work. May the Almighty God bless them always.

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ABBREVIATIONS AND ACRONYMS

AWSD	Athi water service board
DEWA	Division of Early Warning and Assessment
EAC	East Africa Community
EDTA	Ethylene Diamine Tetra Acetic Acid
FAO	Food and Agricultural Organization
GPS	Geographical positioning system
IWRMS	Integrated Water Resource Management
KEBS	Kenya Bureau of Standards
MDGs	Millennium Development Goals
mg/l.	Milligrams per litre
mgPt/l	Milligram platinum per litre
MPN/100 mL	Most probable number per 100 milliliters
NTU	Nepthalometric Turbidity Unit
µS/cm	Micro Siemens per centimeter
RUJUWASCO	Ruiru-Juja Water & Sewerage co Ltd
SPSS	Statistical Package for social scientists
UNEP	United Nations Environment Programme
WHO	World Health Organization
WRMA	Water Resources Management Authority
WSP	Water service provider

ABSTRACT

Water is essential for life and the bloodstream of the green economy. Lack of access to wholesome drinking water adversely affects the public health of many developing countries and Kenya is not an exception. Ruiru, a small but fast growing town in the outskirts of Nairobi, is one area where limited resources and services are facing relentless pressure due to rapid population growth. The residents experience unreliable water supply and are therefore highly dependent on groundwater sources such as boreholes and shallow wells as the main source of water for domestic use. The present study is an attempt to assess the groundwater quality and the seasonal variation with a view of ascertaining its suitability for domestic use. A total of 109 drinking water samples from groundwater source from Ruiru were randomly sampled and assessed to determine their physico-chemical and bacteriological characteristics together with their seasonal variations. Water samples were collected during the dry (January- February, 2015) and Wet season (March- April, 2015) and analyzed for temperature, pH, colour, turbidity, conductivity, total dissolved solids, total alkalinity, total hardness, iron, manganese, fluoride and major cations (calcium, magnesium, sodium and potassium) and major anions (chloride, sulfate, Nitrate) using Standard Methods for the Examination of Water and waste water. The results obtained were compared to guideline values of the World Health Organization (WHO) and Kenya Bureau of Standards (KEBS) to establish the suitability of groundwater for domestic purposes. Generally, seasonal variations showed that there was a decrease in most of the parameters in boreholes with a shift of the season from dry to wet and vice versa for shallow wells. The concentration of fluoride, nitrates, turbidity and Iron in some of the samples exceeded the prescribed KEBS and WHO standards of 15m/l, 10 mg/l, NTU and 0.3 mg/l respectively. The student's t-test performed showed a significant difference ($p \leq 0.01$) between the means of the sampled boreholes and shallow wells water for the following parameters; pH, Electrical conductivity, total Dissolved solids, calcium, total alkalinity, chlorides, fluorides, nitrates, Iron, manganese, total coliforms and *E.coli*. The difference was also significant ($p \leq 0.05$) for colour, turbidity, total hardness and magnesium. The sampled boreholes and shallow wells had faecal coliform contamination and did not conform to the WHO and KEBS guideline value of 0 MPN/100 ml. The study revealed poor bacteriological quality of drinking water sources. Therefore the need for the provision of reliable potable water to the local dwellers by government is highly recommended to avert waterborne related diseases.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Water is life and sound management of the water resources is a vital component for sustainability of a nation (UNEP/DEWA, 2003). Groundwater comprises 97 percent of all the readily accessible freshwater in the world providing water needs of approximately 2 billion people around the world (Mumma *et al.*, 2011).There is lack of adequate supply of potable water in developing countries and this has left the majority of the populations with the only option of using water from groundwater sources like shallow wells, hand dug wells and boreholes to meet their daily water demand. These sources are highly susceptible to contamination rendering the water unsuitable for domestic purposes (UNEP/DEWA, 2003).

Kenya is water deficient, with per capita available water of 650 m^3/year currently (Marshall, 2011) as compared to 1000 $m^{3/}$year which is the acceptable globally (WHO, 2011). Due to population growth experienced in Kenya, this is likely to drop further to 235 m^3/year by 2025 (Marshall, 2011).In Kenya, the piped municipal water supplies is not adequate and given that the existing rivers are already polluted, the majority of the people are left option of relying on boreholes and water vendors (Kimani-murage & Ngindu, 2007) for their daily water needs. Some of these sources are prone to contamination and are likely to result in risks of water borne diseases to the people living in these areas. Access to safe drinking water and sanitation are therefore some of the major developmental challenges facing Kenya as a country (Marshall, 2011).

Groundwater is of considerable importance, since it's provides an alternative source of clean water to supplement the inadequate municipal supplies. Due to its self-cleaning mechanism as the water moves from the surface to the underground rocks through the soil profile, groundwater is believed to provide a clean source of water which is more reliable. However the shallow aquifers are most susceptible to contamination due to the fact that they closer to the surface (Adejuwon & Mbuk, 2011). Groundwater is capable of meeting water needs according to people's demands and this makes it an important source of water in rural and urban water supply for domestic, industrial and irrigation use. More so it is also ubiquitous and drought resilient (Kithiia, 2012).

The importance and value of groundwater is not appreciated and it is perceived to be inexhaustible and yet this is not so (Kithiia, 2012). People have continued with over abstraction and poor management of the resource (Kithiia, 2012). Groundwater is a vulnerable resource and therefore requires enforcement of key policy objectives to come into play to safeguard the resource. The most important among these is the development of functional systems to coordinate actions relating to groundwater amongst all the stakeholders in the water sectors that affect groundwater sustainability. Key among this is giving priority to groundwater management in the activities and programs of the concerned water institutions (Kithiia, 2012).

1.2 Statement of the problem

Problems of water scarcity and poor sanitation issues account for approximate 10% of all deaths relating to water-borne or sanitation-related diseases in Kenya (UN, 2010).The eminent scarcity in water as a resource has population growth as one of the major causes. Ruiru is one upcoming town which, in recent past has experienced a rise in population. The increase in population is attributed to the advantages that the area enjoys; it is strategically positioned along the Nairobi - Thika super highway and connected to the railway network which provides cheap transport to the city. Its proximity to both Nairobi city and Thika town has attracted large numbers of people who commute to their work places. The area is sandwiched between two institutions of higher learning; Kenyatta and Jomo Kenyatta Universities and with the rapid expansion of Kenyatta University, this has seen more students enrolling and looking for residential places for settlement around the area. This has resulted to over population and hence pressure on the housing and water resources to an extent that even the water service provider can no longer meet the habitants demand for water (Mugeraa *et al.*, 2014). Ruiru – Juja water and Sewerage Company (RUJUWASCO) is only able to meet 14% of the water demand (Obanda *et al.*, 2014).Most people have resorted to the use of groundwater which is more reliable.

As an upcoming area in terms of industrial set up, more people have moved in to provide cheap labour to the industries. This has led to unplanned settlements and sprawling slum area. Majority of the people who can't afford a well-constructed well resort to hand- dug shallow wells. Overcrowding in slum areas has resulted to poor sanitation since the area lacks an elaborate sewage system and it is therefore dominated by the use of indiscriminate dumping sites, pit latrines, septic tanks and soaks pits (SIPA, 2008). Currently, Ruiru lacks an adequate solid waste management system and this has resulted to the Murera dumpsite located in the area (SIPA, 2008). These conditions pose a threat to the groundwater quality. The area is also an agricultural base dominated by coffee plantations and flower farms for commercial purposes. These farms utilize the use of pesticides, fertilizers and herbicides and this may contaminate the groundwater through infiltration. There are no elaborate policies or strategies to guide the management of groundwater resources (WRMA, 2010). This research therefore aims at identifying the groundwater status of the area and hence assist the relevant functions in coming up with mitigation measures so as to ensure provision of safe water to the residents.

1.3 Research Questions

1. What are the physical, chemical and microbiological characteristics of ground water in Ruiru area?
2. What is the suitability of groundwater resources in Ruiru for domestic purposes when comparing their quality parameters to the WHO and KEBS standards.
3. How do the physico-chemical and microbiological characteristics of boreholes compare to that of shallow wells in the area.
4. To what extend does the seasonal variability affect the physicochemical and microbiological quality of groundwater.

1.4 Hypotheses of the study

The study tested the following Research Hypotheses;

1. The mean levels of the physical-chemical components of groundwater vary significantly in the two seasons.
2. The mean levels of the microbiological components of groundwater vary significantly in the two seasons.
3. There is a significant difference between the mean levels of the water quality attributes of boreholes and that of shallow wells in the area.

1.5 Objectives of Study

1.5.1. Main objective:

To assess the quality of ground water so as to ascertain its suitability for domestic use by the people of Ruiru.

1.5.2. Specific objectives

1. To determine the Physico-chemical and microbiological properties of the groundwater in Ruiru.
2. To compare the Physico-chemical and microbiological properties of the borehole and shallow well waters in Ruiru to that of WHO and KEBS standards.
3. To assess and compare the physicochemical and microbiological characteristics of boreholes and shallow wells of Ruiru.

4. To explore the effect of seasonal variation on the physicochemical and microbiological quality of groundwater of Ruiru.

1.6 Significance of the Study

Clear and colorless water gives an impression that it is safe for human consumption yet this may not be always true. It may contain many bacteria and objectionable matter which are invisible (UNEP/DEWA, 2003). Approximately 80% of all illness in developing countries is related to water and sanitation (Harvey, 2011). As many as two billion people do not have ready access to clean and potable water. Six thousand children die every week from water related diseases (UNEP/DEWA, 2003).People suffer from water related disorders like dental fluorosis (stained teeth) and weak bones due to consumption of clean water but high in fluorides (Alvarez, *et al*., 2009).

Most people in developing countries do not have access to adequate supply of potable water and therefore resort to using water from shallow wells and boreholes (Louise, 2005). Some of these sources are likely to have unsafe water for domestic purposes since they are prone to contamination (UNEP/DEWA, 2003). This study is therefore aimed at determining the quality of groundwater in the Ruiru and therefore establishing its suitability for domestic use. This will assist the key stakeholders in the water sector and county authorities in developing strategies to address issues relating to groundwater quality.

1.7 Conceptual Framework

This framework illustrates the causes of deteriorating ground water quality in the Ruiru sub-county arising as a result of drivers and pressures as shown in (Figure 1).Population, urbanization, industrialization and commercial farming form the driving force of the study area. The rapid increase in population of Ruiru sub-county brings about pressure on the social amenities. These pressures include the use of fertilizers and pesticides especially in the coffee and flower farms leading to chemical pollution of the groundwater through leaching. The crowding of people also results to poor sanitation in the area due to lack of proper sewerage systems coupled with the use of on-site pit latrines. The indiscriminate disposal of domestic solid waste and waste waters on land surface aggravate the chances of groundwater contamination through leaching. These pressures bring about a change in the state of water by elevation of the chemical compounds and contamination of the water. As a result, the outcome manifest in terms of health problems like, water borne diseases, fluorosis and blue baby syndrome. To reduce the severity of the effects of population growth, agriculture and urbanization on ground water, mitigation measures (responses) can be taken, these include: proper waste disposal management practices and ground water quality monitoring.

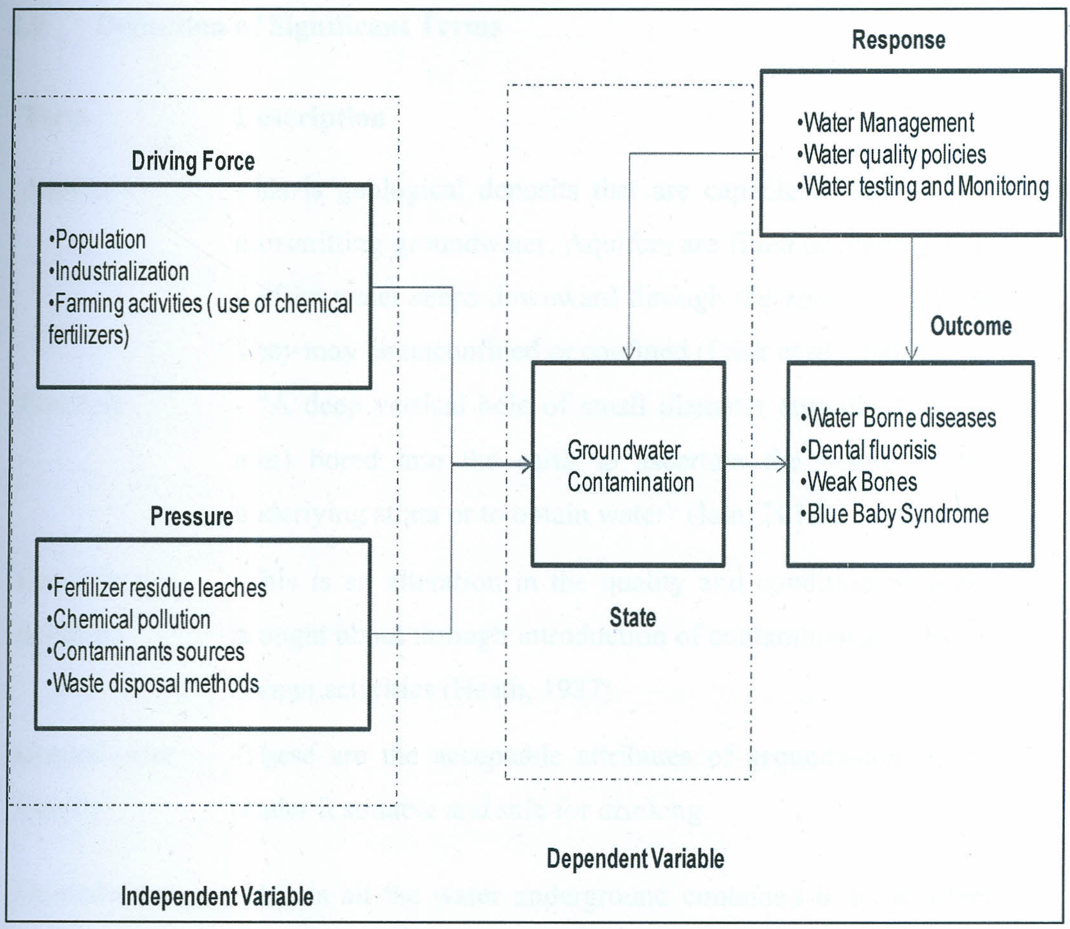

Figure 1.1: Conceptual framework (Adapted and modified from DPSIR framework in relation to water issues (Kristensen, 2004).

1.8 Scope and limitations

The research sought to analyze the physico-chemical and bacteriological characteristics of the waters sampled from 109 groundwater sources from Ruiru area. Seasonal variations were considered and their concentrations compared to those of WHO and KEBS set limits for drinking water. The study was based on timing (season) which was faced with challenge of unreliable climate data of the geographical zones due to current trends in global warming. Consequently, the seasonal data (dry and wet) could not be captured accurately for the study.

1.9 Definition of Significant Terms

Term	Description
Aquifer	-this is geological deposits that are capable of storing and transmitting groundwater. Aquifers are filled or recharged as surface water seeps downward through the zone of aeration. They may be unconfined or confined (Prior *et al.*, 2003).
Borehole	- "A deep vertical hole of small diameter (usually 100-150 mm) bored into the earth to ascertain the nature of the underlying strata or to obtain water" (Iain, 2012).
Groundwater pollution	-This is an alteration in the quality and condition of water brought about through introduction of contaminants or due to human activities (Heath, 1987).
Groundwater Quality	-These are the acceptable attributes of groundwater which render it suitable and safe for drinking.
Groundwater	-This is all the water underground contained in an aquifers located beneath the surface (Siebert, *et al.*, 2010).
Shallow well	-well that is less than 15m in depth. Most of them are hand dug wells. They are usually prone to pollution from seepage and have a tendency of drying up during dry season (UOA, 2011)
Sustainability	-Sustainability is the ability of the groundwater resource to continue to function and serve its intended target population now and in the future.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction to Groundwater

The water beneath the ground is referred to as groundwater (or subsurface water). This water occurs in two different zones (Wehrmann, 2007). First zone occurs immediately below the rock particles and is referred to as the unsaturated zone. The second zone is known as the saturated zone in which all interconnected openings are full of water (Wehrmann, 2007). Recharge of the saturated zone occurs by percolation of water from the land surface through the unsaturated zone. The lowest part of the unsaturated zone is occupied by the capillary fringe which is sandwiched between the unsaturated and saturated zones (IARC, 2010). The capillary fringe results from the attraction between water and rocks and water clings as a film on the surface diameter pores against the pull of gravity due to this attraction (Wehrmann, 2007).

2.2 Groundwater system

Groundwater is an important part of the hydrologic cycle (IARC, 2010). The water moves slowly through the pore spaces in rock controlled by the porosity and permeability of the rocks (Wehrmann, 2007). The natural discharge of groundwater is generally into springs, streams, marshes, and lakes. Gravity is the principal driving force for the flow of groundwater. Moreover, like other parts of the hydrologic system (rivers and glaciers), the groundwater system is an open system where water enters through infiltration to the ground (Morris, *et al.*, 2003). Along this flow path, groundwater does geologic work mostly as a result of solution or precipitation of rock. Whatever the permeability of the rock, groundwater flows slowly and the flow is laminar (Heath, 1987).Thus, the flow of groundwater contrasts sharply with the turbulent flow of rivers. Groundwater is less affected by the harsh dry season and thus more reliable during periods of drought and also its water tends to be of good quality because of natural purification processes making its treatment cheap and easy to develop (UNEP/DEWA, 2003).

2.3 Groundwater Resource

One of the challenges that the world faces today is meeting the water needs for its population (Shiklomanov, 2002).The water resources has experienced increasing stress in the recent past due to increase in population and rising standards of living globally. Catchment degradation and poor waste management may lead to contamination of the groundwater thereby resulting to deterioration of water quality (Shiklomanov, 2002). Climate change has even caused further uncertainty to the availability of the groundwater resource. However, groundwater still remains the most intensively exploited natural resource in the world (Shiklomanov, 2002).

As earlier stated above, an estimated 2 billion people worldwide rely on aquifers for drinking water supply (UNEP/DEWA, 2003). In rural areas, groundwater provides the main water supply for agriculture resources for food security while in urban areas on the other hand groundwater is important as a reliable source for both private and domestic water supply. The use of groundwater has seen the growth in agricultural production across the world (UNEP/DEWA, 2003). The use of groundwater enabled India's agricultural output to rise considerably (Matinez-Santos, 2005). By the end of the first decade of the twenty first century, India accounted for 230 km^3/yr, this represents over 25 percent of global groundwater use. Intensive groundwater abstraction has been of immense benefit to both rural and urban populations globally and in most cases being unnoticed by governments (Matinez-Santos, 2005). However, concerns are growing over its quality and there is need for management strategies that recognize the vulnerability of groundwater resources to contamination through poor urban land use and waste or effluent disposal (Matinez-Santos, 2005).

The lack of knowledge about groundwater creates some uncertainty for future use. There is also a common perception that groundwater is a common pool resource (Marshall, 2011)and that its ownership is " private" such that the land owners consider that they have an absolute right to the water beneath their land, irrespective of what laws may say (WRMA, 2009). This has resulted to unsustainable use of groundwater. Despite all this, groundwater has the potential to mitigate the looming global water crisis. This can only be achieved through proper and appropriate management of the resource (Mumma *et al.*, 2011).

2.4 Groundwater quality

Water, is a commodity that is consumed, a carrier of other substances or properties, such as heat, energy and also harbors disease vectors and pollutants (Ross, 2010).Water pollution accounts for deaths of about 25 million people each year, especially in developing countries (UNEP/DEWA, 2003). Half of the diseases that affect the world's population are transmitted by or through water yet over 2.4 billion people use unacceptable means of sanitation, and more than 1 billion people draw their water from sources whose water quality is questionable (UNEP/DEWA, 2003).

The problem of pollution in the developing countries is increasingly becoming a threat to groundwater (Ross, 2010). This is attributed industrialization and growth of countries across the globe as they seek to develop their economies. Therefore there is need for an urgent action by the water sector to improve the availability and accessibility of clean and safe drinking water (IEA, 2007). Majority of Kenyans especially in the rural areas have limited access to quality water since most of them fetch their water from rivers, lakes, dams and unprotected wells and use it raw and /or untreated. Water from such sources tends to contain turbid water which is contaminated by chemicals and disease causing bacteria (IEA, 2007). The problem is further compounded by the water availability which is more dependent on the seasonal rainfall in most parts of the country.

Lack of adequate sanitation is one of the major courses of water contamination worldwide (Ross, 2010) resulting to various types of waterborne diseases which are a number one killer of children under five years old (Ross, 2010). Kenya as a member of the UN adopted the Millennium Development Goals (MDGs) in 2000 as with an objective of addressing poverty (WHO, 2004).One of the key strategies was to ensure at least half the proportion of people have access to a safe water supply and a sustainable environmental. This eventually translates to tangible health benefits and thus promotes development (WHO, 2004).

2.5 Water quality issues in Kenya

Water resources in Kenya are under threat of contamination from agricultural chemicals (fertilizers, pesticides and herbicides), urban and industrial wastes (Saracino *et al.*, 2002).The surface water is already polluted leaving groundwater as the only reliable and relatively safe option to meet the water needs. Groundwater pollution occurs as the surface infiltrates into the ground. Surface water contains various contaminants such as organic chemicals, inorganic chemicals that occur naturally in the soils, sediments, rocks and it may also contain potential pathogens which may compromise the groundwater quality (Saracino *et al*., 2002).Naturally occurring minerals may also be contaminants as they are carried downwards into the ground through percolation. Water pollution from urban and industrial wastes poses another environmental problem. Kenya has 20.2 cubic kilometers of renewable water resources with only about 42% of the residents in rural areas and 88% of city dwellers having pure drinking water (Saracino *et al.,* 2002). The situation is much worse in the informal settlements in the urban areas due to lack of proper sanitation and sewerage system. These settlements are located near or on top of the rivers courses draining the city of Nairobi and contain significant pollutants which bring about water quality degradation (Kithiia, 2012).

Groundwater requires a recharge zone made of good and suitable geological material in order to maintain its storage (Morris, *et al*., 2003). Point source pollution may arise due to some types of land use which may pollute recharge water and thus the aquifers (Morris, *et al*., 2003), such as industrial waste being discharged from an industry may mix with recharge water, a pit latrine leaching nutrient and bacteria into a shallow aquifer or fertilizer and pesticide residues (nitrates, phosphates) leaching in to the groundwater (Ross, 2010). Another aspect is land use planning which is capable of not only changing aquifer recharge and discharge characteristics, but also capable of influencing aquifer use patterns (Morris, *et al*., 2003).

Pollution of water resources in Kenya is increasing and its impacts are being manifested by water of poor quality which results to water various types of waterborne diseases (Kithiia, 2012), loss of aesthetic value by becoming unsuitable for recreational activities, high cost of water supply as polluted water is expensive to treat (Kithiia, 2012).This is more evident in the urban centers and more in the city of Nairobi. Increase population in Kenyan urban area results to increase in generation of solid, liquid and gaseous wastes (Kithiia, 2012). The report by NEMA (2004) indicates that per capita waste generation ranges between 0.29 and 0.66 kg day-^{1} within the urban areas of the country, and that of the municipal waste generated in the urban centers is 21% emanating from industrial areas and 61% from residential areas (Kithiia, 2012).

2.6 Groundwater quality characteristics

Water quality characteristics are categorized as physical, chemical and biological .The quality of water is judged by authentic standards. World Health Organization (WHO) has recommended guideline values for drinking water for developing countries, which are taken as base for formulating the local values (Ramaraju, 2006).

2.6.1 Chemical characteristics of groundwater

The chemical characteristics of groundwater depend on the type and nature of the underlying rock. The type and concentration of salts are influenced by the geological environment and movement of the water (Ramaraju, 2006). An elevated concentration of some of the constituents brings about alteration in the natural chemical quality of the water causing problems for water use (WHO, 2011). For instance, high iron and fluoride levels in groundwater are widely reported from developing countries, where they are often an important water quality issue (Ramaraju, 2006). The situation is made worse in many areas by the corrosion of ferrous well linings and pump components (Ramaraju, 2006).Most of the minerals in rocks are soluble in water and each mineral has a different solubility in pure water. The solubility varies with the acidity of the water and the amount of oxygen dissolved in it. Groundwater readily dissolves the most soluble minerals in rocks. With increasing depth, the amount and types of materials dissolved in the ground water vary with deeper waters generally having higher concentrations of salt and less oxygen. As water moves from the surface down to the groundwater aquifer, it carries water-soluble chemicals with it which find their way to the groundwater resource through leaching (Ross, 2010).

2.6.2 Biological characteristics of groundwater

Microbiological processes may influence groundwater quality either directly or indirectly and this can transform both inorganic and organic constituents of groundwater. Most micro-organisms grow and attach themselves with extra-cellular polysaccharides, forming a protective biofilm which can be very difficult to remove (Foster, 2000). Microbiological activity primarily affects compounds of nitrogen and sulphur, and some of the metals, principally iron and manganese (Foster, 2000). The reduction of sulphates by obligate aerobes and that of nitrates by denitrifying bacteria are some of the most important biological processes in groundwater. Nitrogen compounds are affected by both nitrifying and denitrifying bacteria (Lucasse, *et al.*, 2010). The possibility of enhancing natural denitrification is currently receiving attention in relation to the problem of nitrate in groundwater (Lucasse, *et al.*, 2010). Under aerobic conditions, ammonia (which maybe produced during the decomposition of organic matter) is oxidized to nitrite and nitrate.

The presence of feacal coliforms in water is principal microbiological concern since this microorganism is an indication of feacal contamination which poses health hazard (Foster, 2000). Pathogenic bacteria contained in human excreta are likely to be transmitted through the soil to groundwater sources. Bacteriological contamination of groundwater remains a major concern, especially in areas with shallow dug wells and boreholes are the major sources of the water supply (Foster, 2000). Broken septic tanks and pit latrines may cause pollution of groundwater sources through seepage. After the rains, the surface run-off water carries fertilizers pesticides, herbicide residues and faecal matter (Kumasi, *et al.*, 2011) that may cause agricultural pollution. The presence of faecal coliforms or *E. coli* has been widely used as an indicator for the presence of pathogenic microorganisms which may cause waterborne diseases (Ibe & Okplenye , 2005; Rajendran, *et a*l., 2006).According to World Health Organization (WHO) no faecal coliform should be present in 100ml of drinking water. Therefore, microbiological processes may influence groundwater quality both positively and negatively. An example of the positive influence involves nitrate and sulphate reduction in groundwater thus removal of organic pollutants (Lucasse, *et al.*, 2010). The negative effect may involve the production of gases like hydrogensulphide which results in deterioration of the water quality (Rajendran, *et a*l., 2006).

2.7 Groundwater Quality Deterioration and Pollution

Groundwater quality is a major environmental concern. Factors affecting the quality of ground water include sea water intrusion and pollution due to anthropogenic activities (Ramaraju, 2006). Seepage from septic tanks; animals' wastes and return flow irrigation where fertilizers and pesticides/insecticides are applied has resulted in high levels of nitrate, potassium and phosphate in some areas of Bihar, Haryana, Gujarat, Uttar Pradesh and Delhi (Ramaraju, 2006).Pollution of ground water with toxic chemicals in areas close to industrial areas and urban settlement has been observed in many parts of the country.

2.8 Anthropogenic activities and ground water contamination

Groundwater pollution is categorized as either point or non-point sources of pollution (Tolba & Saab, 2008). Point sources of pollutants are generally localized and originate from discrete sources (industries, on site sanitation systems, leaking gasoline storage tanks, solid waste disposal sites); (Tolba & Saab, 2008).Non-point sources are more difficult to determine and is caused by pollutants discharged over a wide land area and not from discrete points (agricultural runoff, pesticides and fertilizer applications, storm water from heavily populated areas, and road salt application for deicing during winter (Halwani, 2008). Non - point source pollution is hard to control because the perpetrators cannot be traced (Almasri & Kaluarachchi , 2004).

The ease with which water enters and moves through an aquifer is described as its intrinsic susceptibility (Focazio *et al.*, 2002). Aquifer susceptibility depends on the aquifer properties and other characteristics such as recharge rate, the presence or absence of an overlying confining unit, groundwater travel time, thickness and characteristics of the unsaturated zone, and pumping. The vulnerability of groundwater to contamination is the probability for contaminants to reach a specified part of an aquifer after being introduced, usually at the land surface (Lucasse, *et al*., 2010). Vulnerability depends on the properties of the groundwater system (susceptibility), the proximity of contaminant sources, and the chemical characteristics of the contaminant (Focazio *et al*., 2002).The susceptibility of groundwater to contaminants from surface sources depends highly on the permeability of the overlaying rock/soil units and depth to the water table (Ifabiyi, 2008).

2.9 Climate change impacts on groundwater in Kenya

Climate change has a big effect on the groundwater resource and indeed there is ample evidence that it already has (GoK, 2010).Groundwater systems react in different ways to climate change for instance, the shallow aquifers with short residence times will react more quickly to changes in recharge. Most of them become seasonal as they dry up during the dry seasons. The deeper aquifers (particularly those with large storage) will react more slowly as they are better buffered against climate change (Steenbergen & Turnhof, 2010). Due to lack of understanding of Kenyan aquifers, it is difficult to determine the degree to which they are sensitive to climate change (IPCC, 2001).Groundwater offers good opportunities for adapting to climate change because they serve as reservoirs which provide water even in the dry periods in anticipation of wet season recharge (Steenbergen & Turnhof, 2010).

2.10 Gaps Identified in literature

From the foregoing review, the importance of water quality monitoring for groundwater to ascertain its suitability for domestic use could not be overemphasized. Most of the literature on groundwater quality however highlighted the potential contaminants of this source but fell short of establishing the need to carry out regular water tests for water meant for domestic use. Numerous documented studies exist in Kenya on groundwater contamination but there are only a few that focused on assessment of seasonal variability of shallow wells and boreholes. For example (Devendra, *et al*., 2014) in their study in India on the analysis of ground water quality parameters did not put into consideration the effects of seasonal variability on these quality parameters. Another study done by (Ashun, 2014) assessed and mapped groundwater quality in Kiambu county, Kenya, found that all the shallow wells were in the high risk of contamination and he associated this to their proximity to cattle kraals, pit latrines and domestic waste dumps. This study did not also check on the effect of seasonality as a cause of the deteriorating quality of groundwater in the area. This research investigated the groundwater quality properties of Ruiru with emphasis on the quality properties of water from boreholes and shallow wells in the two extreme seasons. This study set out to assess the quality of groundwater in Ruiru and hence make recommendations which will be beneficial to the people.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 General information of the study area

The study was carried out in Ruiru sub-county of the Kiambu County in Kenya. Ruiru town is an up-coming urban town and is connected by both rail and road. The town covers an area of 292 km^2 (SIPA, 2006).This place is situated in Central, Kenya; its geographical coordinates are 1° 9' 0" South, 36° 58' 0" East. As of 2009, Ruiru's population stood at 238, 858 inhabitants, the rapid population growth being a response to the shortage of available housing in Nairobi (SIPA, 2006). The construction of Thika Super Highway and Northern Bypass placed Ruiru at a strategic point. Nairobi city is at a distance of 21 kilometers while Thika town at a distance of 17 kilometers from Ruiru.

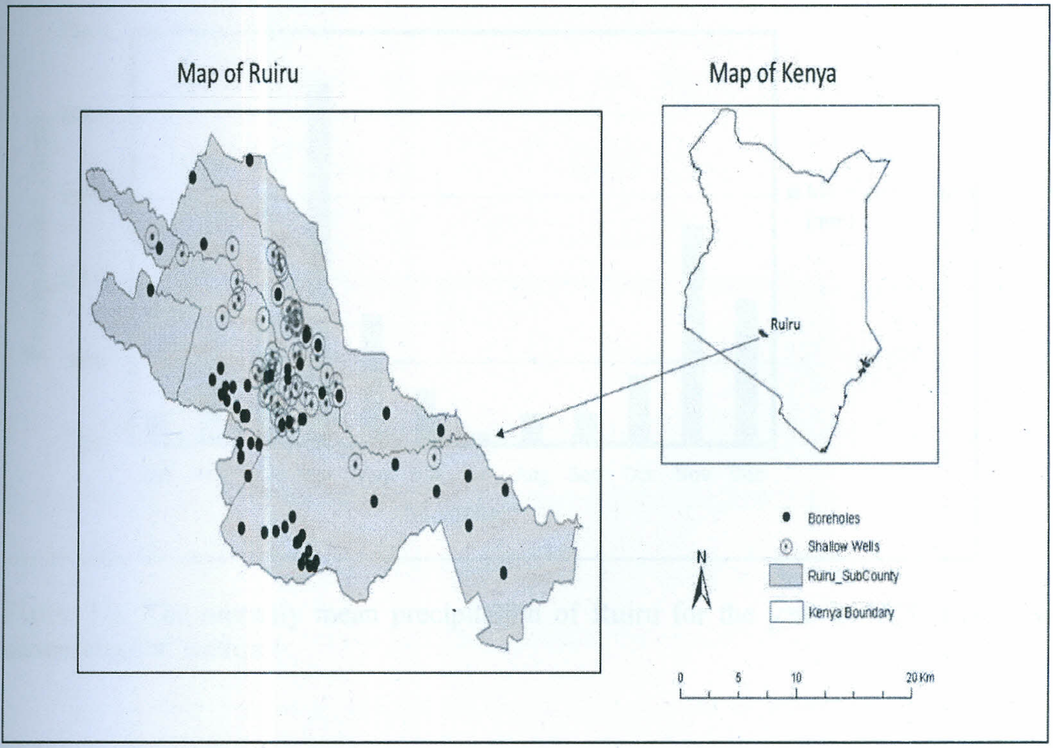

Figure 3.1: Map of Ruiru showing the boreholes and shallow wells sampling points.

3.2 Climatic conditions of Ruiru

The climate in Ruiru is warm and temperate. There is much less rainfall during the cold seasons than during the hot season, a characteristic of the tropical climate.

3.2.1 Rainfall

The average annual rainfall in Ruiru is 797 mm. The rainfall distribution pattern is bimodal with long rains commencing from March to May and short rains from October to December. The maximum and minimum rainfall received is 218.7 mm and 7.0 mm in April and July, respectively (Figure 3.3).

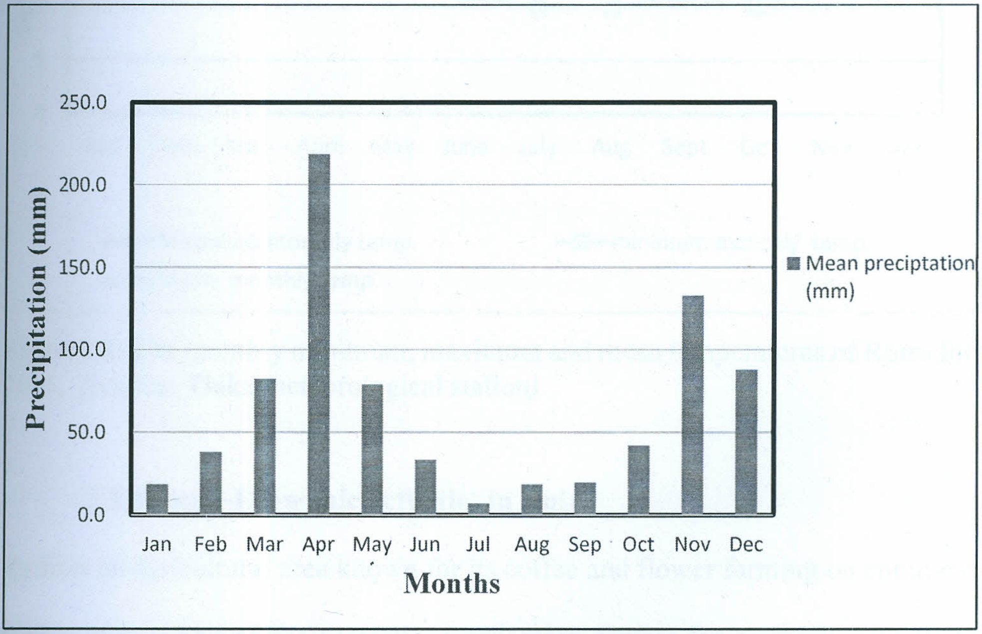

Figure 3.2: The monthly mean precipitation of Ruiru for the year 2015(Source: Thika meteorological station)

3.2.2 Temperature

The average annual temperature in Ruiru is 19.5 °C .The mean annual temperature varies between 15°C to 19.5°C while in the mean minimum temperatures vary between 18°C and 22°C. The annual maximum temperatures range from 21°C to 26°C in the months of August and February, respectively, while the minimum temperatures range from 10°C and 14°C in the months of February and April, respectively, as shown in figure 3.4.

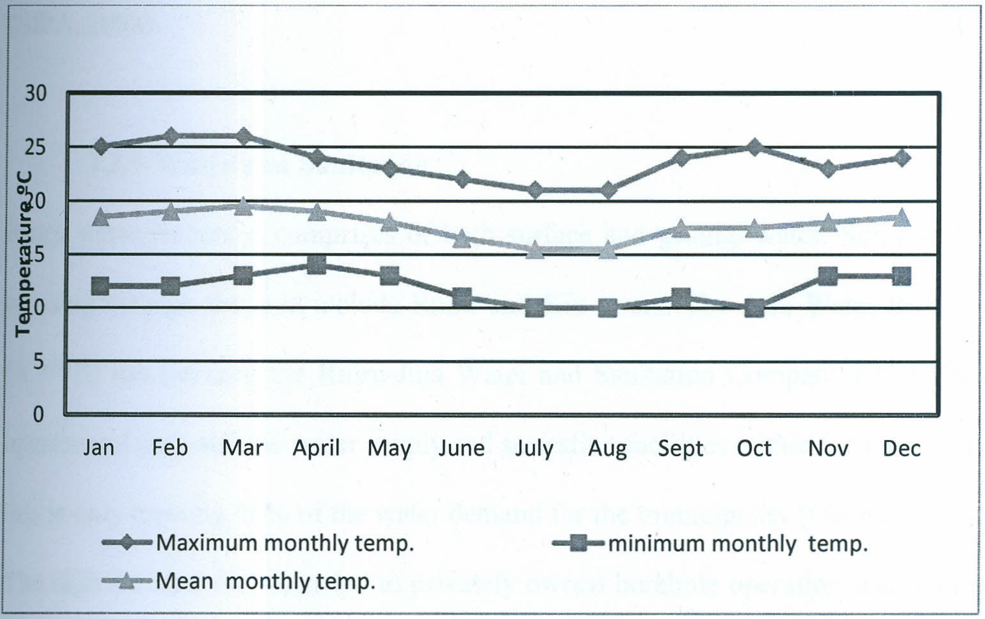

Figure 3.3: The monthly minimum, maximum and mean temperatures of Ruiru for the year 2015. (Source: Thika meteorological station*)*

3.2.3 Social-Economic activities in Ruiru

Ruiru is an agricultural area known for its coffee and flower farming on commercial scale (SIPA, 2006). The coffee plantations and green houses for production of flowers offer employment opportunities to the people in the area. The area is also an upcoming industrial hub and therefore harbors industries which not only provide employment to the residents but also contributed to the growth of the area economically (SIPA, 2006).

3.2.4 Soils and Geology

Ruiru is located on the slopes of the Aberdare Range and the land is generally undulating with a general drainage pattern towards the Athi River basin. The geology of Ruiru comprises of tertiary volcanic rocks. The area is dominated by an alkaline volcanic activity producing a large succession of lavas and associated tuffs. The soils in the study area are derived from volcanic rocks are tend to be dark reddish brown, well drained and friable (SIPA, 2008).

3.2.5 Water and Sanitation

Ruiru water resources comprises of both surface and ground water. Some of the rivers crossing through the area include Ruiru and Kiu rivers. The Athi Water Services Board (AWSB) has licensed the Ruiru-Juja Water and Sanitation Company (RUJWASCO) to operate and maintain the water supply and sanitation facilities within the municipality. But this is only meeting 14% of the water demand for the municipality (Obando, *et al.*, 2014). The high demand for water led to privately owned borehole operation and shallow wells proliferation within the Ruiru Municipality predominantly in the densely populated areas that do not have connections to piped water (RMPDP, 2007).Ruiru lacks sanitation facilities and an elaborate solid waste disposal system and therefore poses a health risk to the residents. Lack of an elaborate sewer system in the area compels the people to use septic tanks and soak pits for waste disposal. Since there are no laws governing the digging of shallow wells, anyone who feels needs one goes ahead to dig one regardless their health concerns (SIPA, 2006).

3.3 The Study design

This study used quantitative research methods. The study adopted a Stratified Random Sampling method (Orodho, 2003; Kothari, 2008). The sampling sites were selected through simple random sampling. This is because the wells are distributed all through the area and it was important to give each well an equal chance of being in the study.

3.4 Target Population

A preliminary survey preceded the actual study in the months of November to December 2014. The aim was to establish the number of shallow wells in the area and their general conditions. The preliminary study found out that for most people in Ruiru, water is used for more than drinking, cooking, and washing, whether or not systems are designed and developed for such uses. The sources of water for domestic and irrigation uses are from surface water and the shallow wells as the water from the water service provider (WSP) was not adequate. The surface water source from the Ruiru River was heavily polluted and thus not frequently used leaving the people in the area with the option of using water from the boreholes and shallow wells for their domestic use. It was established that there were 139 shallow wells across Ruiru, some of which dried up during the dry season.

3.5 Sample Size

Yamane simplified formula to calculate a sample size was used. A 95% confidence level and P = 0.5 are assumed for the Equation (Israel, 2009.).

$$n = \frac{N}{1 + N(e)^2}$$

Where;

n = Sample size

e = error limit (0.1)

N = the population size

According to WRMA the number of boreholes in Ruiru is 104 (WRMA, 2010).

Therefore; borehole sample size (n) = 104 /1 + 104 $(0.1)^2$= 50.980

For the shallow well sample size (n) = 139/ (1+139) $(0.1)^2$=58.159

Thus 51 deep wells and 58 shallow wells were considered in the study.

3.6 Groundwater Sampling and Preservation

A total of 109 groundwater samples from various boreholes and shallow wells from the study area were collected. With the help of water resources management Authority (WRMA) field officers, wells were located for sampling. GPS was used for getting well positioning in the area. The locations of various sampling points were taken using GPS as shown in Figure 3.2. The temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured in the field. These water samples were collected from 51 boreholes and 58 shallow wells. The field sampling was done during the dry (January to February) and the wet (April to May) seasons. This period was selected in order to cover overall variation in groundwater quality during the two seasons. All the samples were collected using appropriate method as described by (APHA, 2005) in Standard method of Examinations of water and waste waters.

Samples for microbiological analysis were collected aseptically in sterilized glass sampling bottles. The bottles were cleaned well with detergent, rinsed thoroughly with clean water before oven drying. The tops were capped loosely and wrapped with an aluminum foil. Sterilization of the bottles was done in an autoclave at a temperature of 121 °C for fifteen (15) minutes. In the case of boreholes, the outlet tap was opened to the full to flush out water, wiped using spirit before sterilizing it using a flame. For the shallow wells, a metallic sampling cup tied on a rope was used to obtain water from the well. The cup was sterilized using a flame before sampling each shallow well. All samples were properly labeled with a code, details of the source, date and time of sampling. The samples were transported to the laboratory for further analysis in cool boxes stacked with ice cubes for testing within 24 hours after sampling (APHA, 2005). Water samples for physical chemical analysis were collected in clean 1 litre plastic bottles. The bottles were washed with a detergent and rinsed with distilled water and finally with the sample before sampling. The samples were well labeled and then transported in cool boxes to the Central water testing laboratories for further analysis.

3.7 Materials and reagents

The analysis was carried out at the Central Water Testing Laboratories (CWTL) - Nairobi, Kenya. Reagents used in analysis were of analytical grade. Distilled water was used in preparation of solutions. They were all prepared using standard methods as highlighted by

(APHA, 2005). Distilled water was used throughout the procedures. The materials used in the study included borehole and shallow well logs, GPS equipment and ArcGIS software and different instruments as highlighted below.

3.8 Field Analysis

The physical parameters which included pH, electrical conductivity, temperature, colour and turbidity were determined *in-situ* at each sampling station.

3.8.1 Determination of Temperature.

Temperature is the degree of hotness or coldness of a liquid. Temperature was determined in situ by immersing a thermometer and a reading was recorded.

3.8.2 Determination of pH

Potentiometric determination of pH was done in situ using a portable pH meter (Winlab Dataline, Windaus Labortechnik).The pH was prior calibrated using three buffers; pH 4, pH 7 and pH 9.2. At each level of analysis, the probe was thoroughly rinsed using distilled water before and after each reading and thereafter lowered into the sample and stabilized readings were taken.

3.8.3 Determination of colour test

Colour was determined by the visual comparison method. Colour test was conducted using Lovibond Nesserriser equipment. Comparison of water colour with that of glass disks was used. One glass tube was filled with the sample and the other with distilled water. Using distilled water as the blank, sample colour was matched with the colored glass disks when viewing by looking towards a white surface. Each disk was calibrated to correspond with the colors on the platinum-cobalt scale.

3.8.4 Determination of turbidity

Turbidimetric method was used for turbidity determination. A portable turbidity meter (Model 6035, JENWAY). The meter was standardized to zero NTU using distilled water, then 80 NTU standard and finally 40 NTU standard. The sample was shaken, poured into a cuvette and readings taken.

3.8.5 Determination of Electrical conductivity and TDS

In situ determination of EC/temperature was done using conductivity meter. Before analysis, the conducting cells were calibrated with known standards whose reading had been pre-determined. At each level of analysis, the probes cells were thoroughly rinsed using distilled water followed by running the control for the experiment. The conductivity cells were then lowered into the sample and standardized reading for EC and temperature taken concurrently in micro Siemens units and degrees centigrade respectively. The TDS readings were also taken in mg/l.

3.9 Laboratory Analysis

The chemical parameters analyzed included ions such as Calcium (Ca 2+), Magnesium (Mg $^{2+}$), Chloride (Cl $^{-}$), Sulphate (SO42+), Fluoride (F-),Nitrates (NO3-), Nitrite (NO_2^-),Iron (Fe $^{3+}$) and Manganese (Mn $^{2+}$). Total Alkalinity (TA) and Total Hardness

(TH).Each sample collected underwent analyses of all parameters mentioned using standard methods for examination of water and wastewater (APHA, 2005)

3.9.1 Total alkalinity

Titration method was used to determine total alkalinity. The principle behind this method is that hydroxyl ions present in a sample as a result of dissociation or hydrolysis of solutes reacting with standard Sulphuric acid. The pH of sample is determined and then the sample is titrated with Sulphuric acid (0.02 N) to a pH of 4.5.

3.9.2 Total hardness

A volume of 50 ml of sample was taken and 1 ml total hardness buffer (ammonium hydroxide solution) was added to the sample. A spatula of the total hardness indicator was added to the solution and titrated against 0.01 N EDTA solution. The colour change from pink to blue was the end point of the titration. The titre volume was read, recorded and multiplied by 20 by dilution factor (D.F).

3.9.3 Calcium and magnesium hardness

To determine calcium hardness, 1.5 ml of Ca^{2+} buffer (Sodium Hydroxide 0.1 N) was added to 50 ml of the sample in a beaker. A spatula of calcium indicator (Murexide) was added and titrated against 0.01 N EDTA until the colour turned purple. Magnesium was calculated from the difference of total hardness and calcium hardness. Titration was carried out immediately after adding the indicator because it is unstable under alkaline media.

3.9.4 Nitrates

Concentration of nitrates (NO_3^-) was determined by the use of ultraviolet spectrophotometric screening method. Standard concentrations were made to obtain a standard curve of Absorbance versus concentrations. Absorbance of standards was read using U-V mini 1240 by Shimandzu. A volume of 50 ml of sample was poured into a beaker and 1.0 ml of nitrate buffer added. Nitrate readings of the sample were read at 220 nm and 275 nm. Because dissolved organic matter may also be absorbed at 220 nm and nitrates does not absorb at 275 nm, this second reading is used to correct the nitrate value. Filtration of the sample was done to remove the suspended particles. 1 ml of 1 N HCL is added to a 50 ml sample to prevent interferences from hydroxide or carbonates. A graph of readings (Absorbance) against concentration (mg/l) was drawn using the standards' readings (Appendix I)

3.9.5 Chlorides

This was determined by Argentometric method which involves titration with standard silver Nitrate solution 0.0141 N. The conductivity of the sample was checked so as to give a guide on which sample required to be diluted. Samples with higher conductivity of greater than 1,000 µS/cm were diluted with distilled water. A volume of 50 ml of the sample was measured into a beaker after shaking thoroughly. 1 ml Potassium chromate (K_2CrO_4) indicator was added into the sample and titrated against 0.0141 N Silver Nitrate ($AgNO_3$) to an end point where the colour changed to pinkish yellow. The blank was prepared from distilled water and treated the same way as the samples. The amount of the titrant used was recorded and the chloride concentrations were estimated from the used volumes of titrant after subtracting the volume consumed by the blank (APHA, 2005).

3.9.6 Sulphates

Sulphates readings were calculated from free turbidity measurements using turbidimetric method. The turbidity meter was standardized as in free turbidity test. A volume of 50 ml of the sample was taken into a conical flask and sulphate buffer (conditioning reagent) 2.5 ml was added. A spatula full (or 1 g) of barium chloride 2-hydrate ($BaCl_2 .2H_2O$) was added and stirred for one minute. The solution was put into a cuvette and turbidity measured. If on addition of $BaCl_2$ the sample turned too milky, the original sample was diluted and dilution factor noted.

3.9.7 Potassium and Sodium

Potassium and sodium ions were determined by flame photometric method. Trace amounts were determined in a direct reading of a frame spectrophotometer at wavelength of 766.5 nm for potassium and wavelength 589 nm for sodium ions. In case the sample was highly concentrated, which was indicated by high conductivity, it was diluted to a factor. The equipment was standardized by standards 2 mg/l, 5 mg/l and 10 mg/l and 1 ml of sample analyzed.

3.9.8 Iron

Iron was determined by phenanthroline method. A 50 ml sample was measured and digested with 2 ml concentrated HCL and 1 ml Hydroxylamine solution ($NH_2OH.HCL$) to a volume of 15 ml. Standards prepared the same way were used for calibration. Colorimetric readings were then obtained at 510 nm.

3.9.9 Manganese

Manganese concentration in the samples was determined by persulfate method. 100 ml of sample was digested in the presences of 5 ml special reagent. (special reagent comprises of 75g mercuric sulphate, 400 ml concentrated Nitric acid, 200 ml 85% phosphoric acid, 200 ml distilled water and 35 mg of silver nitrate, all this top up in litre of distilled water).The digestion is done to a volume of 90 ml and 1gram of Ammonium persulfate ($(NH_4)_2S_2O_8$) was added and brought to boil for about 1 minute and removed. Cooling was done under running tap water. Various known standard manganese solutions of different concentrations were prepared the same way and these were compared visually.

3.10 Microbiological Analysis

Once at the laboratory, the samples were allowed to warm to room temperature. The aseptic technique was employed at every step of analysis. 70% Isopropyl alcohol was used for disinfection of hands and working surfaces. Total coliforms and fecal coliform (*E.coli)* counts were performed using the defined substrate, Idexx Colilert -18/Quanti-tray Method for the Enumeration *E.coli* and coliform bacteria from water. These were chosen because the presence of the two in water is an indication of fecal contamination (Umaru *et al*., 2012).Colilert method uses the Defined Substrate Technology to simultaneously detect total coliforms and *E.coli*. In this method, two nutrient-indicators, o-nitrophenyl-β-Galactopyranoside (ONPG) and 4-Methylumbelliferyl- β-D-glucuronide (MUG) are the major sources of carbon in Colilert.

A volume of 100 ml of the water sample was measured into a sterile Duran bottle. One snap pack of the Colilert-18 (IDEXX) was transferred in the sample and content mixed by shaking gently until it dissolved. The mixture was then transferred into a Quanti-tray, 97 well (IDEXX) .The trays was taped gently in order to expel the trapped air and then left for a few minutes for the foam to dissipate and sealed in a pre-heated Quanti-tray sealer. They were incubated at a temperature of 35°C± 0.5 and 37 °C ± 0.5 for 24 hours. The trays were removed and the numbers of coliforms in the water sample was estimated by the number of positive wells (yellow in colour)using the standard most probable number (MPN) statistical table and recorded as MPN/100 ml.

3.10.1 Determination of total coliforms

The nutrient, o-nitrophenyl-β-Galactopyranoside (ONPG) in the Colilert is metabolized by the coliform enzyme β-galactosidase. As coliforms grow in Colilert, they use β-galactosidase to metabolize ONPG and change it from colorless to yellow. The positive wells (yellow) were counted and the MPN value read from the tables to give the number of total coliforms.

3.10.2 Determination of E.coli

For *E.coli* the trays were put in a cabinet under UV light of 6 watts at 365 nm. Under these conditions, the yellow wells which fluorescence showed the presences of *E. coli.* The *E.coli* uses β-glucuronidase to metabolize MUG to create a bluish fluorescence. Since most non-coliforms do not have these enzymes, they are unable to grow and interfere. The fluorescent wells were recorded and using the MPN tables their numbers were enumerated and recorded as MPN/100 ml of sample (IDEXX, 2011).

3.2 Data Analysis

The data obtained from the Physico-chemical and microbiological parameters were displayed on tables compared to World Health Organization (WHO) (2009) and Kenya Bureau of Standards (KEBS) (2006) to check if they fall within acceptable limits. The collected data was analyzed using Statistical Package for Social Scientists (SPSS) software version 20 to generate means and standard deviation so as to help in answering the research objectives. The student's t-test was used to test the formulated Hypotheses. Physical locations of the boreholes were read by the use of a GPS machine and mapping was done by the help of ArcGIS software.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the findings on the physico-chemical and biological characteristics of boreholes and shallow well waters in Ruiru. A comparison of the levels of the assessed parameters with the WHO and KEBS water guidelines for domestic use is given to ascertain its suitability. The effects of seasons (wet and dry) on the analyzed parameters are also discussed and finally a conclusion and recommendations are given. All the 109 groundwater samples that the study targeted were sampled. This represented 100% of the target sample population. The data was interpreted according to the research questions. The findings have been presented in this chapter in form of tables and graphs. Discussions on the same have also been done accordingly based on the outputs from Statistical Package for Social Sciences software.

4.2 Water quality characteristics and seasonal variability of borehole water

4.2.1 The physical characteristics of boreholes

The mean temperature, electrical conductivity (EC) and total dissolved solids (TDS) exhibited higher values during the dry season while mean values of colour, pH and turbidity were higher during the wet season (Table 4.1). The mean temperature of borehole water was 23.03 ℃ in the dry season against 21.81 ℃ in the wet season.EC and TDS had mean values of 533.04 µS/cm and 341.03 mg/l in the dry season and 497.04 µS/cm and 308.16 mg/l in the wet season respectively. Colour, pH and turbidity on the had mean values of 12.55 mgPt/l, 7.88 and 3.63 NTU in the dry season against 14.02 mgPt/l, 8.01 and 4.31

NTU in the wet season respectively (Table 4.1). All the physical attributes of borehole water were within the WHO and KEBS standard limits.

The dry season temperatures were higher than those of the wet season.The elevation of water temperature is attributed to various factors including solar radiation, heat transfer from the atmosphere, stream confluence and turbidity (Scannell & Jacobs, 2001). In this case the high temperatures were confined to the dry season and this was attributed to the warming effect of the relatively constant solar radiation that was experienced during the dry season. These findings are not different from those of (Ocheri & Ahola , 2007) in his study on seasonal variability of groundwater in Benue state, Nigeria. The student's t-test analysis performed on seasonal variability of the quality characteristics showed that there was a significant difference ($p \leq 0.01$) between the means of temperature for borehole water in both seasons (Table 4.1).

The mean pH values for boreholes were 7.88 and 8.01 in the dry and wet season respectively. There was a significantly different ($p \leq 0.05$) between the mean pH values of the borehole water in the dry and wet season. There is a slight increase in the mean pH values of borehole water during the wet season owing to leaching of dissolved salts into the groundwater (Garg, 2003).The nature of borehole water in the area is slightly alkaline. Similar trends have been reported in previous studies by Kannan and Sabu (2009) in his studies on groundwater in India. The difference was not significant ($p \leq 0.05$) for the rest of the parameters; colour, EC, TDS and turbidity (Table 4.1).

Table 4.1: Statistical analysis of the physical characteristics of borehole water in dry and wet season (n = 51)

		Physical parameters				
		Borehole Dry season	Borehole Wet Season			
Water Quality Parameter	Units	Mean ±Std. Error	Mean ±Std. Error	p-values	WHO (2009)	KEBS (2006)
Temperature	^{0}C	23.03±0.06	21.81 ±0.03	0.000***	—	—
Colour	mgPt/l	12.55 ±5.04	14.02±5.12	0.838	15	15
pH	—	7.88 ±0.04	8.01±0.04	0.04**	6.5 -8.5	6.5 -8.5
Electrical conductivity	(µS/cm)	533.04±22.42	497.04 ±23.80	0.274	2500	2500
Total dissolved solids	(mg/l)	341.03±15.47	308.16 ±14.76	0.128	1500	1500
Turbidity	NTU	3.63 ±1.04	4.31±1.66	0.731	5	5

Note: ***significant (1%); ** significant (5%); WHO-World Health Organization; KEBS-Kenya Bureau of Standards

4.2.2 The chemical characteristics of boreholes

Among the chemical parameters, there is a general increase in the mean values of most of the parameters during the wet season except for fluoride and manganese which show an increase during the dry season (Table 4.2).However there was no increase in potassium levels with the shift of season from dry to wet. Total hardness (TH), calcium (Ca), magnesium (Mg) and sodium (Na) showed an increase in the mean values of 74.41 mg/l, 19.7 mg/l, 6.12 mg/l and 79.08 mg/l in the dry season against mean values of 66.48 mg/l, 17.78 mg/l , 5.41 mg/l and 74.07 mg/l in the wet season respectively; while chlorides, nitrate, Sulphates and Iron also increased with mean values of 16.86 mg/l, 2.70 mg/l, 3.95 mg/l and 0.26 mg/l in the wet season against 15.2 mg/l, 2.3 mg/l, 3.28 mg/l and 0.19 mg/l in the dry season respectively. However most of the parameters were within both the WHO and KEBS standards limits except for fluoride and manganese.

Fluoride showed higher values of 2.27 mg/l in the dry season and 1.77 mg/l in the wet season. These concentrations were observed to be above the permissible limits of 1.5 mg/l for both Standards. Natural sources of fluoride in groundwater are associated with the type of rocks making up the aquifer containing the water (Griffioen, *et al.*, 2004). Its present in groundwater has also been connected to volcanic activities, the use of phosphatic fertilizers in agriculture and industrial activities like use of some types of clays in ceramic industries or burning of coals (Griffioen, *et al.*, 2004).The mean fluoride levels in boreholes were significant ($p \leq 0.1$) in the dry and wet season (Table 4.2). Fluorine can be leached out and dissolved in groundwater during recharge in the wet season which causes weathering of the rocks thereby increasing the concentrations of fluorides in water (Griffioen, *et al.*,

2004) and this could be the main contributing factor. The low values of fluoride observed in this case during the wet season can be attributed to the dilution effect due to the infiltration from the rainwater.

The mean manganese values for borehole water were 0.50 ±0.06 mg/l for the dry season and 0.05±0.01 mg/l in the wet season. The dry season manganese concentrations were within the KEBS standards of 0.5 mg/l but exceeded the WHO permissible limits of 0.1 mg/l. The student's t-test analysis performed on seasonal variability of the quality attributes showed that there was a significant difference ($p \leq 0.01$) between the means of manganese in the dry and wet season (Table 4.2).Manganese in groundwater comes from rainfall, dissolution of manganese in minerals from surrounding rocks and leaching of manganese as it percolates through soils (IMnI, 2013).Manganese dissolves readily in oxygen poor water which is slightly acidic (MGWA, 2015; BGS, 2003). The high concentration of manganese exhibited during the dry season can be attributed to the fact that relatively low pH and anaerobic conditions in the waters manifested during the dry season. Manganese dissolution is supported by such conditions and probably during the wet season, the conditions were not favorable since the rain water recharging the groundwater came in with oxygen and at the same time the water was slightly alkaline.

Table 4.2: Statistical analysis of the chemical characteristics of borehole water in dry and wet season (n = 51)

		Borehole Dry season	Borehole Wet Season			
Water Quality Parameter	Units	Mean± Std. Error	Mean± Std. Error	p-values	WHO(2009)	KEBS(2006)
T.H as(CaCO3)	(mg/l)	74.41 ±6.98	66.48 ±7.58	0.444	500	500
Calcium	(mg/l)	19.7±1.95	17.78 ±1.69	0.463	100	150
Magnesium	(mg/l)	6.12±0.77	5.41 ±0.84	0.537	100	100
Sodium	(mg/l)	79.08 ±3.43	74.07 ±3.89	0.337	200	200
Potassium	(mg/l)	13.04 ±1.14	13.06±1.1	0.993	50	50
TA as (CaCO3)	(mg/l)	133.37 ±12.21	121.18 ±13.48	0.504	500	500
Chloride	(mg/l)	15.2 ±2.24	16.86±2.66	0.636	250	250
Fluoride	(mg/l)	1.77 ±0.16	2.27±0.23	.079*	1.5	1.5
Nitrate	(mg/l)	2.37 ±0.42	2.7±0.39	0.571	10	10
Sulphates	(mg/l)	3.28 ±0034	3.95±0.41	0.213	450	450
Iron	(mg/l)	0.19 ±0.05	0.26±0.06	0.402	0.3	0.3
Manganese	(mg/l)	0.50 ±0.06	0.05±0.01	0.002***	0.1	0.5

Note: ***significant (1%); ** significant (5%);* significant (10%); WHO-World Health Organization; KEBS-Kenya Bureau of Standards; TH-Total hardness; TA-total Alkalinity

4.2.3 Microbiological characteristics of boreholes

The mean total coliform and *E.coli* counts are 0.05 MPN/100 ml and 37 MPN/100 ml for the dry season respectively while in the wet season total coliforms recoded values of 419 MPN/100 ml and 319 MPN/100 ml for *E.coli* (Table 4.3). On seasonal variability, higher values are exhibited during the wet season. The contamination can be attributed to increased infiltration during the wet season. Similar studies by (Nwachukwu & Ume , 2013)attributed the high coliforms numbers in the water to be due to feacal contaminated. Sources of these coliform bacteria in water is attributed to human and /or animal wastes, sewage, and other unsanitary practices (Okonko *et al*., 2008).The total coliforms for the dry season are within the permissible limits of KEBS of 10 MPN/100 ml but above the WHO recommendations of 0 MPN/100 ml while that of the wet season exceeds the permissible limits for both standards. The mean *E.coli* levels during both seasons exceeded the permissible limits of Nil MPN/100 ml for both standards. However, the mean levels of the total coliforms and *E.coli* for the boreholes were not significantly different ($p \leq 0.05$) in both season.

Table 4.3: Statistical analysis of the microbiological parameters of borehole water in dry and wet season (n = 51)

		Microbiological parameter				
		Borehole Dry season	Borehole Wet Season			
Water Quality Parameter	Units	Mean± Std. Error	Mean± Std. Error	p-values	WHO(2009)	KEBS(2006)
Total coliform	MPN/100 ml	37.06 ±21.28	419.04±114.39	0.121	0	10
E.coli	MPN/100 ml	0.05 ±0.02	319.49±97.6	0.509	0	0

Note: Number of samples=51; WHO-World Health Organization; KEBS-Kenya Bureau of Standards;

4.3 Water quality characteristics and seasonal variability of shallow well waters.

4.3.1 The physical characteristics of shallow wells

The mean values for temperature, colour, pH, EC, TDS and turbidity were 25.23, 7.49 mgPt/l, 5.06, 647.94 µS/cm, 393.21 mg/l and 12.26 NTU for the dry season and 23.49° C, 36.64 mgPt/l, 7.59, 718.24 µS/cm, 457.3 mg/l and 14.03 NTU for the wet season respectively (Table 4.4). Increasing trends were exhibited during the wet season in all the parameters except for temperature which is high in the dry season. All other parameters were within the permissible limits for both WHO and KEBS except for turbidity in both seasons, pH in the dry season and colour in the wet season. The increase in most of the parameters especially EC and TDS is an indication of high solutes and can be attributed to pollution of the shallow wells by the surface run-off which carries with it all the dissolved substances (Fatoki, *et al*., 2002). However there was no significance difference ($p \leq 0.05$) between the means of the parameters in the dry and wet season.

The pH levels for the shallow well waters were 5.06 ± 0.17 in the dry season and 7.59 ± 0.08 in the wet season. The dry season pH values were lower than the permissible range of 6.5 – 8.5 for both WHO and KEBS. The water was slightly acidic in the dry season. Water with low pH is acidic, corrosive and could contain dissolved metal ions in elevated levels.

Table 4.4: Statistics analysis of physical attributes of Shallow wells water in the Dry and Wet seasons (n= 58)

Water Quality Parameter	Shallow well dry Season		Shallow well Wet Season			
	Units	Mean± Std. Error	Mean± Std. Error	p-values	WHO (2009)	KEBS(2006)
Temperature	^{0}C	25.23±3.39	23.49 ± 0.09	0.610	—	—
Colour	mgPt/l	7.49 ± 0.12	36.64±9.23	0.476	15	15
pH	—	5.06 ± 0.17	7.59±0.08	0.521	6.5 -8.5	6.5 -8.5
Electrical conductivity	(µS/cm)	647.94 ± 53.27	718.24±56.34	0.366	2500	2500
Total Dissolved Solids	(mg/l)	393.21 ± 33.43	457.3±37.44	0.204	1500	1500
Turbidity	NTU	12.26 ± 3.84	14.03±4.04	0.752	5	5

Note: WHO-World Health Organization; KEBS-Kenya Bureau of Standards

4.3.2 The chemical characteristics of shallow wells

Most parameters showed increasing trends during the wet season except for chloride, fluorides, sodium, Sulphates and manganese which showed a reduction in the wet season. All other parameters were within the permissible limits of both WHO and KEBS except for nitrates with mean values of 12.12 mg/l for dry season and 12.87 mg/l for the wet season. These levels were above the permissible limits of 10 mg/l for both the standards. Considering that Ruiru is an agricultural zone, increased use of dissolved agricultural pollutants especially fertilizers may have resulted to input of nitrates and nitrites. Since nitrates and nitrites are generally soluble, this implies that they might have easily seeped into the groundwater (Olago, 2008). The mean Iron levels exhibited high concentrations of 0.36 mg/l (dry season) and 0.58 mg/l (wet season).These values were above the permissible limits of 0.3 mg/l for Iron for both standards (Table 4.5). The student's t-test analysis performed at 95% confidence interval showed that there was no significance difference ($p \leq 0.05$) in all the chemical parameters of the shallow well water in the two seasons (Table 4.5).

Table 4.5: Statistics analysis of chemical attributes of Shallow well water in the Dry and Wet seasons (n =58)

		Shallow well dry season	Shallow well wet season			
Water Quality Parameter	Units	Mean± Std. Error	Mean± Std. Error	p -values	WHO (2009)	KEBS (2006)
Total hardness as $CaCO_3$	(mg/l)	139.38 ± 18.35	197.72±56.18	0.326	500	500
Calcium	(mg/l)	32.99 ±5.76	37.93±6.80	0.580	100	150
Magnesium	(mg/l)	16.02 ± 2.52	31.25±11.66	0.204	100	100
Sodium	(mg/l)	78.44 ±7.8	68.08±7.34	0.336	200	200
Potassium	(mg/l)	13.47 ± 4.45	15.54±3.22	0.558	50	50
Total Alkalinity as $CaCO_3$	(mg/l)	184.19 ± 17.66	203.16±16.77	0.438	500	500
Chloride	(mg/l)	55.54 ± 8.63	50.10±7.01	0.625	250	250
Fluoride	(mg/l)	1.41 ± 0.27	1.10±0.21	0.386	1.5	1.5
Nitrate	(mg/l)	12.12 ± 2.68	12.87±2.69	0.844	10	10
Sulphates	(mg/l)	18.39 ± 2.42	17.25±2.37	0.609	450	450
Iron	(mg/l)	0.36 ± 0.10	0.58±0.15	0.233	0.3	0.3
Manganese	(mg/l)	0.09 ± 0.03	0.08±0.02	0.725	0.3	0.3

Note: WHO-World Health Organization; KEBS-Kenya Bureau of Standards ;(Source: Laboratory Analysis Appendix 2015)

4.3.3 Microbiological characteristics of shallow wells

The mean values for total coliforms for the dry and wet season of the sampled shallow wells were 1804.22 MPN/100 ml and 2097.4 MPN/100 ml respectively while those of *E.coli* were 277.31 MPN/100 ml for the dry season and 1524.33 MPN/100 ml for the wet season. This study reveals that all the shallow wells were contaminated in both seasons and the trend increased even more in the wet season as shown by the increased microbial loads in the same season. All the shallow wells exceeded the permissible limits of 0 MPN/100 ml (WHO) and 10 MPN/100 ml (KEBS) for total coliforms and 0 MPN/100 ml for *E.coli* for both standards. There was a significant difference ($p \leq 0.05$) between the means of the total coliforms concentration for shallow wells in the dry and wet season and for *E coli* the difference was significance ($p \leq 0.01$) as shown in (Table 4.6). The contamination can be attributed to increased infiltration during the wet season and that these wet conditions favors the movement and reproduction of the organisms especially from surface run off, sewage and waste material. The majority of the populations in the area live in the slums and they lack proper sanitation. Indiscriminate defecation and the use of pit latrines is a common practice, especially in slum areas (Simiyu, 2015).These findings are consistent with the findings by Mwaguni (2002) whose studies on effects of sewage on public health also confirmed the wide spread contamination of groundwater by sewage and pit latrines in Mombasa.

Table 4.6: Statistics analysis of microbiological attributes of Shallow well water in the Dry and Wet seasons (n=58)

		Microbiological parameters				
		Shallow well dry season	Shallow well wet season			
Water Quality Parameter	Units	Mean± Std. Error	Mean± Std. Error	p -values	WHO (2009)	KEBS (2006)
Total coliforms	MPN/100 ml	1804.22±108.7	2097.4±80.3	0.032^{**}	0	10
E.coli	MPN/100 ml	277.31±74.8	1524.33±131.2	0.000^{***}	0	0

Note: WHO-World Health Organization; KEBS-Kenya Bureau of Standards;

4.4 Comparison of water quality characteristics of borehole and Shallow wells

The levels of the physicochemical and microbiological characteristics in the present study revealed a wide range of variations in the quality of the shallow wells and boreholes.

4.4.1 Comparison of the physical characteristics between borehole and shallow well waters.

From the mean differences, majority of the elements in the shallow wells are higher than those of the boreholes except for the pH. The student's t-test analysis performed at 95% confidence interval showed that , the mean levels of turbidity (NTU) are significant ($p \leq 0.05$) between the boreholes and shallow wells while temperature, pH, electrical conductivity (µS/cm) and Total dissolved Solids (mg/l) are significant ($p \leq 0.01$) (Table 4.7). The shallow wells exhibited higher mean temperature of 25.23 ºC against 23.03 ºC for the boreholes in the dry season and 23.49 ºC against 21.81 ºC for shallow well and boreholes in the wet season respectively (Table 4.1 and 4.3).The mean temperature for boreholes and shallow wells are significantly different ($p \leq 0.01$) in the dry season but the difference is not significant ($p \leq 0.05$) in the wet season. The higher mean temperatures in the shallow well could be attributed to the fact that most of their depths are closer to the surface and tend to have the sun's direct influence as compared to the boreholes which tend to be deep and therefore their waters tend to be cool. Temperature affects physical, chemical and biological processes in water bodies. As water temperature increases, the rate of chemical processes generally increases and the solubility of gases in water such as oxygen, carbon dioxide, Nitrogen and others decrease (WHO, 2011). This eventually impact on the taste, colour and odour and thus the acceptability.

The mean pH values of boreholes and shallow wells are significantly different ($p \leq 0.01$) in both dry and wet season (Table 4.7). Results showed that the borehole water samples gave pH values suitable for drinking purposes in both seasons. As earlier seen in the discussion, boreholes have higher pH as compared to the shallow wells in the study area. Thus the boreholes are more of alkaline type while the shallow wells show slightly acidic trends. The low values of water pH can be attributed to the dissolution of carbon dioxide in to the groundwater via leachates produced during the decomposition of the waste materials (Lawal *et al.*, 2013). Similar trends have been reported in previous studies by Kannan and Joseph (2009).The high pH in some of the wells can be attributed to the influence of fertilizers like ammonium Sulphates and super phosphate in agriculture and to some extent the sulphur and amino acid compounds from human and animal excreta(Navaraj & Krishnammal, 2012).Low pH values in groundwater can cause gastrointestinal disorders like hyper acidity, ulcers and stomach pain with burning sensation (Rajesh *et al.*, 2001).

From the mean differences, the shallow wells have higher turbidity in both seasons as compared to boreholes (Table 4.7). A previous study by (Orisakwe & Kanayochuku, 2008) confirms the same. The mean turbidity values of boreholes and shallow wells are significant ($p \leq 0.05$) in both seasons. Comparatively higher levels of turbidity were recorded in shallow wells and could be attributable to soil erosion, increase in the influx of surface runoff into the water (MPCA, 2008). The high turbidity is often associated with higher levels of pathogenic microorganisms (Schwartz *et al.*, 2000). Turbidity values over the two seasons showed some remarkable differences. Turbidity directly influences the colour of water and there is a general increase in colour with increasing turbidity values. The turbidity values recorded in the dry season for the shallow wells almost doubled in the wet season. This can be attributed to increased infiltration (peculation) into the aquifers during the raining season leading to increased dissolution of substances that made the ground water turbid. However in the dry season when there is virtually no infiltration into the aquifers, most of the dissolved substances settle down leading to a reduction in the overall turbidity of the water. Turbidity in water causes increases the cost of water treatment and may also increase the possibility of microbiological contamination (Momba *et al*., 2006).

Electrical conductivity (EC) indicates the presence of dissolved solids and contaminants but does not specify the chemicals. There is a significance difference ($p \leq 0.01$) between the mean EC levels of the boreholes and shallow wells in both seasons (Table 4.7). The electrical conductivity of the water sample is completely proportional to the TDS value and thus increases with increase in EC. Boreholes have electrical conductivity with mean values of 533.04 μS/cm and 497.04 μS/cm in the dry and wet seasons respectively. Shallow wells contain comparatively higher mean levels of Electrical Conductivity of 647.94 in dry season and 718.24 in the wet season. Electrical conductivity in shallow wells was noted to be higher in the wet season than the dry season and vice versa for boreholes. The high EC in boreholes during the dry season is due to concentration build-up of the minerals associated with low water volumes. It may also be contributed by the geology, soil and land use activities in the environment (Ocheri & Ahola , 2007).

Total dissolved solids (TDS) measures the total amount of dissolved minerals in water. It gives the total sum of concentrations of all dissolved constituents in water. The TDS levels of the water will depend on the amount of soluble minerals that comes in contact with it. TDS content is usually the main factor, which limits or determines the use of groundwater for any purpose (WHO, 2011). Total dissolved solids (TDS) are an indicator of polluted water and determine the water's palatability and acceptability. From the mean differences, the shallow wells exhibit higher mean values of total dissolved solids as compared to boreholes. There was a significance difference ($p \leq 0.01$) between the mean TDS values of the boreholes and shallow wells in both seasons (Table 4.7). Season wise, the mean values show that the concentrations are high during wet season. The increase of TDS in the wet season could be attributed to weathering intensity; and the increased amount of groundwater recharge (Makwe & Chup, 2013). These findings are similar to that of Satyanarayana *et al.* (2013) in study on the groundwater in India.

Table 4.7: Independent Samples t-test of means of Boreholes versus shallow wells Dry and Wet Season (n=109)

Physical Parameters				
Water quality parameter	B/hole vs S/Well dry season		B/hole vs S/Well wet season	
	p-value	Mean Difference	p-value	Mean Difference
Temperature °C	0.000***	-1.68	0.547	-2.19
pH	0.000***	0.52	0.005***	0.28
Colour (mgPt/l)	0.119	-15.90	0.035**	-22.62
Electrical Conductivity(µS/cm)	0.012***	-150.90	0.003***	-185.20
Total Dissolved Solids (mg/l)	0.023***	-85.05	0.005***	-116.27
Turbidity (NTU)	0.034**	-8.63	0.029**	-9.72

Note: Number of samples = 109; ***significant (1%), ** significant (5%), * significant (10%); B/hole- borehole; S/Well-shallow well

4.4.2 Comparison of chemical characteristics of boreholes versus shallow well waters

In natural waters, the probable sources of chlorides comprise the leaching of chloride-containing minerals (like apatite) and rocks with which the water comes in contact, inland salinity and the discharge of agricultural, industrial and domestic waste waters (Sayyed & Bhosle, 2011). The use of potassium (K) containing fertilizers results in chloride contamination of recharging shallow groundwater.The mean chloride concentrations of sampled boreholes were 15.20 mg/l in dry season and 16.86 mg/l in the wet season. The shallow wells exhibited higher mean concentration of 55.54 mg/l and 50.10 mg/l in dry and wet seasons respectively but there is a decrease in the concentrations in the wet season. The high chloride levels in shallow wells could be attributed to anthropogenic sources of chloride like human and animal waste, use of fertilizers and industrial applications sources because chloride is readily transported through the soil (Sayyed & Bhosle, 2011) and considering the fact that they are shallow, they tend to be more polluted. Boreholes are deeper and therefore undergo a self -filtration process which probably prevents most solutes from dissolving in the water. Previous study by Kannan and Sabu (2009) observed similar trends. There was a significance difference ($p \leq 0.01$) between the mean chloride values of the boreholes versus shallow wells in the dry and wet season.

Shallow wells exhibit higher mean chloride values as compared to boreholes.The sources of chlorine in water may be from drainage waste and from dissolving rocks. Chloride in water may combine with sodium to form sodium chloride which can impacts a salty taste in the water thus making the water aesthetically undesirable for drinking purposes (WHO, 2011). The high chloride values in shallow wells can be attributed to leachates from the surface runoff. An increase in the mean value of chloride content of water may be an indication of possible pollution from human sewage, animal manure or industrial wastes (Mechenich & Andrews, 2004). Chlorides can travel a great distance in groundwater. They can get in groundwater from solid waste when it comes in contact with rain water and then gain entrance into aquifer. When combined with calcium or magnesium, it may increase the corrosive activity of water (Mechenich & Andrews, 2004). Chlorides in small concentrations are not harmful to humans in drinking water. However, concentration of above 250 mg/l may impart salty taste to water (Hauser, 2001).

Sulphates occur naturally in numerous minerals. Gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$) are generally the common sources of sulphate. The mean sulphate values of the boreholes are 3.28 mg/l and 3.95 mg/l in the dry and wet seasons respectively while those of shallow wells are 18.39 mg/l in dry season and 17.25 mg/l in the wet season. Sulphates in boreholes and shallow wells are significant ($p \leq 0.01$) in both season (Table 4.7).Shallow wells exhibited higher values than boreholes in both season. On seasonal variability, the wet season values are higher as compared to the dry season values. The source of sulphates in groundwater is through drainage waste or the dissolution of sulphur containing rocks. On the other hand, this may be as a result of high-level combustion of Sulphur containing hydrocarbon fuels in the study area (Efe *et al.*, 2005). Water with sulphate levels above the recommended can have a laxative effect until an adjustment to the water is made. Increased sulphate levels can cause deficiencies in trace minerals the most serious being thiamine deficiency (WHO, 2011).

Nitrate is a major problem in some shallow aquifers and is increasingly becoming a threat to groundwater supplies. There are numerous sources of nitrogen in groundwater systems. Most of them are strongly influenced by human activities. Nitrogen fertilizers are widely used in agricultural practice, organic nitrogen is present in number of waste products, notably sewage effluents, animal excrement and manure and municipal wastes. The mean nitrate levels of boreholes and shallow wells were significant ($p \leq 0.01$) in both seasons (Table 4.8). The mean nitrate values for the boreholes for the dry season were 2.37 mg/l and 2.70 mg/l in the wet season (Table 4.2). Shallow wells had mean values of 12.12 mg/l and 12.87 mg/l in dry and wet seasons respectively (Table 4.5). Shallow wells exhibited higher values than boreholes while season wise, the high nitrates were exhibited during the wet season. Nitrate concentration in most of the boreholes is below both WHO guidelines (Table 4.2).

The nitrate concentration in shallow well waters during both seasons was above the permissible WHO and KEBS standards. Nitrate is loosely bound to the soils and therefore dissolves in water during the rainy season. These findings are consistent with that of Kannan and Sabu (2009).The higher nitrate levels can be attributed to leachates from nitrogen fertilizers widely used in agricultural practice, waste, notably sewage effluents, animal excrement and manure and municipal waste (Akinbile & Mohd, 2011). High nitrate concentration causes methaemoglobinaemia (blue baby syndrome) in babies in which blood loses its ability to carry sufficient oxygen (WHO, 2011).The recommended amounts of nitrates is 10 mg/L.

Boreholes have high mean values of fluoride as compared to shallow wells (Table 4.7) as indicated by the mean differences. The boreholes recorded mean fluoride values of 2.27 mg/l in the dry season and 1.77 mg/l for the wet season while shallow wells show decreasing values of 1.41 mg/l and 1.10 mg/l in dry and wet season respectively. There is no significant difference ($p \leq 0.05$) between the means of boreholes and shallow wells in the dry season but significance exit ($p \leq 0.01$) between their means in the wet season (Table 4.7). Shallow wells exhibit lower levels of fluoride and this can be attributed to the fact that fluoride in groundwater is associated with the fluoride bearing rock which as reported earlier, the dissolution of fluoride bearing minerals may be contributing the high percentage of fluoride in borehole samples. The low fluoride levels observed in the shallow wells is due to the dilution effect from the rain water (Lilly *et al.*, 2012). In this case, the prevailing conditions which are slightly alkaline and moderate EC favored the dissolution of calcium fluoride in the potable water. The reduction of fluoride observed during the wet season is due to the dilution effect from the rain water which leads to increase in water table. Fluoride is one of the vital minerals required by the body for strengthening of the bones. Lack of fluoride in children nutrition can lead to failing of healthy teeth and bones production which may result to tooth decay or dental caries (Fawell *et al.*, 2006). Whereas, high concentrations of fluoride in water may results to dental or skeletal fluorosis which exhibit with mottling and yellowish or brownish teeth (Bramhanand & Ashok , 2010).

Water hardness is the measure of the capacity of water to react with soap to form lather (Eaton *et al.*, 2005). Hard water often produces a noticeable deposit of precipitate (e.g. insoluble metals, soaps or salts) in containers (Eaton *et al.*, 2005). The hardness is mainly caused by calcium and magnesium ions, although other cations like aluminum, barium, iron, manganese, strontium and zinc also contribute (WHO, 2011).The mean hardness values for the sampled boreholes were 74.41 mg/l and 66.48 mg/l in the dry and wet season respectively while those for shallow wells are 139.38 mg/l for the dry season and 197.72 mg/l for the wet season. According to (McGowan, 2000)water hardness as classified depending on the calcium carbonate content is as follows; at concentrations below 60 mg/l is generally considered as soft; 60–120 mg/l, moderately hard; 120–180 mg/l, hard; and more than 180 mg/l, very hard. Considering this classification, borehole water was found to be moderately hard while that of shallow wells was found to be hard in the dry season tending towards very hard in the wet season and this can be attributed to the climatic and geological type of the area. Further, geologically, and the rock type in the area could be associated with crystalline limestone.

Table 4.8: Independent Samples t-test of means of Boreholes versus shallow wells Dry and Wet Season (n=109)

Chemical parameters					
Water quality parameter		B/hole versus S/Well dry season		B/hole versus S/Well wet season	
	Unit	p-value	Mean Difference	p-value	Mean Difference
Total Hardness ($CaCO_3$)	mg/l	0.000^{***}	-72.89	0.034^{**}	-123.31
Calcium	mg/l	0.014^{***}	-15.20	0.012^{***}	-18.24
Magnesium	mg/l	0.000^{***}	-10.61	0.036^{**}	-25.13
Sodium	mg/l	0.611	-4.36	0.189	11.01
Potassium	mg/l	0.822	-0.42	0.486	-2.48
Total Alkalinity ($CaCO_3$)	mg/l	0.004^{***}	-63.02	0.002^{***}	-69.80
Chloride	mg/l	0.000^{***}	-40.334	0.000^{***}	-33.24
Fluoride	mg/l	0.284	0.36	0.000^{***}	1.17
Nitrate	mg/l	0.001^{***}	-9.42	0.000^{***}	-10.50
Sulphates	mg/l	0.000^{***}	-14.47	0.000^{***}	3.89
Iron	mg/l	0.150	-.169	0.000^{***}	-16.98
Manganese	mg/l	0.018^{***}	0.17	0.001^{***}	-.54

Note: Number of samples is 109, ***significant (1%), ** significant (5%), * significant (10%)

The leaching of calcium and magnesium from these rocks contributes to the hardness and to some extent, the agricultural activities involving the use of fertilizers and pesticides containing chemicals directly or indirectly affect the concentrations of a large number of inorganic chemicals in groundwater such as nitrates, chlorides, Sulphates, phosphates, potassium, magnesium and calcium levels (APHA, 2005).

Total hardness concentration of the sampled water was within the WHO guideline values of 500 mg/l and 300 mg/l for KEBS for drinking water in both seasons. The mean concentration of total hardness in water is higher during the wet season than in the dry season and its pronounced in shallow wells than in boreholes. This so because the solvent action of rainwater coming is capable of dissolving calcium and magnesium from the rocks, thus promoting water hardness (Eaton *et al.*, 2005). This effect is more pronounced in shallow wells by the agricultural activities which directly or indirectly affect the levels of concentrations of the inorganic chemicals in groundwater (Lilly *et al.*, 2012). Water hardness has no harmful effects on human health but it can affect the taste of water as well as reacting with soap to form scum and promote scale formation in boilers and in hot water systems (WHO, 2011).

Most of the alkalinity of natural waters is caused by bicarbonates, carbonates and hydroxides. The seasonal means for the boreholes and shallow wells were 121.18 mg/l and 184.19 mg/l in the dry and 133.37 mg/l and 203.16 mg/l in the wet season Table 4.1 and 4.4 Shallow wells have higher mean concentration as compared to the boreholes in both seasons. On seasonal variability, there is an increase in the wet season. This result confirms the findings of Lilly *et al*., (2012). All the boreholes and shallow wells exhibited alkalinity values below the permissible limit of 500 mg/L for both WHO and KEBS. It may also be noted that in polluted waters, other negative ions like phosphates and nitrates may contribute to alkalinity. The primary source of carbonate and bicarbonate ions in groundwater is the dissolution of carbonate minerals in the study area. The decay of organic matter present in the soil releases carbon dioxide (CO_2) which makes the water acidic resulting to dissolution of carbonate minerals, as it passes through soils and rocks to give bicarbonates .Total alkalinity was significant different ($p \leq 0.01$) between the mean value of the boreholes and that of shallow wells in both seasons Table 4.7.

The mean calcium values for boreholes and shallow wells were 19.7 mg/l and 32.99 mg/l for the dry season and 17.78 mg/l and 37.93 mg/l in the wet season respectively. Shallow wells exhibit higher values and on seasonal variability, the wet season higher concentrations especially in shallow wells while in boreholes there is a reduction. The increase in the calcium and magnesium in the shallow wells during the wet season can be attributed to the surface run-off which contains different types of substances that may result to their increase. For the boreholes the decrease exhibited during the wet season is due to the dilution effect from the rain water through infiltration to the ground water. However all the mean concentrations were within the WHO and KEBS calcium permissible limits of 100 mg/l and 150 mg/l respectively. As discussed above, high concentration of calcium contributes to hardness which does not promote formation of lather and thus not desirable in washing and laundering (Lilly *et al*., 2012). The main sources of Ca in groundwater resources are mainly the crystalline limestone associated with khondalitic rocks, but also prolonged agricultural activities prevailing in the study area may also directly or indirectly augment the mineral dissolution in groundwater (Makwe & Chup, 2013).The content of magnesium was comparatively less than that of calcium with mean value of 6.12 mg/l and 16.02 mg/l for borehole and shallow wells in the dry season while those for the wet season are 5.04 mg/l and 31.2 5 mg/l. The boreholes show lower concentrations as compared to shallow wells. Previous studies by (Kannan & Sabu, 2009) showed similar trends in their study on the quality of groundwater in the Shallow Aquifers in India. There is significance difference ($p\leq 0.01$) between the mean concentrations of the boreholes and shallow wells in both seasons.

The mean Iron values for the borehole and shallow wells were 0.19 mg/l and 0.36 mg/l for the dry season and 0.26 mg/l and 0.58 mg/l in the wet season. The shallow wells have higher Iron as compared to boreholes and the wet season exhibits higher values than the dry season. The boreholes values were within the recommended levels of 0.3 mg/l of both WHO and KEBS but the shallow wells values exceed the limits. There was no significance difference ($p\leq 0.05$) between the mean values of Iron for the boreholes and shallow wells in the dry season but significance exist ($p \leq 0.01$) between iron values of boreholes and shallow wells in the wet season. This connects with the study of Bolaji and Tse (2009) which observed that most shallow well water contains high iron concentration. This high concentration of metallic iron has a direct effect on the colour and turbidity in shallow wells during the wet season. The primary source of the iron in groundwater is from the weathering of Iron bearing mineral and rock (Askuland & Eldvall, 2005). The high iron levels in these waters could be attributed to natural sources such as the geochemical and biochemical processes (Tay & Kortatsi, 2008) and the dissolution of iron oxides within their aquifers.

High iron concentrations may not pose health hazards to users but cause colorations of the water and which may results to staining of laundry and scaling in pipes (WHO, 2011). The presence of iron in water may promote the growth of pathogenic organisms (Khan & Ahmed, 2001).Iron in ground water may originate from a variety of mineral sources. Oxidation-reduction potentials, organic matter content, and the metabolic activity of bacteria can influence the concentration of iron in ground water. Low concentrations in some of the bedrock systems may be attributed to precipitation of iron minerals from activity of reducing bacteria or by the loss of iron from cation-exchange processes (DNR, 2002).

The mean manganese value for the borehole and shallow wells were 0.50 mg/l and 0.09 mg/l for the dry season and 0.05 mg/l and 0.08 mg/l for the wet season. Boreholes exhibit relatively higher concentration than shallow wells .On seasonal variability, dry season show higher values. There is significance difference ($p \leq 0.01$) between the mean values of boreholes within the seasons as well as between the mean values of boreholes and shallow wells in the dry and wet season. The boreholes exhibited higher values during the dry season and thus exceeded the permissible value of 0.1 mg/l for WHO but were within the 0.5 mg/l of KEBS. Manganese is also a naturally occurring element in rocks and is released into the soil through weathering of the rocks. It can therefore be deduced that the high levels of manganese contamination is as a result of the underlying geological formation (rocks). Manganese like other trace metals is essential to the sustenance of life. Manganese is one of the minerals required besides molybdenum, selenium and zinc in very low concentrations as catalyst for enzyme activities. However, water with high levels of these essential metals or elements may be a risk to human health (EPA, 2004). Its contact to groundwater is however through leaching.

4.4.3 Comparison of microbiological quality of the borehole versus shallow well water

4.4.3.1 Coliform and *E.coli*

Total coliform bacteria are known as "indicator organisms" meaning that their presence provides indication that other disease causing organisms may also be present in the water body. Coliforms are aerobic or facultative anaerobic and hence, can live in both environments (with or without oxygen). The coliforms are indicative of the general hygienic quality of the water and potential risk of infectious diseases from water. The presence of these microorganisms in water causes water-borne diseases such as diarrhea, typhoid and hepatitis (WHO, 2011). A high coliform population in all the water samples is an indication of poor sanitary conditions in the area. Faecal coliforms (FC) of which *E.coli* is one of them, are the most commonly used bacterial indicator of faecal pollution (Igboekwe & Chukwunenyoke, 2012). They are found in water that is contaminated with faecal wastes of human and animal origin. Total coliforms (TC) comprise bacterial species of faecal origin as well as other bacterial groups (e.g. bacteria commonly occurring in soil). The result indicated that all the water samples were contaminated with faecal coliforms (faecal contamination). The mean total coliform values for the sampled boreholes are 0.05

MPN/100 ml (dry season) and 319.49 MPN/100 ml (wet season) while those for *E.coli* are 37.06 MPN/100 ml and 419.04 MPN/100 ml in the dry and wet season respectively table 4.3. Shallow wells recorded higher values of 1804.22 MPN/100 ml and 277.31 MPN/100 ml for TC and *E.coli* in the dry season and 2097.4 MPN/100 ml and 1524.33 MPN/100 ml in the wet season respectively (Table 4.6).

The shallow wells were more contaminated as compared to the boreholes with shallow wells recording higher total coliform values in the wet season. This is clearly indicated by the mean differences of borehole versus shallow wells of 1484.73(dry season) and 1678.357(wet season) (Table 4.9).The same applied to *E.coli* in which shallow wells exhibited higher mean differences of 240.25 and 1962.80 in the dry and wet season respectively. High coliform bacteria counts appear to be a characteristic of all the shallow wells in the study area, consistent with the findings of (Mwaguni, 2002)who determined the microbiological pollution status of groundwater sources in Mombasa. Season wise, groundwater contamination was more during the wet season. The contamination can be attributed to increased infiltration during the wet season. The high concentrations of these coliform during the wet season could be due to the fact that water availability favors the movement and reproduction of the organisms especially from surface run off, sewage and waste material. However, there is significance difference ($p \leq 0.01$) in the mean counts of total coliforms between boreholes and shallow wells in the dry and wet season. The mean *E.coli* concentrations are significant ($p \leq 0.01$) between boreholes and shallow wells in both seasons.

Table 4.9: Independent Samples t-test of means of Boreholes versus shallow wells Dry and Wet Season (n=109)

		Microbiological parameters			
		B/hole versus S/Well dry season		B/hole versus S/Well wet season	
Water quality parameter	unit	p-value	Mean Difference	p-value	Mean Difference
Total coliforms	(MPN/100 ml)	0.000^{***}	-1484.73	0.001^{***}	-1678.357
E.coli	(MPN/100 ml)	0.003^{***}	-240.25	0.000^{***}	-1962.80

Note***significant (1%), ** significant (5%), * significant (10%); B/hole-borehole; S/Well-shallow well,

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The general objective of this study was to evaluate groundwater quality in Ruiru and to ascertain its suitability for domestic purposes for an understanding of the present status of ground water quality in the area.

5.2 Summary of Findings

Groundwater contamination is one of the environmental problems in urban areas, resulting out of improved living standards, growing population and interference with natural eco-system. In this study, the majority of the physico-chemical characteristics of the water samples from the area were found to be within the WHO and KEBS recommended guide except for fluoride, nitrates and manganese. Water from boreholes seemed not to contain high levels of microbiological and physical-chemical contamination. However the analysis showed high mean levels of fluoride, which might pose a health risk on children below eight years of age. The analysis also showed that water from shallow wells was not adequate for human consumption too as it had significant levels of microbiological and physical-chemical contaminants. These are far higher than the contamination levels established by WHO and KEBS standards. In this case the levels of microbiological contamination represent the strongest concern, as high levels of *E.coli* were present in all sampled shallow wells. There was no significant difference $P \leq 0.05$ in the water quality characteristics between boreholes in both seasons, however the difference was significant ($p \leq 0.05$) in the microbiological characteristics of shallow wells during the dry and wet season. The difference in the water quality characteristics was also significant ($p \leq 0.05$) between the boreholes and shallow wells in the area.

5.3 Conclusion.

The compositions of the groundwater of the study areas showed that the water quality was poor in terms of bacteriological quality and is a major concern to public health. The presence of both total coliforms and E.coli in the groundwater is a sign of contamination from human or animal feacal and/or sewage.

The higher values of iron exhibited in shallow well waters, greater than WHO and KEBS standard from the study areas could also affect the taste of the water. The presence of considerable concentrations of fluoride in Ruiru groundwater samples is a major concern to public health too and would definitely affect the taste of the water. However, other parameters like pH, TDS, conductivity, sulphates, nitrates, potassium, total hardness, calcium, magnesium, chloride, Iron and manganese were within the permissible standard. In terms of abundance of ions, the predominant ions in the aquifers are: bicarbonate, sodium, potassium, chloride then sulphate, while calcium and magnesium levels were very low.

The results of the study showed that there was a significance difference ($p \leq 0.05$) in the quality characteristics of borehole and shallow well waters. The borehole water in Ruiru was less contaminated as compared to the shallow well waters. The shallow wells exhibited high numbers of total coliforms and *E.coli* in the sampled waters. On seasonal variability, the dry season showed higher concentrations of ions than the wet season. The low concentrations in the wet season compared to dry season was attributed to the rapid movement of water into the ground hence low concentration in the wet season caused by dilution effect from the rain water and higher flow rates within aquifer. During the dry season, it is the reverse of the wet season. Recharge during the wet season also conveys pollutants into the aquifers which then concentrate in the dry season hence higher levels. Generally, the results showed that the shallow well water in Ruiru is highly turbid with turbidity levels increasing during the wet season. Shallow wells water did not comply with the WHO and KEBS standards. This could be attributed to their shallow designs and way of constructions which involves hand digging and no casing to protect water from coming in direct contact with the soils.

The variations of the physical and chemical parameters observed in the groundwater may be affected by some controlling factors such as hydrological regime of groundwater at different times of the year which cause changes in water rest levels as a result of recharging groundwater with the nature of the bedrock influencing the dissolved ions in the water e.g. the higher averages of fluoride exhibited by the borehole water. Anthropogenic sources like poor waste management practices contribute negatively by adding pollutants which find their way to the groundwater through recharge zones and seepage. Parameters that exceeded the WHO (2009) drinking water standards may expose the large population in Nairobi to health hazards due to long-term and cumulative effects of those ions.

5.4 Recommendations

In view of the findings revealed by this study, some of the recommendations that were arrived at are as follows.

i. The groundwater in Ruiru is microbiologically contaminated by total coliforms and E.coli; therefore it is not suitable for drinking. The water should be treated to render it suitable for domestic use.

ii. The borehole water was less contaminated as compared to the shallow wells water which had high levels of microbiological contaminants. This study recommends boiling of this water before drinking as a short term remedy.

iii. The borehole water from the area exhibited high fluoride concentrations above 1.5 mg/l which is the recommended levels of WHO and KEBS. Fluoride removal from the groundwater in the study areas could be expensive since it cannot be done by ordinary filtration or boiling. However, the visible method of its removal could be achieved by reverse osmosis or deionization.

iv. More contamination of the groundwater sources was experienced during the wet season as compared to the dry season. This paper recommends proper and routine monitoring of groundwater resources in Ruiru and its environs.

v. The use of shallow wells in the area should be abolished in the area since the study showed clearly that they are more prone to contamination. Their construction should be regulated and monitored just like in the case of boreholes.

5.4.1 Recommendations for further Research

Further research is required in the following areas in the Ruiru area;

i. Health implications of groundwater contamination on the inhabitants of Ruiru.
ii. Analysis and characterization of the microbiological factors that affect the groundwater quality in the area.
iii. A study to find out the exact route cause of contamination of the groundwater in Ruiru area so as to provide solutions.

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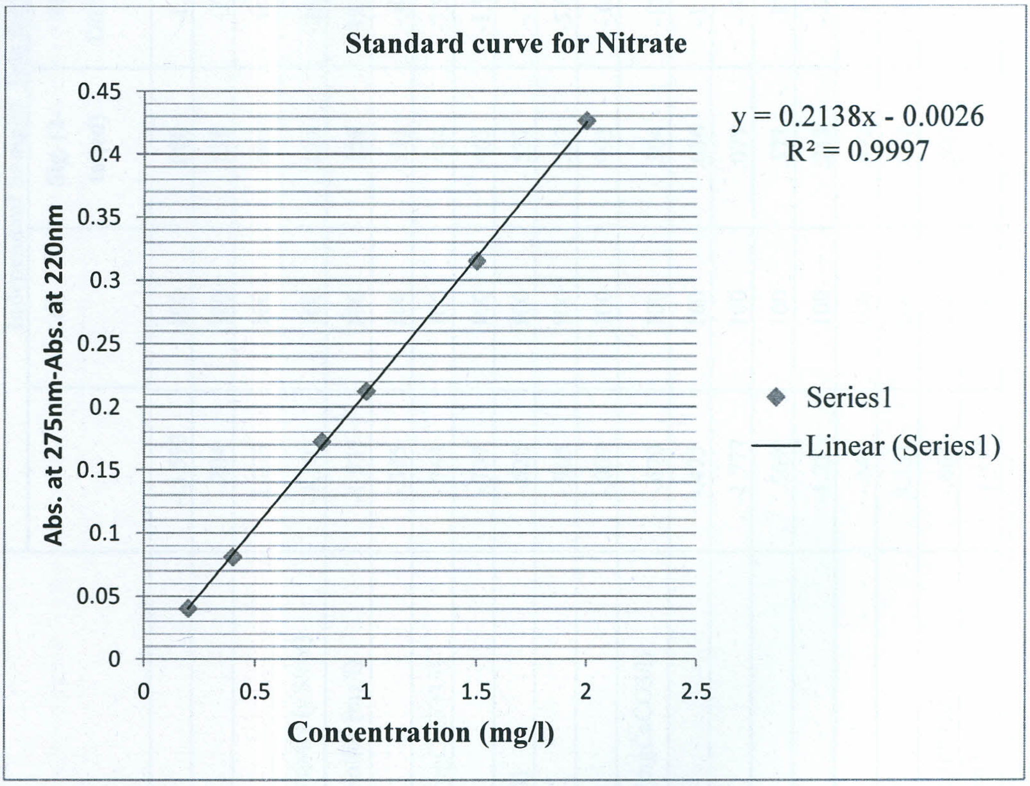
7.0 APPENDICES

Appendix i*:* Standard curve for Nitrates

Standards for calibration curve	
Concentration(mg/l)	Absorbance
0.2	0.04
0.4	0.081
0.8	0.172
1	0.212
1.5	0.315
2	0.426



Appendix ii: **Independent Samples Test for Equality of Means of borehole dry season (MBDS) vs boreholes wet season (MBWS)**

	Independent Samples Test for Equality of MBDS versus MBWS						
	t	df	**Sig. (2-tailed)**	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Temperature °C	-15.593	100	.000	-1.2235	.0785	-1.3798	-1.0672
Colour (mgPt/l)	-.204	100	.838	-1.471	7.191	-15.738	12.797
pH	2.079	100	.040	0.137	.066	.006	.268
Electrical Conductivity (μS/cm)	-1.101	100	.274	-36.0039	32.7083	-100.8963	28.8885
Total Dissolved Solids (mg/l)	-1.537	100	.128	-32.86431	21.38607	-75.29366	9.56503
Turbidity (NTU)	-.345	100	.731	-.67784	1.96511	-4.57657	3.22089
Total Hardness (mgCaCO3/l)	-.768	100	.444	-7.92471	10.31417	-28.38773	12.53832
Calcium (mg/l)	-.737	100	.463	-1.91118	2.59177	-7.05318	3.23083
Magnesium (mg/l)	-.620	100	.537	-.71255	1.14939	-2.99290	1.56780
Sodium (mg/l)	-.965	100	.337	-5.01000	5.19279	-15.31234	5.29234
Potassium (mg/l)	-.009	100	.993	-.01490	1.58962	-3.16867	3.13887
Total Alkalinity (mgCaCO3/l)	-.670	100	.504	-12.196	18.198	-48.300	23.908
Chloride (mg/l)	-.475	100	.636	-1.6549	3.4838	-8.5667	5.2569
Fluoride (mg/l)	-1.777	100	.079	-.50490	.28408	-1.06851	.05871
Nitrate (mg/l)	.569	100	.571	.33118	.58246	-.82440	1.48676
Sulphates (mg/l)	-1.253	100	.213	-.67412	.53790	-1.74130	.39306
Iron (mg/l)	-.842	100	.402	-.07216	.08568	-.24215	.09783
Manganese (mg/l)	3.331	100	.002	0.217	.065	.087	.348
Total Coliforms(MPN/100ml)	-.663	100	.509	-99.549	150.218	-397.578	198.480
E.coli (MPN/100ml)	-1.571	100	.121	-97.529	62.076	-221.575	26.516

MBDS- Means of borehole dry season, MBWS- Means of borehole wet season

Appendix iii: Independent Samples t-Test for Equality Means of shallow wells dry season (MSDS) and shallow well wet season (MSWS)

	Independent Samples t-Test for Equality MSDS vs MSWS						
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Temp^{0}C	-.512	114	.610	-1.7397	3.4007	-8.4765	4.9972
pH	-.715	114	.476	-.106	.148	-.399	.188
Colour (mgPt/l)	-.643	114	.521	-8.190	12.730	-33.407	17.028
Electrical Conductivity	-.907	114	.366	-70.306	77.540	-223.912	83.301
Total Dissolved Solids (mg/l)	-1.277	114	.204	-64.086414	50.2038	-163.5398	35.3670
Turbidity (NTU)	-.317	114	.752	-1.771	5.582	-12.830	9.288
Total Hardness (mgCaCO3/l)	-.987	114	.326	-58.345362	59.1045	-175.43087	58.74015
Calcium (mg/l)	-.554	114	.580	-4.94603	8.92127	-22.61900	12.72693
Magnesium (mg/l)	-1.276	114	.204	-15.23034	11.9347	-38.87279	8.41210
Sodium (mg/l)	.966	114	.336	10.360	10.727	-10.893	31.613
Potassium (mg/l)	-.587	111	.558	-2.066	3.520	-9.042	4.909
Total Alkalinity (mgCaCO3/l)	-.779	114	.438	-18.97086	24.3634	-67.23457	29.29284
Chloride (mg/l)	.489	114	.625	5.444	11.122	-16.592	27.480
Fluoride (mg/l)	.871	114	.386	.306862	.352429	-.391297	1.005022
Nitrate (mg/l)	-.197	114	.844	-.75000	3.79966	-8.27711	6.77711
Sulphates (mg/l)	.513	111	.609	1.725	3.360	-4.934	8.384
Iron (mg/l)	-1.200	114	.233	-.22534	.18786	-.59749	.14680
Manganese (mg/l)	.353	114	.725	.01534	.04346	-.07074	.10143
Total Coliforms (MPN/100 ml)	-2.170	114	.032	-293.172	135.120	-561.093	-25.251
E coli (MPN/100 ml)	-8.260	114	.000	-1247.017	150.979	-1546.940	-947.095

MSDS- Means of shallow well dry season, MSWS- Means of shallow well wet season

Appendix iv: Independent Samples t-test for Equality of means of boreholes dry season (MBDS) versus shallow wells dry season (MSDS)

	Independent Samples t-test for Equality of means MBDS vs MSDS						
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Temperature °C	-16.837	107	.000	-1.6777	.0996	-1.8762	-1.4791
pH	4.055	107	.000	.524	.129	.266	.781
Colour (mgPt/l)	-1.572	107	.119	-15.899	10.114	-35.993	4.194
Electrical Conductivity (µS/cm)	-2.586	107	.012	-150.895	58.349	-267.049	-34.741
Total Dissolved Solids (mg/l)	-2.327	107	.023	-85.050023	36.552490	-157.820443	-12.279603
Turbidity (NTU)	-2.166	107	.034	-8.627	3.983	-16.584	-.671
Total Hardness (mgCaCO3/l)	-3.711	107	.000	-72.89049	19.64090	-112.03494	-33.74603
Calcium (mg/l)	-2.529	107	.014	-15.20428	6.01096	-27.20299	-3.20557
Magnesium (mg/l)	-3.986	107	.000	-10.61355	2.66276	-15.92482	-5.30228
Sodium (mg/l)	-.511	107	.611	-4.36347	8.53317	-21.35202	12.62507
Potassium (mg/l)	-.225	107	.822	-.424	1.881	-4.154	3.305
Total Alkalinity (mgCaCO3/l)	-2.934	107	.004	-63.0218	21.4812	-105.6463	-20.3973
Chloride (mg/l)	-4.522	107	.000	-40.334	8.920	-58.156	-22.512
Fluoride (mg/l)	1.077	107	.284	.359057	.333368	-.301806	1.019921
Nitrate (mg/l)	-3.466	107	.001	-9.41794	2.71696	-14.85291	-3.98298
Sulphates (mg/l)	-6.026	107	.000	-14.471	2.401	-19.277	-9.665
Iron (mg/l)	-1.451	107	.150	-.16928	.11667	-.40111	.06254
Manganese (mg/l)	2.418	107	.018	.172	.071	.030	.314
Total Coliforms (MPN/100 ml)	-10.175	107	.000	-1484.734	145.926	-1774.021	-1195.447
E coli (MPN/100 ml)	-3.090	107	.003	-240.252	77.739	-395.458	-85.045

MBDS- Means of borehole dry season, MSDS- Means of shallow well dry season

Appendix v: Independent Samples t-Test for equality of means MBWS versus MSWS

	Independent Samples t-Test for equality of means MBWS vs MSWS						
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Temperature °C	-.605	107	.547	-2.1938	3.6279	-9.3857	4.9981
pH	2.867	107	.005	.28088	.09798	.08621	.47554
Colour (mgPt/l)	-2.142	107	.035	-22.618	10.558	-43.600	-1.636
Electrical Conductivity(μS/cm)	-3.054	107	.003	-185.19639	60.64398	-306.02225	-64.37053
Total Dissolved Solids (mg/l)	-2.870	107	.005	-116.27212	40.51797	-196.97722	-35.56702
Turbidity (NTU)	-2.223	107	.029	-9.72021	4.37307	-18.43085	-1.00957
Total Hardness (mgCaCO3/l)	-2.175	107	.034	-123.311143	56.691764	-236.748114	-9.874172
Calcium (mg/l)	-2.575	107	.012	-18.23914	7.08341	-32.38046	-4.09782
Magnesium (mg/l)	-2.150	107	.036	-25.13135	11.69045	-48.53662	-1.72607
Sodium (mg/l)	1.324	107	.189	11.006	8.312	-5.522	27.534
Potassium (mg/l)	-.699	107	.486	-2.476	3.544	-9.502	4.551
Total Alkalinity (mgCaCO3/l)	-3.243	107	.002	-69.79659	21.52444	-112.47720	-27.11598
Chloride (mg/l)	-4.431	107	.000	-33.236	7.501	-48.189	-18.282
Fluoride (mg/l)	3.681	107	.000	1.17082	.31804	.54034	1.80130
Nitrate (mg/l)	-3.861	107	.000	-10.49912	2.71934	-15.93962	-5.05863
Sulphates (mg/l)	9.432	107	.000	3.89084	.41252	3.06233	4.71935
Iron (mg/l)	-7.136	107	.000	-16.984	2.380	-21.754	-12.215
Manganese (mg/l)	-3.396	107	.001	-.53855	.15859	-.85601	-.22109
Total Coliforms (MPN/100 ml)	-12.232	107	.000	-1678.357	114.39492	-1950.364	-1406.350
E. coli (MPN/100 ml)	-19.784	107	.000	-1962.808	99.211	-2159.617	-1766.000

MBWS- Means of borehole wet season, MSWS- Means of shallow well wet season