UNIVERSITY OF NAIROBI

THE EFFECT OF SEPTIC TANKS SEWAGE DISPOSAL SYSTEM DISTANCES ON BOREHOLE WATER QUALITY IN ONGATA RONGAI, KAJIADO COUNTY, KENYA.

BY

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DECLARATION

This thesis is the original work of the author except where due references are made. It has not been submitted partially or wholly for the award of degree to this or any other institution of learning. Where other people's work has been used, these have properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

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This thesis has been submitted with our approval as university supervisors

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ABSTRACT

Onsite disposal of domestic effluent by septic tank systems is the most common method practiced by the people that live in Ongata Rongai in Kajiado County, Kenya. Moreover, water for domestic use is primarily supplied from private water boreholes because of absence of piped water and lack of sewerage system in the area. The main goal that this research was targeting was, to assess the effect of septic tanks disposal system on the borehole water quality. Water for physical, chemical and bacteriological laboratory analysis, was sampled from ten different boreholes at different distances from five septic tanks in the high to medium density settlement areas that rely on borehole water for their domestic use. The parameters analyzed and results were: pH 6.5 ± 0.2 to 8.4 ± 0.4; Turbidity 1.9 ± 0.8 to 4.9 ± 1.5 (NTU); Alkalinity 116 ± 2.3 to 186.9 ± 6.1 (mg/l); Phosphates below detection limit (BDL) to 0.12 ± 0.01 (mg/l); Chlorides 134 ± 3.8 to 144.4 ± 4.6 (mg/l); Nitrite 4.12 ± 1.1 to 16.8 ± 1.0 (mg/l) ; Nitrate 2.17 ± 1.5 to 7.07 ± 3.2 (mg/l); Ammonia BDL to 1.4 ± 0.7 (mg/l); Sodium 8 ± 2.38 to 217 ± 4.24 (mg/l); TDS 174 ± 2.1 to 896 ± 1.9 (mg/l); Conductivity 802 ± 0.7 to 1265 ± 1.32 (μS/cm), Sulphates 66.7 ± 3.6 to 198 ± 1.25 (mg/l); Phenol BDL to 0.15 ± 0.0 (mg/l); COD 4.0 ± 1.7 to 75.0 ± 8.0 (mg/l); E.coli BDL to 3 ± 1.0 (cfu), surfactants (as methylene blue active substances, MBAS) were not detected. The parameters analyzed are those that were relevant to the assessment of water contamination by domestic effluent disposal system. The differences in concentrations of the selected parameters were also determined in wet and dry seasons. The samples were collected in the months of March (dry) and May (wet), 2014, to represent the dry and wet seasons respectively. The levels of contaminants increased with decreasing distance from septic tank systems and were also higher in May, compared to March, 2014. Total dissolved solids (TDS), conductivity and sulphates did not show any seasonal variation in all the sites. The results indicated that the selected boreholes in Ongata Rongai that were more than 70 m away from the septic tanks, the values of most physico-

chemical parameters were within the World Health Organization (WHO) standards. The findings from this study showed that water quality is affected by seasonal variations and the distance of the borehole from the septic tank sewage disposal system. The contamination problems in borehole water from Ongata Rongai call for stringent management measures to be put in place by the Kajiado County Government to safeguard the human health and environment.

DEDICATION

This thesis is dedicated to my wife Selian, my mother Mrs. Mary Mbugua, friends and teachers who gave me the necessary guidance, wisdom and support in achieving my goals in life.

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List of Abbreviations

CFU   Colony Forming Units

COD   Chemical Oxygen Demand

D- ST   Distance in meters between the borehole and septic tanks

D-WRL   Distance of the water Rest Level or potentiometric surface of   the water table

GIS   Geographic Information System

KEWI   Kenya Water Institute

KGWG   Kenya Ground Water Governance

KS   Kenya Standards

KNBS   Kenya National Bureau of Statistics

MBAS   Methylene-blue Active Substances.

NTU   Nephelometric Turbidity Units

ST-SAS   Septic Tank- Soil Absorption System or septic tank system

TDS   Total dissolved solids

WHO   World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background information

With rapid population growth worldwide and an increased demand for essential amenities, the need for clean and adequate water for domestic use is one of the factors that need urgent attention (Mumma *et al.,* 2011). A direct result of this is water scarcity and inaccessibility of portable water to people. It is therefore inevitable to address the issue of provision of portable and safe drinking water that is essential for life. To fulfill this demand, groundwater is increasingly used as a water source globally (Mumma *et al.,* 2011). Groundwater makes up 97% of all the fresh water reserve in the world and is the most exploited natural resource (Mumma *et al.,* 2011). Currently, the Nairobi Water and Sewerage Company policy addresses surface water and little is addressed on ground water (Foster and Tuinhof, 2005). Probably, in the future, the use of groundwater will be a viable option in the provision of sufficient water for the growing urban population and also be an important water reserve during prolonged dry seasons. For instance, the drilling of boreholes in Nairobi, may have began as early as ninety years ago in the 1930s and the number of water wells have increased from fewer than ten in 1940 to almost two thousand in 1997 and two thousand two hundred and fifty in 2001 (Foster and Tuinhof, 2005).

The movement of populations to the towns has increased dramatically and at the same time the financial resources of the county governments in Kenya are fully extended trying to maintain existing services (Kazungu, *et al*, 2011). This is the situation in Kajiado County of Kenya. Ongata Rongai is one of the non-planned peri-urban settlements in Kajiado County that is fast growing but with a persistent water scarcity challenge which has not yet been resolved. The Oloolaiser Water and Sewerage Company are mandated to serve Ongata

Rongai and Ngong areas of Kajiado County; although over the years the resources have proved to be unreliable (Kazungu, *et al*, 2011).

As stated by the USEPA, "the degree to which the world's waters were contaminated was at 90% (USEPA, 2008). The sources of contamination include heavy metals, disease causing micro-organisms, inorganic and organic chemicals substances. To mitigate the potential risk to human health, as a result of using contaminated water, methods of water treatment that are easy to use, effective, affordable, functional and sustainable need to be used(Sosbey, 2002).

It has been observed that there is a direct link between access to portable water and the reduction in epidemic diseases as well as infant survival rates (Omwenga, *et al.,* 2009); as a result, many programs for sustainable development have laid emphasis on improving water quality and its accessibility to people. According to studies conducted by WHO (2003a), 50% of preventable diseases in Kenya are related to poor hygiene and sanitation. Nairobi and its environs that fall under the metropolitan region are faced with a population influx that has resulted into rapid and unplanned urbanization, without regard to the severity of lack of a proper sewerage system. At household level, access to water supply and waste disposal are low and only 66 % of households have sewer connections (Omwenga, *et al.,* 2009). The overreliance on ground water is threatened by overwhelming numbers of septic tanks, improper disposal of household wastes and wastewaters (WHO, 2003a). The Kenya vision 2030 agenda is to address the issues of development by improving accessibility to water for all and promote sanitation, through implementing high quality infrastructure in the whole of Kenya in the management, storage and harvesting capacity of water as a resource which includes; re-establish the hydro-meteorological information management system; construction of dykes along flooding river banks in the Western and Nyanza regions of Kenya; and building water and sanitation facilities capable of supporting a growing urban and

industrial population (GOK, 2008). Groundwater is prone to degradation on its quality, due to the unsanitary state of the overall (sub-surface and also surface) environment.

Hand dug boreholes that are not very deep, especially found in the rural areas are specifically endangered by careless solid waste disposal as well as seepage of untreated sewage from pit latrines and septic tanks. Danger of contamination for shallow wells in urban areas increases proportionately to the number of human beings in that live in unplanned settlements where sanitation coverage is lowest. Groundwater is equally under threat of contamination in the urban areas, resulting from solid waste leaches, un-treated domestic effluent (containing faecal matter and other substances of chemical and physical nature) and wastewater from industries seeping into the ground and reaching water bearing rock formations (Adelekan, 2010). This study was therefore, aimed at determining the extent of groundwater contamination in Ongata Rongai as a first step in implementing the need for providing safe drinking water and sanitation to the residents.

1.2 Problem Statement

Any urban development that practices on-site effluent disposal methods of domestic effluent treatment like septic tanks soil absorption systems (ST-SAS) and pit latrines and septic tanks, creates a risk to ground water contamination (Mumma, *et al*, 2011). There are many homes in Ongata Rongai and the number of new ones is rising daily. Plot sizes are small which means more effluent from households, disposed through septic tanks and consequently a bigger threat to the sub-surface environment. The population of this area depends on groundwater abstracted from boreholes in the area, for domestic uses including drinking. Therefore, there is a need to assess the impact that sanitation has on the quality borehole water, which the population depends on. This will sensitize all concerned parties on the need to protect ground water, and possible mitigation measures that can be employed. As the

population of Ongata Rongai increases, developers are still drilling more water supply boreholes in built up places there the number of ST-SAS built for the dwellers are many within a small area. It is necessary to analyse and have knowledge on the water quality and pollutant levels of the boreholes in the area and decide what needs to be done so as to protect groundwater from physical, chemical or microbial contamination. There is need to investigate the borehole waters' suitability for drinking. No studies have been done in Ongata Rongai for monitoring effect of septic tanks contamination on the quality of ground water, to date. This research will provide information on the levels of the selected or likely contaminants in the boreholes or in the groundwater sources in the area under investigation. The findings will help in developing a policy on the mitigation measures to be put in place to safeguard water quality.

1.3 Overall Objective

The overall objective is to assess the impacts of the distance of septic tank sewage disposal system on the quality of the borehole water.

1.3.1 Specific Objectives

The specific objectives were;

1. Locating septic tanks sewage disposal systems closest to the selected water boreholes using structured interview questionnaires.

2. Sampling and water analysis (of physical, chemical and biological parameters) to determine the impact of septic tanks sewerage on the quality of the selected borehole waters.

3. Compare the obtained results to the available previous baseline data (results of analysis done at the time of drilling the boreholes).

1.4 Justification

There is need for clean safe water for human consumption, which will not pose any health hazards. However, the information to show the current state of the quality of drinking water, supplied from private boreholes to population of Ongata Rongai is not available. Concerns have been expressed by environmentalists, public health officials, and environmental scientists and general public that septic systems are non-point sources of pollution which create public health hazard and threaten surface and ground water resources. Pathogens including viruses and bacteria that have caused severe health related issues due to septic system failures (Adelekan, 2010) and not much has been done and reported on chemical contamination of boreholes and their likely health effects in Ongata Rongai. The finding from this study will give information on ground water quality and help the county government to mitigate possible failures in land use and planning for onsite waste disposal.

1.5 Significance of the study

Data obtained from this study will be used to advise regulators and authorities on ensuring ground water safety, environmental impact assessments in relation to septic tanks use, construction design, sizing and sitting, by formulating relevant policies and sensitizing residents on environmental protection of the sub-surface environment.

CHAPTER TWO

LITERATURE REVIEW

When the functions and qualities of water in its natural pure condition are not normal, then the water is said to be polluted (De, 2010). Water, that is of good quality is important to humans and is associated with their welfare. Pollution to natural water sources is mainly from domestic (rural and urban areas) and industrial waste being discharged therein (De, 2010). Water for domestic use, including drinking, should be within specific ranges of physical, chemical and biological parameters. These parameters have been reported, documented and accepted as a reference to ensure suitability of purpose and safety, any deviations of parameters from the listed range of minimum and maximum contaminant levels will mean poor quality that is unsafe for consumption and would cause adverse effect on the heath of the consumer.

The water pollutants may be broadly classified as: organic, inorganic, sediments, radioactive material and thermal pollutants. Substances that contaminate water and result in pollution that is of an organic nature are; oxygen demanding wastes, disease causing agents, plants nutrients, sewage, synthetic organic compounds and oil (De, 2010). The production and use of synthetic organic compounds would contribute to water pollution if not properly handled and disposed. These include; fuels, solvents, elastomers, detergents, paints, insecticides, food additives and pharmaceuticals, pesticides, chlorinated hydrocarbons, and detergents. These may find their way into ground water reserves through leaching from on-site waste disposal systems. Surfactants (anionic, cationic and non-ionic), optical brighteners and builders (phosphate-based) cause water pollution problems. Inorganic pollutants consist of substances such as acids and salts that are derived from inorganic compounds, metals (lead, mercury, arsenic, selenium, chromium) in ionic or colloidal states in different compounds and polyphosphate in detergents.

Groundwater has been contaminated and polluted by anthropogenic activity that has going on, increasingly over time without any regard for environmental consequences which eventually result in the deterioration of physico-chemical and biological properties of water (Longe *et al.,* 2010).

Sub-surface, on-site, methods of domestic effluent or waste water disposal are the main sources of wastewater to the ground, and are the most frequently reported causes of ground-water contamination (Miller, 1980). The absence of piped municipal water has necessitated a need for other reliable and sustainable source of water. Groundwater has been a ready source. Therefore the sub-surface environment within which ground water is reserved could be exposed to contamination by disposal of waste in the soils. Most soils can filter solids including pollution solids. However this ability varies with different sizes, shapes and arrangement of particles. Clays and other selected minerals capture and exchange some elements and compounds when they are in solution. Such exchanges are important in the capture of pollutants such as heavy metals (Mc Ginnis *et al*, 1983).

The ground water reserve is maintained by a hydrostatic balance within the soil pores, below the water table which is naturally recharged by rain water, streams or rivers. The ground water also discharges from streams or from drilled wells e.g. boreholes. Over-pumping or over abstraction of ground water from boreholes (where there is a declining ground water level) may lead to infiltration of septic tank effluent (Canter and Knox, 1985).

2.1 Effect of Urbanization on Natural Resources

Land as a resource in Kenya, comprises of natural water bodies that have fresh water, trees (both indigenous and foreign trees) and a broad biological ecosystem, all of which hold vast potential for development if managed sustainably. Many of the opportunities they provide include; agriculture, tourism, human settlements and a carbon sink for the city which is vital

for the well being of the residents (UNEP, 2010). Kenya's urbanization process is characterized Nairobi, in which infrastructure services are concentrated, more than other areas in Kenya. Provision of amenities and services such as water, transport, energy, infrastructure to promote hygiene and good management of both industrial and domestic solid waste and waste water, which underpins growth, improvement of livelihoods and urban development. Housing constitutes a major dilemma for Nairobi and its environs, whose numbers are increasing (UNEP, 2010).

In addition, development of the urban infrastructure such as water and sewerage systems that support housing development have been overlooked (UNEP, 2010). For instance, Ongata Rongai is a rapidly developing residential urban area within Kajiado County whose population by 1999 census was 35,000 people, with the current estimates being between 66,042 and 147,000. The town is situated in Kajiado that borders Nairobi (Kazungu *et al*., 2011). There are high rates of economic activities as evidenced by numerous apartment complexes and business premises. This has led to a total disregard for social, aesthetic and environmental long-term impacts on the area's inhabitants. Private developers dictate the pace of physical developments. This has resulted in high population densities, overcrowded housing, unsanitary conditions, diminishing open spaces and haphazard peripheral development (Kazungu *et al.,* 2011). Which is hindered by the model urban and regional planning, that is very centralized, and that does not give sufficient authority to county and municipal governments. Local authorities also lack an adequate capacity to plan and manage urban development (GOK, 2008)

2.2 Boreholes

The water reserve beneath the land surface (groundwater) is found below the water table in soils and geologic formations that are fully saturated; the pore spaces within the rock or soil

matrix are filled or saturated with water. Ground water occurrence is widespread in many environments and a very important supply for many purposes including domestic use and agriculture (irrigation). Tolman 1964, has indicated the importance of ground water as follows that, a very large amount of all the water in the world is saline; ground water comprises about two-thirds of the earth's fresh water, and that; ground water comprises 90 to 95 percent of the usable water (excluding glaciers and ice cap)

The principle water bearing strata is termed as aquifers. An aquifer is defined as a geologic formation from which water in usable quantities can be obtained from springs or borehole wells.

There are three classification systems for types of wells; the following may be used as a basis for the classification of wells (Harlan, et al, 1989): Methods of construction – dug or drilled; purpose of use – water supply well, test well, observation well, monitoring well, special purpose well, injection well, or disposal well; formation in which the well is completed – bedrock (consolidated), or unconsolidated (alluvial/poorly unconsolidated) well.

In this study, we are only focusing on the drilled wells for purposes of water supply.

2.3 Ground Water Contamination

Groundwater resource is available, across the globe, to most countries of the world. It is reliable even during prolonged dry seasons or droughts because of the large storage and, is cheaper to develop, since, if unpolluted, it requires little or no treatment and it can often be tapped where it is needed, on a stage by stage basis. As a result, groundwater has become important for human water supply in urban and rural areas in developed and developing nations alike. Groundwater is a key aspect in water supply through private water supply boreholes in the selected area of Ongata Rongai. However, in other places, there is an

uncertainty of sustainability of this source of water, where research findings show that ground water contains contaminants that are deleterious to human health in certain regions. In its natural state, the constituents in the make-up of groundwater depends on the composition of the soil which has organic matter (humic substances) and minerals (e.g Fe^{2+}, Mn^{2+}, NH_4^+, H_2S, HCO_3^-, SiO_2 and F^-). The composition or make up of groundwater is affected by human polluting activities, which include agriculture, cattle breeding, industrial and domestic activities. In this case, shallow aquifers suffer most (WHO, 2007).

Groundwater is very important to continents like Africa, Asia, Central and South America (UNEP, 2010). Groundwater is a resource that sustains life. It provides water to billions of people worldwide. It has an effect in the well being of plants and animals co-existence and has a central role in irrigated agriculture. Studies to assess the water resources across the world tend to concentrate more on surface water, but unsustainable depletion of groundwater has recently been documented on both regional and global scales. The level and speed at which the world's ground water is diminishing compared to that of natural renewal supply needed to support ecosystems, has not yet been fully determined (Gleeson *et al*., 2012).

The provision of water and also sanitation services in Kenya is characterized by limited access particularly in rural areas and urban slums, and inconsistent supply of water by the suppliers. About 16% of all the companies that are mandated to supply water, do so un-interrupted resulting in inhabitants looking for alternative water sources (Mumma *et al*., 2011).

Many countries in Africa rely on ground water (UNEP, 2010).

The pollution of groundwater resources is often a consequence of inadequate planning for land use, resulting in the practices of high risk activities in places where they have a negative impact on groundwater resources (Sililo *et al*., 2001). A holistic approach is therefore

required in the management and protection of groundwater resources. Increasingly methods that protect groundwater resources are being incorporated into land-use planning, or at least considered in the approval of new developments. The development and acceptance of Environmental Impact Assessment legislation has brought the impact of developments on groundwater resources to the attention of many decision makers (Sililo *et al.,* 2001). Without an elaborate sewerage system in rapid growing population, human health will always be at risk due to likelihood of a disease outbreak occurring (Sililo *et al.*, 2001). Due to overreliance on ground water by residents of Rongai, precaution must be taken since sewer water and ground water might come into contact with each other and expose residents to various health hazards.

Point sources of pollution are described as those that are readily identifiable and typically discharge water through systems of pipes, but non point sources originate from a wider area (USEPA, 2008). Septic tank systems are a non point source. Comparison with streams or rivers, the flow of ground water is very slow and has very little turbulence or mixing. As a result, when a contaminant enters into the ground water, it is not disturbed. It forms a flux of high concentration of the contaminant within the fluid (a plume) that flows along the same path as the ground water. Among the factors that determine the size, form, and rate of movement of the contaminant plume are the amount and type of contaminant and the speed of ground-water movement (Figure 2.1).
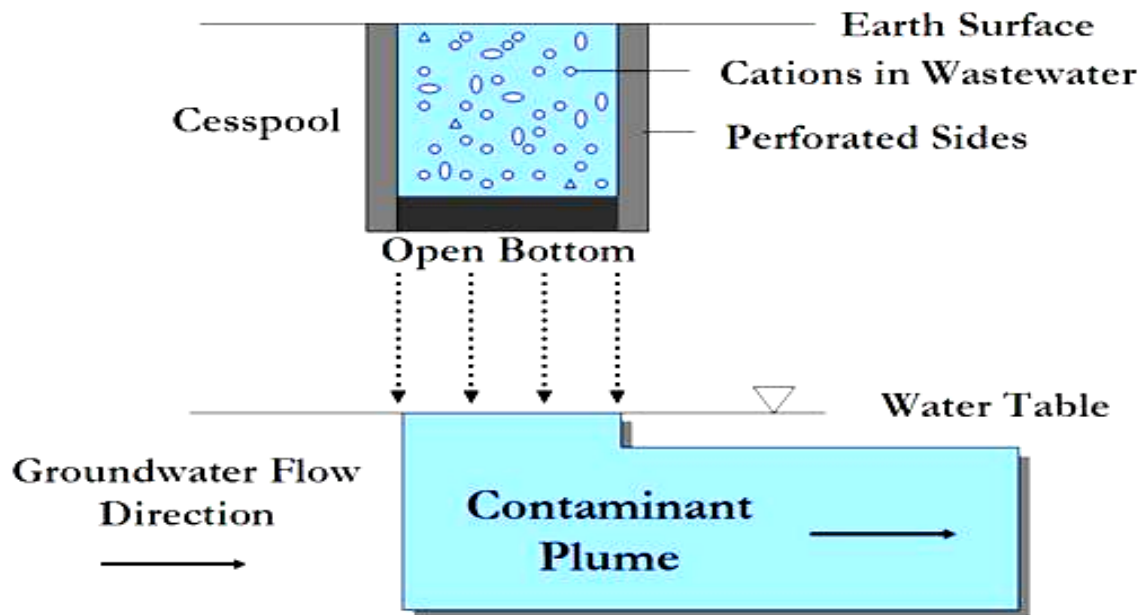
Figure 2.1: Cesspool or septic system showing mechanism of ground water contamination by a septic plume below the soak pit (University of Maryland, 2015).

The contaminant plume is not easily noticed and can stay in the water even for years until the water is abstracted from the borehole (Kaplan, 1987) Figure 2.2. The size of community that produces unacceptable ground water pollution will be determined by many factors according to Reed (1995), which are; the number and size of infiltration systems; the depth to the water table; soil and rock conditions within and above the aquifer; the aquifer depth and ground water flow rate and direction.
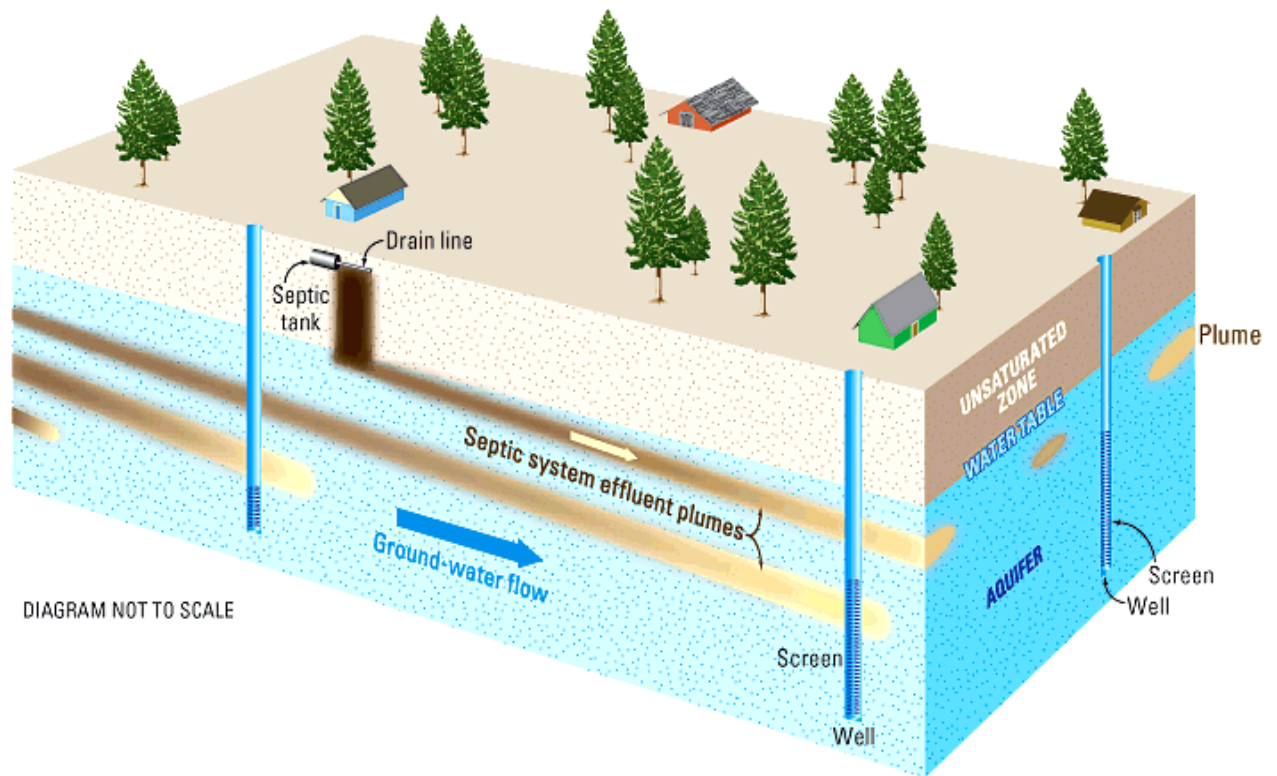
Figure 2.2: Illustration of the sub-surface environment showing the effect of septic tanks sitting on boreholes (U.S. Geological Survey Oregon Water Science Centre, 2014).

If the ST-SAS in developed settlements are not located ideally, poorly built or unmaintained, they can allow contamination of the ground water by synthetic detergents, anions, cations, bacteria and viruses. In isolation, an individual septic tank-soil absorption system (ST-SAS) has got no impact as far as contamination to groundwater is concerned. When considered collectively, the sheer number of such systems and their wide spread use in every area that does not have a public sewage treatment system makes them serious contamination sources (USEPA 2008).

Virtually all onsite sanitation systems will pollute surrounding soil. This pollution takes two forms: bacterial and chemical. Bacterial pollution, is direct health hazard, is usually quickly rendered harmless by natural processes. Indeed, provided the bottom of the soak pit or filtration system of the septic tank is more than 2m above the water table, bacterial pollution

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of ground water is not likely to happen (Reed, 1995). Chemical pollution is predominantly nitrogenous and can increase the level of nitrates in the water. Chemical pollution is more problematic than bacterial pollution because it is longer lasting and more difficult to remove.

The pollution from a single latrine/ septic tank-soil absorption system (ST-SAS) is expected to be unlikely when located at more at more than fifteen metres (Franceys *et al,* 1992). A more significant consideration is the cumulative pollution produced by a large number of septic systems in a confined area. Shallow ground water abstracted within the area will almost certainly be contaminated by bacteria and chemicals (Figure 2.2). Deep ground water and abstraction points downstream of the area may be contaminated by chemicals. Nitrates dissolve in groundwater without degradation and that is why it is usually found as a contaminant due to ST-SAS (Reeds, 1995).

Several decades have passed and many chemistry researchers have been identified some indicators to assess impacts of septic tanks on the quality of groundwater. For instance, the concentration of nitrate in community water supply wells was associated with the population of ST-SASs and geologic features and type of land use (Lichtenberg *et al,* 1997) and (Katz *et al*., 1980 and Perkins, 1984).

Indicators of contamination from septic-tank systems also include household-cleaning products, chemicals in personal-care products, pharmaceutical compounds, and pesticides (Godfrey *et al.,* 2007). Microbiological and chemical pollution indicators have seasonal variations whereby, in another study, analysis from the wet season found double the count of fecal coliforms and higher concentrations of nitrate and phosphate than samples from the dry season (Adelekan, 2010).

The point at which the pollution becomes unacceptable will normally be when the concentration of chemical indicators such as nitrates exceeds World Health Organization

recommendation of 50 mg/l (WHO 2004). Contamination in groundwater happens in places where there are many ST-SAS producing a large quantity of organic contaminants within a confined area (Reeds, 1996). The issue of unwanted pollution due to unsanitary septic systems is made more serious when the residents in the same area depend on the boreholes as the only source of water for drinking (Reeds, 1994). Other likely inorganic contaminant substances from septic tanks include phosphates, nitrogen compounds, chlorides, and metal ions. Ammonium (NH_4^+), from the ST-SAS infiltrates the soil where, by nitrification it is oxidised to nitrite (NO_2^-), then further oxidised to nitrate(NO_3^-) by obligate autotrophic micro-organisms. Denitrification takes place in the soil under the septic system, whereby the reduction of NO_3^- to N_2O or N_2 is done by obligate facultative heterotrophs. In the presence of oxygen, nitrates (NO_3^-) take up the electrons produced by the breaking down of organic sources of energy. Since ammonia is present, then nitrification precedes denitrification. Nitrate (NO_3^-) has the highest mobility in saturated and unsaturated soil conditions, travelling with little transformation in water over long distances if the right conditions are present. However, NO_3^- can be immobilised when taken up by plants within the immediate area (Kaplan, 1987).

Chlorides (Cl^-) are anionic and mobile making them good tracers of septic tank system pollution. Chlorides are naturally present and common in surface water, groundwater, and waste waters. The amount of Cl^- in effluent depends on the natural quality of the water supply and if the level is high, it cannot be treated by the ST-SAS or even conventional wastewater treatment plants (Canter *et al,* 1985).

Every time a borehole is drilled, a pathway of vulnerability is created with a potential for contamination and degradation of the ground water resource by creating a hydraulic link in the inter-phase of the polluted surface and the underground water (Chesnaux, 2012). The

pollution sensitive areas can be zoned into five segments of varying vulnerability as shown in Figure 2.3.
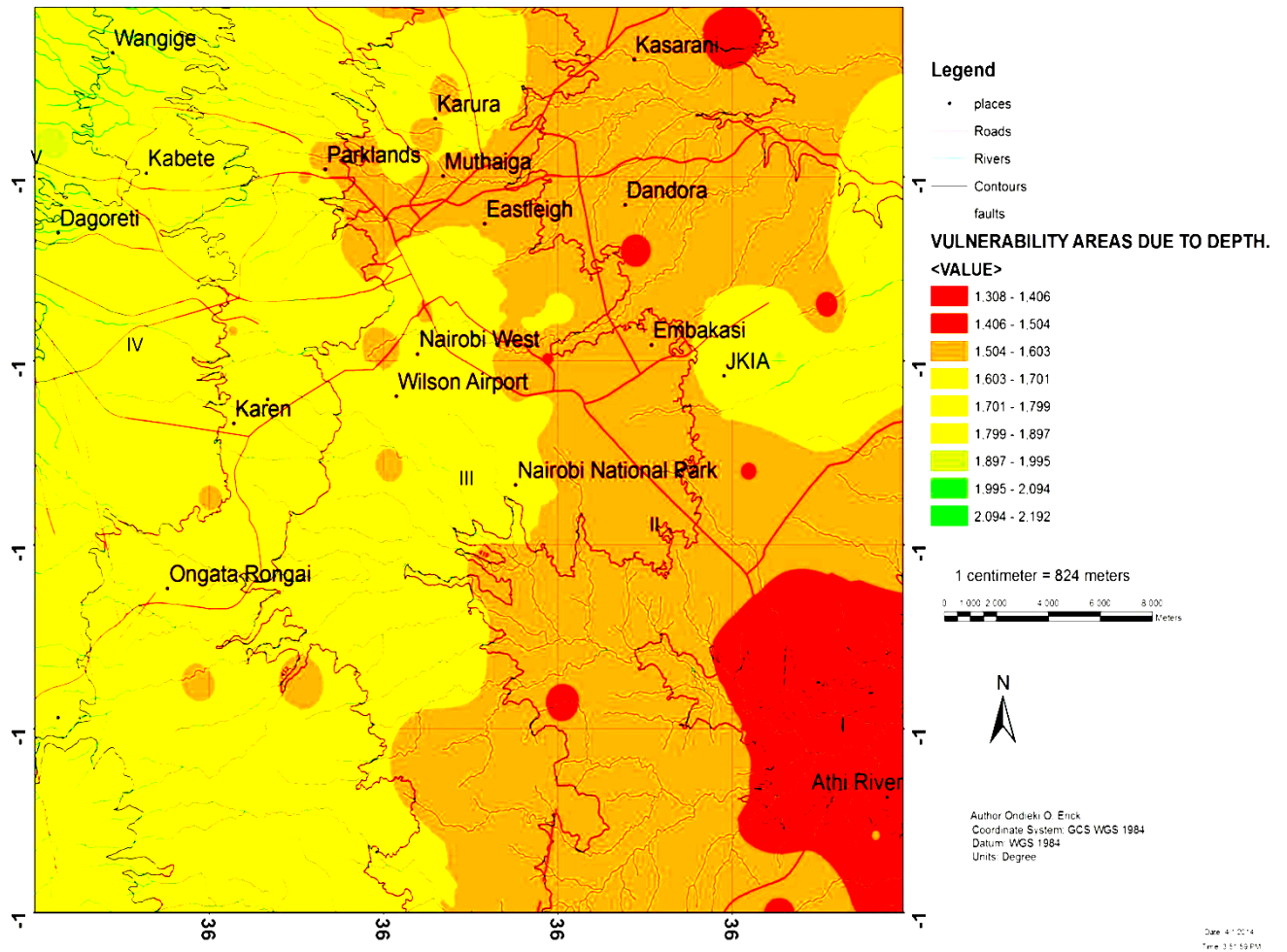
Figure 2.3: Map showing ground water vulnerability due to depth of aquifer (Ondieki, 2014).

Ongata Rongai's water table is at 1504-1701 m below ground level (Figure 2.3) hence it is marginally vulnerable (Ondieki, 2014).

2.4   Septic Tanks

Septic, is a Greek word (septikos), which means causing petrefaction (Webster, 2001). ST-SASs are constructed in such a manner that they hold raw domestic effluent that contains faecal matter and other suspended material disposed from the homes so that the denser solids are sedimented as a sludge in the septic tank and partially digested in the absence of oxygen, leaching the effluent into the ground (soil absorption system). They are not designed to destroy pathogens that may be in the human waste that enters the septic tank and therefore can allow bacteria, viruses, protozoa, and intestinal parasites to spread and cause diseases (Kaplan, 1987).

One of the main concerns associated with septic systems is the problem of human population density. Too many septic systems in any given area will overload the soil's natural purification systems and allow large amounts of wastewater to contaminate the underlying water table (Hallberg and Keenley 1993). When the density of household septic tanks systems is greater than forty per square mile (2.59 square kilometers), the area can be polluted in the sub-surface environment (US EPA, 2008). While sewerage systems transport waste water to a remote treatment facility, on-site systems treat or discharge in-situ (Kaplan, 1983). The tanks have different shapes and capacity. The material of construction should be resistant or slow to corrosion by hydrogen sulphide gas and other possible corrosive contents, therefore concrete tanks should be regularly inspected for structural integrity to prevent leaks of raw sewage that cause soil contamination and pollution by pathogens. Other materials include, galvanized and coated steel, fiberglass or polyethylene (Otis 1985). The tanks purpose is to retain sewage and hold it for a while (Kaplan, 1987).

During this detention period, the "floatables" on the sewage float on top where they undergo microbial decomposition and results to a scum, Figure 2.4. Heavier material settles at the

floor, acquire a black colour and become sludge. The mid-section is a clarified translucent clarified sewage which trickles to the soil or soak pit (Kaplan, 1987).
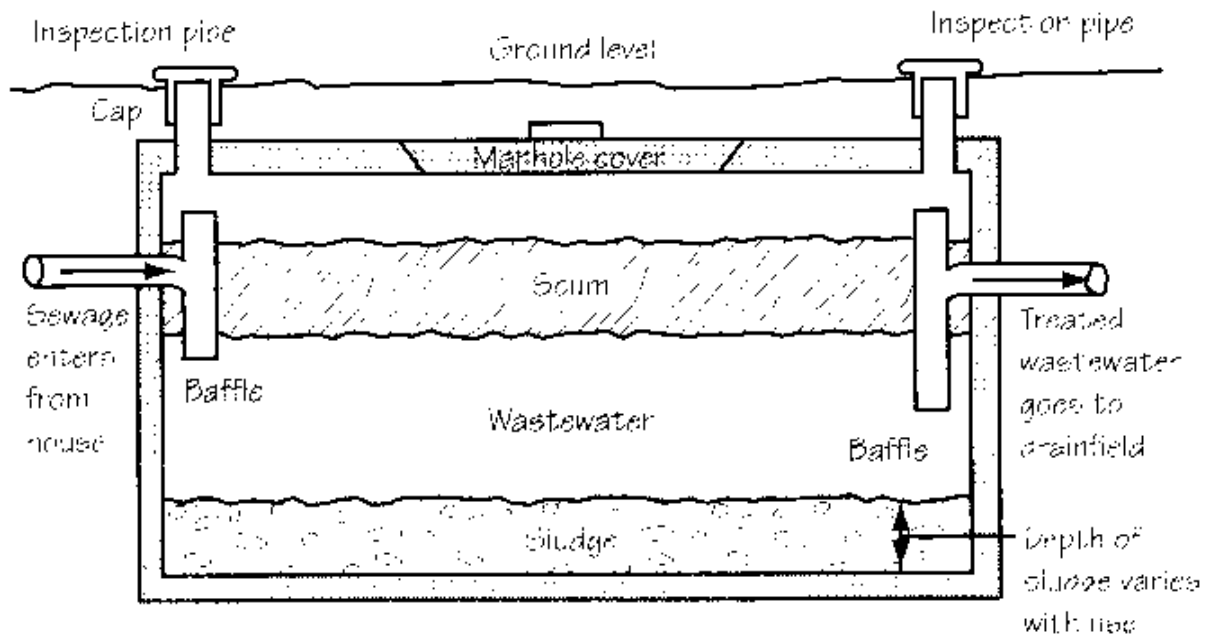
Figure 2.4: Schematic diagram of a septic tank, showing the three layers of septage (University of Maryland Extension, 2015).

The purpose of the drain field or soak pit is receiving clear waste water from the tank's outlet for underground infiltration through soil which purifies this liquid by decomposing organic matter while at the same time retaining parasitic worms, eggs and microbes. In the soil, the waste water is also discharged by vaporization and plant uptake (evapo-transpiration) (Hallberg and Keenley, 1993). The dimensions of standard soak pits range from about 4 to 6 feet in diameter and 4 to 10 feet in depth (Kaplan, 1983).

Poor drainage of soils that result in bad septic tanks can be expected in areas with clay, compacted soil with low permeability, high water table and impermeable rock near surface or frequent flooding (Botkin and Keller 1987). The soil structure has a big role to play in determining soils permeability. Permeability is an important factor to consider for septic

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system sites. In some areas which have shallow soils (10 feet or less) over impermeable bedrock, the sewage can discharge through leach lines located at higher elevations and may raise the ground water level and flood leach fields at lower elevations (Kaplan, 1983). This was observed in the area under study, where people were forced to dig deeper through the bed rock, until sometimes they reach the saturated zone (the water table) in an effort to increase soak pit capacity and remedy the flooding issue. The county council department of health recommends that, septic tank sitting in a construction area should be at a general distance of six meters all around any construction, a dwelling house or a perimeter boundary, this will result to mounding. If sewage flows downwards through a porous material and is stopped or slowed down by a barrier, it accumulates above the barrier and forms a dome. The hydrostatic pressure builds up and pushes the sewage laterally (Kaplan, 1983). When this dome forms below a soak pit or drain field, the separation between the bottom of the soak pit and the ground water may decrease to less than recommended and it may grow high enough to flood the soak pit. Also, saturated soil facilitates movement of pathogens and chemicals to the ground water table. Mounds may form over two kinds of "barriers". One kind is clay or other low permeability stratum; the other is ground water table's surface (Kaplan, 1983). Mounding may be more of a problem in septic systems installed in some stratified soils with low permeability and especially if they are concentrated within a small area (Kaplan, 1983).

The national building code, gives the guidelines and regulations on siting of septic tanks and soak pits, such they should be impervious to liquid; be so designed and sited that it is not be a nuisance or a health risk, capacity of not less than 1.7 m^3 and be capable of receiving one day's sewage and it is provided and accessible purpose of emptying and cleaning' and 'that wastewater from industries should not be allowed into septic tanks (National Building Regulations, 2014).

A soil percolation test and type of waste therefore, should be considered to check the suitability of septic tank construction and the plot size available as a factor for sizing the septic system. The septic system requires regular maintenance, failure to maintain the septic tanks by pumping out the sludge at the recommended rate of once every 3 years and disposing it in a proper manner is also a big challenge for some users especially where there is an overwhelming demand for this service (USEPA, 2008). The main pollutants from septic tanks are parasites and viruses that cause illnesses such as gastroenteritis and shigellosis. These are synonymous to feacal wastes. Soil acts as a sieve for these microbial pathogens, however as their sizes get smaller, the trapping is less efficient. The efficiency of the soil to purify this is also affected by other factors including soil pH. In this regard, Hagedorn and Romeo (1994), concluded that: Micro organisms travel farther and more efficiently in saturated soils then in unsaturated soils: bacterial retention is higher in fine textured soils; a major limitation to movement through soil is physical straining or filtration of bacteria or larger microbes; adhesion of bacteria in the soil increases with clay content and: death of microorganisms plays an important role.

Coarse textured soils absorb much rainfall which creates a layer or layers of nearly saturated soils. While raining, bacteria and viruses may be washed down.

Mounding on effluent can raise the level of ground water and increase the danger of contamination by septic tank effluent. Movement of typhoid causing bacteria, through at least 3 to 4 feet of sand and 210 feet of saturated soils (distance from bottom of soak pit to ground water table) was reported by Mc Ginnis and De Walle (2001), and stated that, lateral and downward movement of leachate can be up to 30m down, and that rainfall desorbs microbial pathogens including viruses and carry them down in still viable states. He also concluded that, vertical separation between soak pits and ground water are more important than the horizontal separations between soak pits and wells.

Septic tanks effluent discharged into soil carries various constituents that may reach and degrade ground water. Some may be natural chemicals like chlorides, nitrates, phosphates oil fractions, fuel oil, pesticides, chlorinated hydrocarbons, turpentine just to name a few. Some common reasons for failures of onsite sanitation include; insufficient plot area for ground infiltration of waste, ground infiltration failure due to soil percolation rate, surface water pollution and ground water pollution (Kaplan, 1987)

2.5   Pollution Pathways

In a multi-aquifer systems, intensive abstraction from the lower strata will depress the piezometric surface (a hypothetical surface representing the surface to which groundwater would rise if not trapped in a confined aquifer), whereby the head between the shallow and deep aquifer water levels may induce downward leakage of water that is polluted into lower aquifers, if, the intervening beds are sufficiently permeable or fractured. The long time scale that is typically involved in the leakage to the deep aquifer means that the most persistent pollutants will reach the supply intakes (Canter and Knox1985).

According to Canter and Knox (1985), factors that ought to be considered to determine the likely extent of the contaminant loading includes:

i.   Classification of the contaminants: Persistence and mobility being the main characteristics of the contaminant in relation to its likelihood to pollute groundwater. The efficiency of the pollutant to percolate through soil to the water table or not depends on the sorption, ion exchange and precipitation processes in the soil. Some pollutants may be toxic and mobile, but, there persistence and rapid degradability renders these compounds non-toxic.

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ii. Mode of disposition: This is the spatial area in the zones of saturated and or unsaturated soils, where the application of the pollutant is made. Non-point sources of pollution result in low levels of pollutants distributed over a large area. Conversely, the point source produces localized contamination of higher concentration.

iii. Intensity of contamination: The potential of the ground water contamination increases with the amount of pollutants being charged into the sub surface environment. It will be considered that low intensity of application will make the soils capable of eliminating and attenuating many contaminants. However, a progressively higher percentage will be leached, above a certain critical threshold.

iv. Duration of application: The time span of loading the contaminant is of concern. The release of the contaminant to the water bearing strata in a brief episode is easily dispersed and diluted during the migration through the saturated zones particularly in the deeper ground water systems. But, the exceptions arise where the contaminants are especially toxic e.g chlorinated solvents, heavy metals and radioactive waste. A small quantity can cause a threat to ground water (Harman *et al*, 1996).

Pollutants from human activities on the surface which acts as the re-charge zone enters shallow aquifers and are mobilized by gravity following the basement flow of the ground water. In high density informal settlement area like Kibera, Korogocho, Kariobang'i, kwanjenga, Huruma etc, lack sanitary infrastructure which can be associated with the bacterial contamination of the ground water (Kazungu *et al*, 2011). The presences of general coli in the majority of the sampled boreholes indicate that contamination is evident for bacteria of faecal origin that is non-pathogenic (E.colli and Enterococcus spp). The origin of the microbial contaminant would most likely be from the nearby pit latrines and unlined septic tanks. In the alimentary canal, symbiotically, Escherichia coli are usually present in

large numbers. But, in other parts of the body, E. coli can cause serious disease, such as meningitis, urinary tract infections and bacteremia (Kazungu *et al*, 2011).

2.6   Chemical Toxicology

The U.S EPA, under the Safe Drinking Water Act (USEPA, 2006), established Water Regulations for over 80 contaminants with the aim of bringing down their levels, in all drinking water, closer to recommendations in the Maximum Contaminant Level Goals (MCLGs) previously established by the EPA . For nitrate, the MCL is 10 mg/L (ppm) as nitrogen. The basis of the action taken by the EPA, setting the MCL at 10 mg/L, was the occurrence of methemoglobinemia in infants under six months. The MCL reflects the levels at which this condition may occur (USEPA, 2006), Mitigation actions must be implemented so that the child should not become sick from methemoglobinemia. People, who live away from urban areas or in informal settlements, would be safer from this disease if their boreholes are routinely tested, especially if pregnant women or infants are consumers of the well water (USEPA, 2006).

2.7 Physico-chemical and biological parameters

In chemical analysis, substances that make water un-palatable at concentrations higher than the existing standards for proper health or that affect the look, smell and taste and that are of health concern, are investigated. These investigations help to establish health-based summary statements and guideline values. These summary statements and guideline values for each substance, upon adoption by water authorities, aid in the provision and usage of water which is satisfactory aesthetically and has uniform quality (WHO, 2007).

Bacteriological analysis investigates microbiologically, both quantitatively and qualitatively, microbial contaminants in the water. The importance of bacteriological analysis of drinking

water helps to determine the presence of potential water-borne pathogens. It suffices here to say that bacteriological analysis of water provides the most sensitive quality parameter.

2.7.1 pH

pH (pondus Hydrogenium), is the degree of the basicity or acidity of a water solution or simply as the measure of hydrogen ion concentration of a water solution $[H]^+$. pH has no unit of measurement, since it is a dimensionless quantity, by virtue of its logarithmic nature. It is a parameter that determines the quality of all waters, which also affects most physical, biological and chemical processes in water supply treatment (WHO, 2007). Water, in its pure state, for example, has a pH of 7 (neutral); the exact values depend on temperature. For most natural waters, the pH ranges from 6 to 8.5, values below 7(acidic waters) in waters that are high in organic content and values above 7 (alkaline waters) in eutrophic waters, ground water brines and salt lakes (USEPA, 2006). However, for clean water, the pH may be due to, among other reasons, the types of rocks and vegetation within the watershed (WHO, 2007). It also a factor of great significance, since some methods or processes of water treatment, geared towards improving water quality can only take place when water has a certain pH, e.g, the reactions of chlorine take place only when the pH is between a value of 6.5 and 8. Major reasons for variations of pH in water are; industrial and domestic effluent and acid rain from atmospheric depositions. Respiration and photosynthesis of algae in eutrophic waters can also cause fluctuations of pH in water (WHO, 2007). pH is a very technical parameter for the quality of water, even though it doesn't affect water's consumption, it should be monitored at all stages of water treatment to ensure satisfactory water clarification and disinfection. Low pH values, (less than 4), indicate that the water is corrosive and that it will tend to dissolve heavy metals such as lead and chromium and other substances that it interacts with. These heavy metals and other dissolved substances tend to become toxic when dissolved in water.

pH values that are greater than 8.5 (high pH), mean that the water is alkaline, and that it will tend to form scale on heating (APHA, 1994). pH adjustment in water is achieved through the use of: calcium carbonate, carbon dioxide, hydrochloric acid, lime (quicklime and hydrated lime), sodium carbonate, sodium hydroxide and sulphuric acid (APHA, 1994).

The minimum and maximum allowable range of pH for portability as issued by the WHO (2003a) the Safe Drinking Water Act and the European Community is 6.5-8.5. The Kenyan standard (KS 05-459, 1996), however, has adopted a minimum value of 4 for carbonated waters.

2.7.2 Total alkalinity

The acid neutralizing ability of a water solution, to the equivalence point of carbonate or bicarbonate is referred to as Alkalinity. The acid neutralizing capacity of a solution, alone, is not alkalinity (Wayman and Robertson, 1956). Only three types of alkalinity can be determined from water analysis namely: hydroxide (OH^-), carbonate (CO_3^-) and bicarbonate (HCO_3^-) alkalinity. These subdivisions are useful in the softening process and in the boiler water analysis. Waters that has a low level alkalinity does not have a stable pH, since they have a low buffering capacity. Volume of an acid that dissociates 100%, required to be added to lower the pH of a sample to 8.3 gives the free alkalinity (Caustic and sodium carbonate alkalinity), and to a pH of between 8.3 and 4 gives the total alkalinity (APHA, 1994). Most of the natural alkalinity in waters is due to hydrogen carbonate (HCO_3^-) as a product from its reaction with limestone or chalk. The measurement is expressed in terms of calcium carbonate ($CaCO_3$).

Alkalinity in drinking water emanates from bicarbonates, carbonates, and hydroxide ions components in treated or untreated (raw) water supplies. The major components are bicarbonates due to weak carbonic acid reacting with basic materials of soil; borates,

silicates, and phosphates may be minor components. Alkalinity of raw water may also come from salts formed from organic acids, such as humic acids (Ademoriti, 1996). There are no recommended guideline values for alkalinity in drinking water. However, looking at it from a probability viewpoint; alkalinity is not a significant parameter. Concentrations that vary from 5 to 125 mg/l $CaCO_3$ equivalent are expected, and the extremes of these values are tolerated in water supplies (Ademoriti, 1996).

2.7.3 Chlorides

Chlorides are soluble in water and are unaffected by biological processes, hence, reducible by dilution. They are compounds of chlorine which occur as chloride ions (Cl^-) in solution.

The concentrations of chlorides ions depend on the composition of the geologic make up in any given area. The presence of chlorides is common in most natural waters (Ademoriti, 1996). Small quantities of chlorides of calcium and magnesium are found in many waters. This characteristic adds palatability to the water thus is desirable for consumption. Chloride concentration in natural waters is usually below 10 mg/l in areas with high humidity and in isolated fresh water bodies. Tidal streams contain increasing amounts of chloride (as much as 19,000 mg/L) as the bay or ocean is approached.

Chloride is introduced in water through the leaching process of chlorides from sedimentary rocks (e.g. rock salt deposits) and soils (Ademoriti, 1996). Higher concentrations of chloride can be found near salt water intrusions, wet coastal areas, irrigation drains, in sewage and other waste outlets. Chlorides in large amounts (above 100mg/l) affect the taste, making it salty and unfit for humans and animals. Corrosion of metallic piping and plumbing fittings is made more severe by excessive chloride concentrations, depending on the alkalinity of the water, which contribute to the total metal ions content of water in the supply (WHO, 2004). High levels of chloride are catastrophic to individuals who are affected by heart and kidney

diseases (Ademoriti, 1996). The removal of chloride in water is not done by conventional treatment. Levels of chloride in water, however, can be lowered by the process of dechloridation which is achieved by the use of agents like activated carbon, aluminum ammonium sulphate, ion-exchange resins, sodium bi-sulphite (sodium pyrosulphate), sodium sulphite, and sulphur dioxide. Pollution control and dilution can also be used to reduce chloride concentration. The actual removal of chloride, however, can be accomplished through a demineralization process, which includes reverse osmosis or electrodialysis (Ademoriti, 1996). The WHO (1963) listed 200 mg/l as a guideline value for chloride as a maximum acceptable value, and 600 mg/l as a maximum allowable value. On the other hand, The European Community used 250 mg/l as a guideline value and 200 mg/L as a level over which effects may be registered. A secondary drinking water standard for chloride was issued by the USEPA (2008), at 250 mg/l and a guideline, listed by WHO (2004), of a guideline value of 250 mg/l (Ademoriti, 1996). The 250 mg/l as the standard for chloride in drinking water has been adopted by Kenya standard (KS 05-459-1, 1996).

Domestic effluent has a higher concentration of chlorides than in natural water, and therefore acts as a suitable pollution tracer for borehole water contamination. The method used was a rapid determination by titration with $AgNO_3$ solution using K_2CrO_4 as an indicator. The end-point was indicated by the appearance of a permanent reddish tinge (Mohr's method).

2.7.4 Electrical Conductivity

The measure of the ability of a water solution to conduct an electrical current is referred to as it electrical conductivity, which is expressed as milisiemens per centimeter (mS/cm). The total amount of solids dissolved in water (TDS) in parts per million (ppm) or mg/l, can also be estimated by the electrical conductivity. Its value has a direct relationship to the temperature of water, in that; when the temperature of water is raised by 1° C, the value of

electrical conductivity of water goes up by 2-3%. It also has a direct relationship to solute concentration and therefore to the total dissolved solids (TDS). Dissolved salts dissociate to anions and cations, which conduct electricity. During field work, the conductivity of water is preferred, since it is more difficult to measure the TDS. Liquid water, that is chemically pure, has a very low electrical conductance. The presence of dissociated ions in solution, however, renders the solution conductive. The most important factors in determining how well a given solution will conduct an electrical current are: variations in dissolved mineral salts (dissolved solids, the number and kinds of ions present, the extent of dissociation of the dissolved minerals into ions, their relative charge of ions, temperature of the solution and mobility of the ions (De, 2010). Water in most freshwater bodies, has conductivity values that range from 10 to 1000 μS/cm. Higher values, greater than 1000 μS/cm, can be observed in waters which are loaded with huge volumes of surface run-off or those that are polluted (De, 2010). Electrical conductivity arises from dissolved mineral matter in water. Free carbon dioxide and ammonia also impart conductivity in water, though their effect is negligible, except in waters of very low salinity. Because water conductivity has a direct relationship with TDS and temperature; waters with very high conductivity may possess repugnant tastes and thus less attractive to consumers. No known method has been proposed for the management of the levels of conductivity in water, and no guideline values has been proposed for conductivity in drinking waters.

2.7.5 Nitrates and Nitrites

Natural unpolluted water, practically, does not contain nitrites. Nitrites are the first product of oxidation of free ammonia by biochemical activity. The nitrite concentration present is due to the organic matter in the soils. Concentrations that are higher than the very low value of 0.001mg/l are of sanitary significance (Kaplan, 1987).

Nitrates represent the mineralization of nitrogen from organic matter and the last stage of oxidation of ammonia. This oxidation is achieved by nitrifying bacteria and can also occur in a well oxygenated environment. In excessive levels, nitrate may cause serious illness and occasionally, death in infants (Kaplan, 1987)

Nitrates generally occur in trace amounts in freshwater bodies on land, however, the concentration could be much higher in some in some ground water (APHA, 1994). Nitrates are reduced to NH_3 by Devarda's alloy (containing 50% Cu, 45% Al, 5% Zn) in strongly alkaline solutions; the NH_3 is distilled into excess standard acid and finally estimated titrimetrically.

$$3NO_3 + 8Al + 5OH^- + 2H_2O \rightarrow 8AlO_2 + 3NH_3 \tag{3}$$
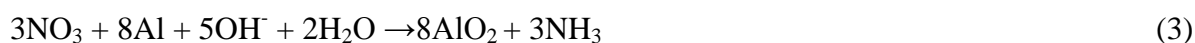
Nitrites are an intermediate product, both in the oxidation of NH_3 to NO_2 and in the reduction of NH_3, which occurs in natural waters, water distribution systems and waste-water treatment plants. A method based on the diazotisation reaction was used and a reddish-purple azo-dye colour is formed at pH 2.0 - 2.5 by the bonding of diazotized-sulphanilamide with N-(1-naphtyl) ethylenediamine dihydrochloride.

2.7.6 Ammonia

Ammonia is generally present in surface water, ground water and domestic sewage (APHA, 1994). It is produced largely by the hydrolysis of urea and deamination of organic nitrogen-containing compounds (De, 2010). Water samples were analysed using the Nester's method (Kazi *et al*., 2009). A method based on the reaction of HgI_4^{2-} (tetraiodomercury (II) anion and NH_3 in alkaline solution.

$$NH_3 + HgI_4^{2-} + 3OH^- \rightarrow NH_2Hg_2IO + 7I^- + 2H_2O \text{ (orange-brown)} \tag{4}$$
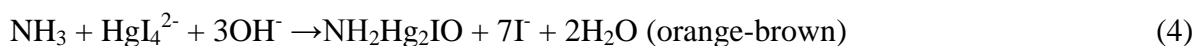
The orange-brown reaction product was measured spectrophotometrically at 420 nm.

2.7.7 Sulphate

Sulphate occurs in natural waters from a few to several thousand milligrams per litre in natural water and waste waters. Excess Na_2SO_4 should be absent in drinking water as they cause cathartic action (APHA, 1994).

2.7.9 Phosphate

Phosphate occurs is found in waste waters and natural waters as inorganic and organically bound phosphate since they are mainly used for laundry purposes. Primarily, they are naturally produced in biochemical processes and are also constituents of domestic sewage (APHA, 1994). The phosphate concentration in water, comprises; ortho-phosphates and condensed phosphates, both soluble and insoluble organic species. A digestion method is necessary to oxidise organic-bound P by rupturing both C-P and C-O-P bonds and releasing P as soluble PO^{3-}_4. $HNO_3 - H_2SO_4$ digestion shall be used for these samples. In dilute ortho-phosphate solution, ammonium molybdate reacts in acidic medium to form molybdophosphoric acid which is measured at 460 nm (APHA, 1994).

2.7.10 phenols

Phenol analysis is important because of the objectionable taste from chlorinated phenols even at very low concentrations. It can also be an indication of contamination of borehole water from septic tanks. It is common at high concentrations in waste waters. In this method, phenols and other phenolic compounds are first separated from the sample by distillation (APHA, 1994). Reaction of phenol and 4-aminoantipyrine at pH 10 using $K_3Fe\ (CN)_6$ as a catalyst, develops a red coloured species which is extractable into $CHCl_3$. The absorbance is measured at 460 nm.

2.7.11 surfactant as methylene blue active substances (MBAS)

This is an alkyl aryl sulphonate having a structure made-up of a straight-chain alkyl group, a benzene ring and a sulphonate. It is commonly used as a surfactant in synthetic detergents.

Anionic surfactants such as linear alkylbenzene sulphonic acid (LAS) react with methylene blue to produce a blue salt which is measured spectrophotometrically at 625nm. This method is applicable for LAS in the 0.025 -100ppm ranges (Wayman *et al*, 1956).

2.7.12 Total dissolved solids (TDS)

TDS, in high concentrations, is likely to result in stomach discomfort to people, objectionable taste and cause involuntary bowel movement, particularly upon transits (WHO, 2003b). There is a strong correlation between TDS and parameters like Cl-, $SO4^{2-}$ and Na+, indicating their availability in solution. Therefore, this shows that it be used to give an estimate of several other parameters (Ravindra and Gargl, 2003).

2.7.13 Sodium

Sodium salts are highly soluble and naturally of occur in ground water from sodium bearing rock minerals. At levels of above 200mg/l litre, sodium salt can be tasted by most people (Alhajjar, *et al,* 1990).

2.7.14 Chemical oxygen demand (COD)

This parameter gives a measure oxygen equivalent to the organic matter content of the water that can be oxidised by a strong chemical oxidant and thus is an index of organic pollution (APHA, 1994).

2.8.15 Colour and Odour

These two parameters are physical characteristics in drinking water affect the smell and appearance are of more importance to esthetics than for health of the consumer (Alhajjar, *et al*, 1990). Colour in water may be as a result of algae or decaying leaves. They may also be due to the effect of organic matter or gasses in solution. For example, borehole water could have a pungent smell caused by hydrogen sulfide gas. Chemical impurities associated with the aesthetic quality of drinking water include iron, manganese, copper, zinc etc.

Metal ions in solution cause a metallic taste and would likely stain laundry and plumbing fixtures (Sosbey, 2002). Excessive chlorides give the water an objectionable salty taste. Pure water is colourless. Presence of colour in water is due to minerals and organic matter from the environment. Colour is classified as either apparent colour (colour contributed by suspended matter in water) or true colour (after filtration). True colour is the most difficult to remove by conventional water treatment methods. Colour is a physical parameter that is not necessarily related to toxicity or pathogenic contamination of water. Nevertheless the colour affects its preference for industrial and domestic use. It causes psychological rejection and fear to consumers (Sosbey, 2002). The Kenya Standards (KS) and World Health Organization guidelines specify 15 Total Colour Units (TCU) as the acceptable level of colour in water (Sosbey, 2002). The WHO guidelines are based on acceptance of the fact that at 15 TCU no colour is detected visually.

Water with a bad taste and odour, is not attractive to consumers as the consumers normally associate the water with contamination. Tastes and odours can also be cue to algae growth which secretes a substance that is oily and that may result to taste and odour, phenols and chlorophenols, or salts and metals from the soil. Some odours are indicative of increased biological activity in water. Water that is alkaline tastes bitter. If it has a taste but not

accompanying smell, the cause is usually inorganic contamination. When it has both, then it could be due to organic materials. Gases and liquids from decaying matter can cause odour and taste in water (Sosbey, 2002). When some specific substances combine, for example, organics and chlorine, they shall have an effect on taste and odour (WHO, 2003a). Taste and odour can be neutralized by oxidizing substances responsible for causing the problem. For this, oxidants like chlorine and potassium permanganate can be used or using activated carbon prior to filtration to remove odour and tastes and later regenerated to maintain it effectiveness (WHO, 2003a). The KS and WHO guidelines specify that the physical properties of drinking be acceptable by consumers.

2.7.16 Turbidity

Turbidity is defined as the dispersion and interference of light passage that is caused by the organic matter like silt, clay and other finely divided organic or inorganic particles suspended in water (WHO, 2007). The surface characteristics and size of the suspended matter has an influence on the scattering and absorption of light. It is caused by colloids in suspension, which are mainly clay particles, microorganisms and vegetable material. Colloidal matter harbors microorganisms and chemicals that affect the quality of water and hinder disinfection during treatment (Sosbey, 2002). The degree of turbidity of water is often taken to be an approximate measure of the extent of pollution. However it is not the only measure when determining presence or absence of pollution. This is because water may be clear but is contaminated by acids, toxic metals or other substances that do not cause turbidity. Following rainfall, variation in colour of water may indicate contamination due to surface runoff and may lead to the need of treatment prior to use especially for public supplies (Sosbey, 2002). The KS and WHO guidelines value for turbidity is 5 NTU and above this value water can be

objected for aesthetic value. A value of turbidity that is higher than 5 NTU may be repulsive to consumers.

2.7.17 Coliform and total bacteria

A group of bacteria called coliforms are a microbiological measure that is most important in drinking-water quality (WHO, 2003a). Coliforms, if found present in water, act as a sign for contamination by microbial pollutants and as a measure of the biological quality, easily. The coliform count thus reflects the chance of pathogens being present; the lower the coliform count, the less likely it is that pathogens are in the water. Biological contaminants constitute water quality parameters since their absence or presence maybe an indication of the attributes of the water source. Pathogens are of primary importance to water specialists, they include bacteria, viruses, protozoa and parasitic worms. They infest their host for a part of their life cycle and also thrive in water systems (Spellman, 2003). Autotrophic bacteria require carbon dioxide to multiply by binary fission while heterotrophic bacteria require organic compounds. Photosynthetic bacteria get their energy from sunlight, whereas chemosynthetic bacteria, from chemical reactions. They are very adaptive can be found in almost any environment (Spellman, 2003). Faecal waste is the main source of bacterial contamination in water, especially through wastewater discharge from septic tanks and sewage treatment facilities. Bacteria from these sources can enter wells that are either open at the land surface or do not have watertight casings or caps (Sililo *et al*, 2001). Escherichia coli are faecal coliforms and are a subset of the total coliform family. The distinction in the laboratory is by their ability to produce the enzyme glucuronidase and their ability to grow at elevated temperatures (44.5°C). Under the total coliform rule, specimen that test positive for total coliform are supposed to be further tested for confirmation of faecal coliform or E.coli. E.coli and faecal coliform do not distinguish between human and animal contamination. However, they are

better indicators for the presence of recent faecal contamination than total coliform. Their densities are much lower than those for total coliform, and thus are not used as an indicator for treatment effectiveness and post-treatment contamination. E.coli confirmation test gives better sign to show faecal pollution than tests for faecal coliform group (Sililo *et al*, 2001).

These are important water quality parameters since they play a key role in water borne diseases (Kaplan, 1987). Escherichia Coliform (E.coli) and, total bacteria counts were performed by incubating the water samples at specified temperature and culture medium for 48hrs and the colony that shall have grown on the plate/ Petri dish, counted

CHAPTER THREE

3.0 Materials and Methods

3.1 Study area

Ongata Rongai spans an area of 16.5 km^2 with a current population of 41,000 people and a projection of 52,513 people in 2015 (KNBS, 2009, GOK: Kajiado County Development Profile, Ministry of Devolution and Planning May, 2013). It is a fast developing residential urban aggregation within Kajiado County; at latitude (0° 53' 60 S), and longitude (36° 25' 60 E). It is located 50 Km from Kajiado County offices and 20 Km from Nairobi County head office on the Langata-Magadi Road, Figure 3.1.
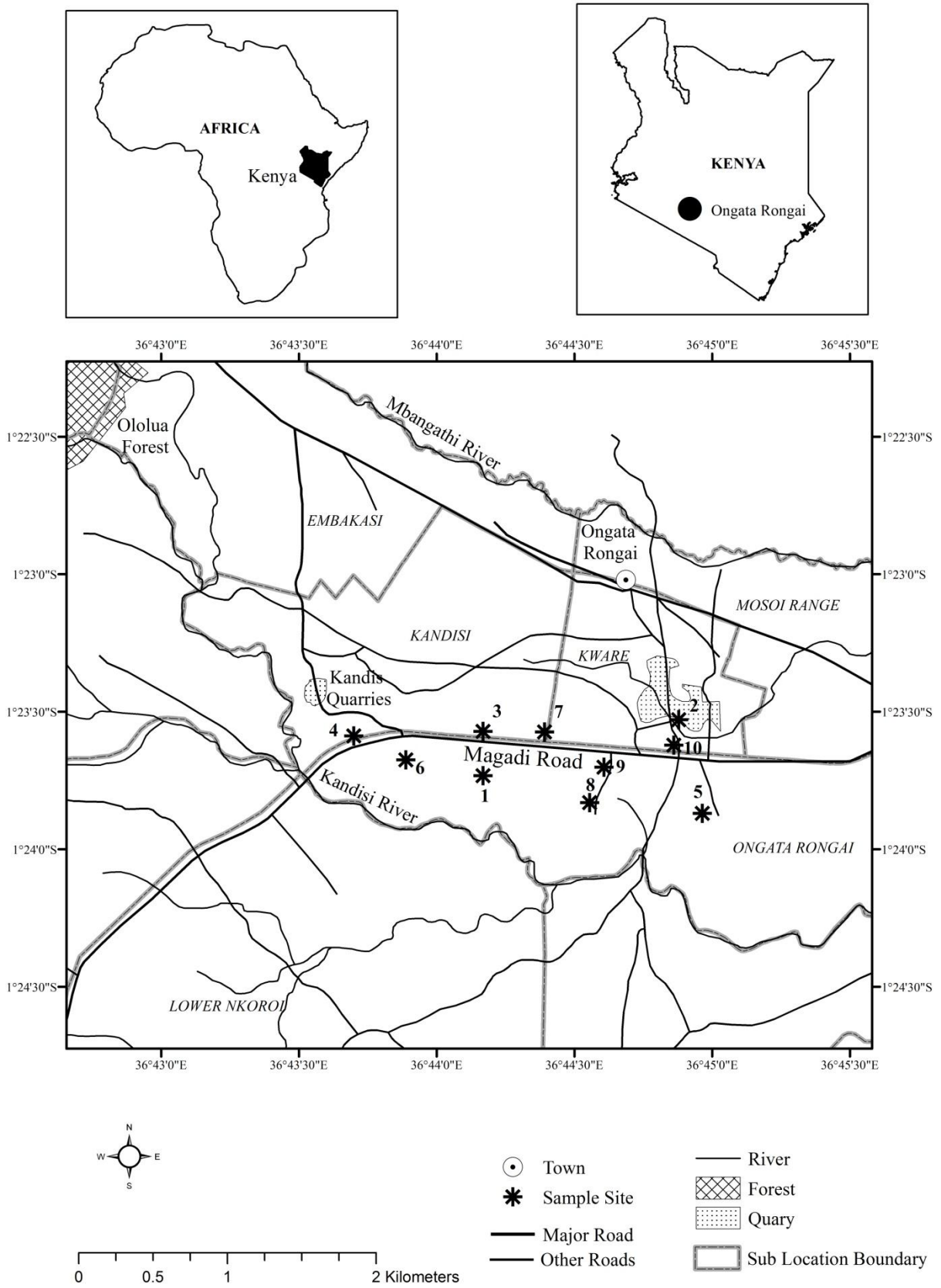
Figure 3.1: Map showing selected borehole sampling sites in Ongata Rongai.

3.1.1 Climate, geology and soils

The climate of Ongata Rongai areas is warm and temperate with enough precipitation all the year round, and a mean annual temperature of 18.3^{o}C and annual rainfall of 844 mm (Kenya Meteorological Services 2014, climate data, 2014). The warmest period occurs between January to March. The area has two rainy seasons, the long rains starts at the beginning of March and continues up to May while the short rain season starts at the beginning of October and lasts till December (Kenya Meteorological Services, 2014)

The geological make up of this area comprises of volcanic layers of basalts, trachytes, phonolites and tuffs all overlain by thick layers of clay soil. The soil structure of the area is considered poor because it is mainly rocky and black cotton soil which hardly drains water easily (Kazungu *et al,* 2011). This explains why there is flooding of the open earth drains and surroundings even a week after a heavy rainfall. Ongata Rongai's geology comprises of two distinct areas, the Ngong Hills and the upper Kajiado plains which Ongata Rongai town is located (Kazungu *et al,* 2011). There are five drainage basins in Kenya with Ongata Rongai being part of the Athi River catchment Mbagathi and Kandisi rivers in Ongata Rongai are tributaries of the Athi River, Figure 3.1. The Athi drainage basin covers a catchment area of 66387 km^2 with an annual rainfall of 739mm.

3.2 Site Selection and Sampling Plan

Field visits were made to the study area, Figure 3.1. Initial trips were for site selection, Table 3.1. Selection of physical, chemical and biological parameters to be determined were done. Acquisition of topographical map and historical data of water quality parameters at the time of drilling of the selected borehole sites; a general survey of the study area: Familiarization with the county authorities and borehole owners. Feasibility studies involved the: determination of the resource requirements: risk assessment: design of the data collection

techniques including questionnaires and the schedule for data collection was designed at this stage. Actual field operations, involving data collection and sampling, began on the 31st of January 2014. Geographic Information System (GIS) data was obtained for the 10 sampling sites by GPRS instrument and a cartographic map of the sampling area was made, Figure 3.1.

The precautions taken during sample collection were; rinsing the sampling bottle twice with the sample water before filling, proper labeling of samples; at least two liters of the sample for the full analysis and proper handling and storage for a maximum of 48 hours before analysis. These assured us that reliable results would be obtained.

Limitations encountered during this study included; denied access to borehole sites by the operators and lack of sufficient data in the records filed at the ministry of Water, Environment and Natural Resources.

Horizontal distances between boreholes and septic tanks on the ground were measured before the sampling works began, to meet sampling points siting criteria. The boreholes whose locations were next to or adjacent to septic tanks sewage disposal systems (≤ 200 m) were the ones selected. Samples were then drawn from the selected boreholes, at least from the primary storage where variables due to interference and interactions were minimal and where there was no access to borehole casings.

Questionnaires were used in the field for the different respondents (appendix B), to get information from the ministry of Water, Environment and Natural Resources, to identify the borehole locations, area intelligence for security purpose, septic tanks maintenance history and any complaints or remarks pertaining to the perceived quality of water supplied from these boreholes. Verbal consent was also sought from the borehole owners.

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

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

3.3 sampling procedure

Sampling process was aided by a qualified water chemist from KEWI laboratories. Sampling was done twice in the year, during the dry month (March) and wet month (May) seasons in 2014. Samples collected in month of May were to capture the effects of the long rain (wet) seasons on water quality. Samples for March (dry season) were to capture the levels of

contaminants in water samples without seasonal influence. Water samples were collected from ten identified boreholes sites (Figure 3.1) representative of the Ongata Rongai area in both seasons.

Water samplings were done according to the processes in APHA (1994). Samples from 10 boreholes in Ongata Rongai area were taken in well pre-cleaned two-litre plastic containers for physico-chemical parameters, packed in cooler box or ice-box then transported to the laboratory for testing. On-site data and observations and the description of the surroundings of the sampling site (Table 3.1), the exact water resource location, weather conditions at the time of sampling, the type of soil, presence of possible sources of pollution and indicators of contamination or pollution were recorded. Laboratory tests were undertaken as specified in APHA (1994). Actual field operations, involving data collection and sampling processes were done at this stage. Care was taken in ensuring that the samples were representative of the source and handled carefully so that no contamination occurred before testing. Sample analyses were done at the Kenya Water Institute laboratories.

3.3.1 Septic sewage disposal systems distance measurement

The distance from the selected boreholes and the septic tanks were taken using a measuring tape and the best sites which were ≤200 m were chosen due to their accessibility, septic tank density and distance apart. The mean distance of 5 septic tanks located around a selected borehole was measured and recorded. 10 boreholes were identified and permission was obtained from the owners for sample collections during the wet and dry seasons. Observations from the surroundings areas were also noted (Table 3.1).

3.3.2 Sampling water for Physico-chemical Analysis

The Ongata Rongai sampled boreholes comprised Sites 1 to 10, (Table 3.1). Sample site selection criteria were based on population densities (low vs. high human impact) and water quality (Table 3.1). The inclusion criteria was such that all boreholes that were within close proximity to high density of septic tanks which supplied drinking water, and had a record at the Ministry of Water, Environment and Natural resources of borehole data (water analysis results at the time of drilling, baseline data, yield, depth and water rest level). And the exclusion criteria, that boreholes that were ≤ 200m away from high density of septic tanks and those whose purpose was not to supply drinking water but for other uses or whose records were not available. Samples were collected in 2-litre plastic containers each, for physical and chemical analysis, which had been thoroughly cleaned by rinsing with 50 ml of 8M HNO_3, then repeatedly rinsed with de-ionized water and then rinsed thrice with sample water before collection. Water samples were collected at the site drawn from primary storage tanks by fully opening the taps and allowing the water to drain out from the storage tank, up to an estimated volume equivalent to the length of pipe to the faucet and then collected the water into the 2 litre plastic containers. The sample containers were labeled and the samples were temporarily stored in polyurethane cool boxes containing dry ice in the field vehicle for transportation to the laboratory for analyses. A total of forty samples were collected from each location, twice within the study period, during the dry and wet season. In the laboratory the samples were stored in the refrigerator at ≥ 4˚C and analyzed within 48hrs after sampling. Temperature, pH, and conductivity were measured on site at the time of water sampling. The other parameters targeted for analysis were chloride, sodium, methyl-blue Active Substances (surfactants), ammonia, nitrate (NO_3), nitrite, phosphorous, sulphates and phenols

3.3.3 Sampling Water for Bacteriological Analysis

1-litre glass bottles that were thoroughly cleaned and initially sterilized in an autoclave were used for sample collection (appendix B). The hands were cleaned using the cotton swab soaked in methylated spirit and the mouth of the water faucet were also cleaned in the same manner (APHA, 1994). The faucet from the borehole water storage tanks were fully opened and water allowed to drain out, up to an estimated volume equivalent to the length of pipe to the faucet, then the flow was adjusted to a fine stream and gas flame from the butane burner torch was brought close to the opening of the sample bottle as sample was being collected. This was done very fast and closed to prevent ingress of dust and spores from the air so as ensure that aseptic sampling is achieved. The sampling bottle was then labeled and the samples temporarily stored in polyurethane cool boxes containing dry ice in the field vehicle for transportation to the laboratory for analyses. Samples were stored in the refrigerator at $\geq 4°C$ and analyzed in the laboratory within 6 hrs after collection. The parameters analyzed were E-coli and total coli forms

3.4 Materials

Analytical grade (high purity) reagents and chemicals, instruments, apparatus and water sampling kit used were available at the Kenya Water Institute laboratory. A mapping tool for Global Positioning System (GPS) receiver (Map 410 Magellan) was used to obtain sampling site coordinates from Geographic Information System (GIS) at the borehole sites. This was obtained from the University of Nairobi Pesticides Analytical Research Laboratory.

A water sampling kit, cool boxes, 40 glass bottles with caps, 8M HNO_3 acid, 100ml sterile glass bottles, hand sanitizer,, alcohol glass thermometer, permanent marker pen, 500ml wash bottles and deionised water was used. 10ml class B pipettes, 1ml class B pipettes, 250ml conical flasks, 100 and 500 ml measuring cylinders, 250 and 500ml beakers, 50ml burettes,

spatula, micro culturing petri dishes, Mackatney bottles, culturing media (Mackonkey broth and malt agar media).

Instruments included: Hot plate, thermometer, magnetic stirrer, pH and conductivity meters, TDS meter, haze meter, lamina-flow micro analysis work bench, 37°C culturing incubator, UV spectrophotometer and a stop watch, reagents and chemicals. The personal protective gear included gumboots or closed shoes, lab-coat and head gear.

3.5 Analysis of water samples

Samples were prepared for analysis and the physico-chemical and bacteriological parameters analysis done in the laboratory. The determination of temperature was by an alcohol-in-glass portable thermometer dipped into the water samples to obtain the reading. To determine turbidity, the Nephelometric method was used (using HACH 2100AN turbidity meter) (APHA, 1994); total dissolved solids, by gravimetric method (Kazi *et al*., 2009); electrical conductivity was determined using the Jenway conductivity meter (4510 model), by dipping the probe into the container of the water samples until a stable reading was obtained and recorded; pH level was determined by use of HANNA pH meter (Model HI 28129) and sulphate by turbidimetric method using barium chloride and concentration reading through UV spectrophotometer (Model: UV-1601) (Ademoriti, 1996) and sodium by flame photometry (Buck Scientific Flame Photometer, Model PFP7). The fecal bacteria (E.coli and faecal streptococci) was microbiologically analysed, using the membrane filter technique (APHA, 1994). This technique determines the number of colony forming units per 100 ml (cfu/100 ml) of water sample (APHA, 1994). The mean for each of the parameters were calculated for each season and the result obtained were statistically analysed. The electrical conductivity was measured by a Jenway conductivity meter with dip-type cell (4510 model).

3.5.1 Determination of pH

A pH-meter, with an accuracy that gave a reading within +/- 0.1 pH unit, and a glass electrode that produces a potential varying linearly with pH of solution in which it is immersed. 50 ml of sample was drawn into a 50 ml beaker and placed in a water bath at $25^{o}C$. The instrument was calibrated with two standard buffer solutions of pH 10 and 4.0 before measurement. The stable reading displayed was recorded.

3.5.2 Electrical Conductivity

50ml of sample was drawn from the sampling container into a 250 ml beaker and placed in a water bath at $25^{o}C$. The instrument and cell was calibrated using 0.005M KCl solution (conductivity = $654\mu mho\ cm^{-1}$) before measurement. The electrode was rinsed by washing with distilled water after calibration and then dipped into the sample and reading recorded.

3.5.3 Determination of Ammonia

To a 100 ml sample, 2ml NaOH was added so as the acid initially used for sample preservation to be neutralize and then 1ml of 10% $ZnSO_4.7H_2O$ was added, followed by 1ml of 10% sodium hydroxide solution (10% NaOH), stirred and filtered (Ca, Fe, Mg, S^{2-} were precipitated), and the colourless middle fraction was drawn using a 100 ml pipette. Then, using a tit dropper, 0.1ml (1 drop) of 50% EDTA (disodium salt) was added and mixed well, then 2ml of Nessler's reagent (70g KI + 160g NaOH (ice cooled, diluted to 1 litre and mixed well by shaking). The resulting yellow colour was determined spectrometrically at 420nm and the level of ammonia (ppm) recorded.

3.5.4 Determination of Nitrate

500ml of sample was taken in NH_3 distillation apparatus; 50ml of 10% (w/v) NaOH was added and evaporated to about 200 ml then cooled. 3g of Devarda's alloy, then 30ml of 10% NaOH was added and immediately connected to the flask with a vertical condenser whose outlet drips into a receiver containing 200ml of 0.2N H_2SO_4. The mixture was distilled for 1 hour then the receiver was disconnected from the distillation apparatus and the volume of the distillate made up to 250ml. 10 ml aliquot was drawn, accurately, using a bulb pipette, into a 50 ml volumetric flask then neutralized to pH 4.5 using 0.2 N H_2SO_4. 2ml of Nestler's reagent was then added and the distillate directly back titrated with standard alkali (0.2 N NaOH) using Methyl red as indicator.

1ml H_2SO_4 = 0.0621g NO_3.

The volume of titre was then recorded as nitrate (NO_3, ppm).

3.5.5 Determination of Nitrites

40ml of sample carefully drawn into a 250ml conical flask and then the pH adjusted to 7.0 using H_2SO_4 or NaOH, 2ml of sulphanilamide solution (50g in 500ml of 1.2N HCl) was added, shaken then allowed to stand for 10 minutes, 2ml of N-(1-naphthyl) ethylenediamine dihydrochloride (0.83 g in 200ml cold water, cooled, filtered, and diluted to 250ml with glacial acetic acid) was added, and diluted to 50 ml and mixed thoroughly. The mixture was left to stand for 1 hour and the resulting purple azo dye measured spectrometrically at 543nm, against standards covering the range of NO_2 ,1 to 25 μgl^{-1} (at the final dilution).

3.5.6 Determination of Chloride

From the sample, 100ml was drawn and measured in a 250ml conical flask and the pH adjusted to 7-10 using 1 M H_2SO_4 or NaOH. 0.5 g of $Na_2B_4O_7$ was then added as a buffer to keep the pH at 9.0 then 1ml of 5% K_2CrO_4 solution added as an indicator and stirred well.

The solution was titrated with 0.0282 N $AgNO_3$ (282ml of 0.1N $AgNO_3$ diluted to 1litre) to a permanent reddish tinge.

$$Cl^- + Ag^+ \leftrightarrow AgCl_{(s)} \rightarrow 2Ag^+ (excess) + CrO_2^{-4} \rightarrow Ag_2CrO_4 \text{ (red)} \tag{7}$$
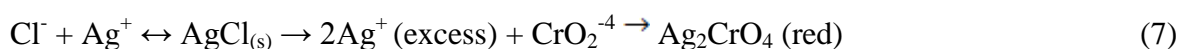
The amount of chloride in the sample is related to the amount of $AgNO_3$ using the relation

$$1ml \text{ of } 0.0282N \text{ } AgNO_3 = 1mg \text{ } Cl^- \tag{8}$$

3.5.8 Determination of Sulphate;

From the sample, 250ml was drawn into a conical flask, then 5 ml of 3M HCl was added and shaken to mix and then 1g of $BaCl_2$ was added and the solution heated to near boiling point, removed and allowed to rest for 5 minutes, after which, sulphate was precipitated in HCl medium as $BaSO_4$, then allowed to rest undisturbed for a few minutes, filtered and washed until free from Cl^-, then ignited and weighed as $BaSO_4$.

3.5.9 Determination of Phosphates

100ml of sample in a beaker was reacted to digest in a mixture of 1ml conc. H_2SO_4 and 5 ml concentrated HNO_3, then evaporated to dryness. The process was repeated (digestion and evaporation). The residue was leached with 5 ml of 5N HNO_3 and transferred to a 50 ml volumetric flask. 5ml of 10% ammonium molybdate was added, followed by 5 ml of 25% ammonium vanadate (in 6N HCl) and diluted to the mark and left to stand for 10 minutes (APHA, 1994). Then the absorbance of the resulting yellow coloured liquid was measured at

47

460nm. A blank was taken through the same steps as the sample, and analysed. A calibration curve was prepared using a series of standard solutions of phosphate, (220g KH_2PO_4 / l). 1ml = 50μg PO^{3-}_4 ... (10)

3.5.10 Analysis of Sodium

Preparation of a 100.0 ppm standard sodium stock solution, was done by accurately (to 0.1 mg) weighing out by difference 0.1271 g of reagent grade NaCl inside an analytical balance and then carefully transferring the salt quantitatively into a 500-ml volumetric flask. (0.100 g Na/l = 100 mg/l = 100 μg/ml = 100 ppm Na).

3.100 ml of deionised water was added to the flask then swirled until all the salt was dissolved before diluting to volume with deionised water.

The instrument (a single-channel photometer) was switched on. The flame was lit for 15 minutes while aspirating deionized water, to ensure stability.

Five 25-ml volumetric flasks were filled with five standards (1, 2, 3, 4, and 5 ppm Na) and the unknown solution(s) – in that order – and aspirated .The blank was set to 0.00 ppm. Then standard (5 ppm) until the meter reading has stabilized. Using the fine sensitivity knob, the meter reading was set to 5.00ppm. The unknown sample was then analysed and the emission values recorded.

3.5.11 Determination of Phenols

250ml of sample was added to a 1 litre distillation flask containing 5ml of 10% $CuSO_4$ +1ml glacial H_3PO_4, then distilled. The distillate was diluted to a volume of 500 ml using distilled water, 10 ml of 5% NH_4Cl was added, pH adjusted to 10 using conc. NH_4OH.Then 33 ml of 2% aqueous solution of 4-aminoantipyrine and 3 ml of 8% $K_3Fe (CN)_6$ was added. The

mixture was left to react for 5 minutes and the resulting red coloured antipyridine was extracted three times with 10 ml, 10 ml and 5 ml $CHCl_3$. The absorbance of the $CHCl_3$ extract was then measured at 460 nm.

3.5.12 Determination of Surfactant as Methylene Blue Active Substances (MBAS)

100ml of sample was taken in a separating funnel. 1M NaOH was added drop-wise to make the solution alkaline to phenolphthalein. The pink colour of the indicator was discharged by drop-wise addition of 1N H_2SO_4. 10ml $CHCl_3$ and 25 ml methylene blue reagent (30 mg methylene blue in 500 ml distilled water + 6.8 ml concentrated $NaH_2PO_4.H_2O$ and diluted to 1litre. These were extracted for 30 seconds and allowed phase separation. The extraction was repeated twice with 10 ml $CHCl_3$ each time. The $CHCl_3$ extracts were combined in a secondary separatory funnel, shaken with 50 ml wash solution (6.8 ml concentrated H_2SO_4 in 500 ml distilled water + 50g $NaH_2PO_4.H_2O$, mixed thoroughly and diluted to 1 litre) then withdraw the organic extract was added into a 100 ml volumetric flask and dilute to the mark with $CHCl_3$. Measurement was done at 625 nm against a $CHCl_3$ blank.

3.5.13 Determination of Escherichia Coliform (E.coli) and Total Bacteria

3.5.13.1 Escherichia Coliform (E.coli)

The culture medium for incubating Escherichia coliform was made from a mixture of 10g peptone, 10g lactose, 2g KH_2PO_4, 15g agar, 4g eosin Y and 0.065g methylene blue in 1 litre distilled water (pH 7.1 after sterilization). 0.1 ml of water sample was incubated in the culture media on a membrane at 37 ± 1° C for 48 hours and the number of coliform colonies were counted and expressed as colony counts per 100ml of water sample.

3.5.13.2 Determination of total bacteria

The culture medium for incubating the total bacteria was made from a mixture of 3g beef extract, 5g tryptone, 1g glucose and 15 g agar in 1 litre distilled water (pH 6.8 − 7.0 after sterilization). 0.1 ml of water sample was incubated in the culture media on a membrane at $35\pm0.5^{o}C$ for 48 hours. The number of bacteria colonies were counted and expressed as colony counts/ 100ml sample.

3.5.14 Determination of COD

Estimation of COD was done by reflux titrimetry (APHA 1994).

3.6 Statistical data analysis

Correlations between the seasonal variation and the level of physico-chemical and biological parameters detected were determined using Statistical Package for Social Sciences tools (SPSS). The results obtained were represented by use of text, graphs and statistical tables to show the interrelationships of various variables such as pH, TDS, electronic conductivity, etc, on the water quality parameters.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Structured interviews

Results of questionnaire interviews (appendix B), showed that; 90% of the residents do not know the quality of water supplied to them from private boreholes; 50% of the residents have experienced or heard complaints due to seasonal changes in the physical characteristic of the water from boreholes; 100% of the residents treat the water prior to consumption and assured us of safety during the day; 50% of all the participants agreed that there is some impacts on boreholes water qualities due to the location of the septic tanks. The officer at the ministry of water agreed that there is a probability that ground water in Ongata Rongai area could be vulnerable to contamination from septic tanks sewage systems close to the boreholes as a result of onsite waste disposal and agreed that the environmental impact assessments for new developments should consider the impacts of septic tanks on ground water quality. Records were availed and permission granted to access boreholes for sampling.

4.1.2 Septic tanks system distances from selected boreholes

The most ideal sampling site for the study was selected, where septic tanks and boreholes were located within close proximity of ≤150 m from each other and with easy access. The mean distance measurements of the five septic tanks close to each sampling site, is shown in Table 4.1. The data of the water rest levels, depths and yields for each sampled boreholes were obtained from records maintained at the ministry of environment, water and natural resources.

Table 4.1: Water rest levels, depths and distance from septic tanks that characterize the boreholes Sites.

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

Site 6 has the highest borehole depth of 296 m; this was followed by Site 8 with a depth of 286 m while borehole 8 has the highest water rest level (116 m) while 5 has the highest yield of 12.6 m^3hr^{-1} (Table 4.1). Sites 7 and 5 are very close to all the septic tanks while site 10 was further from the septic tanks (Figure 4.1).
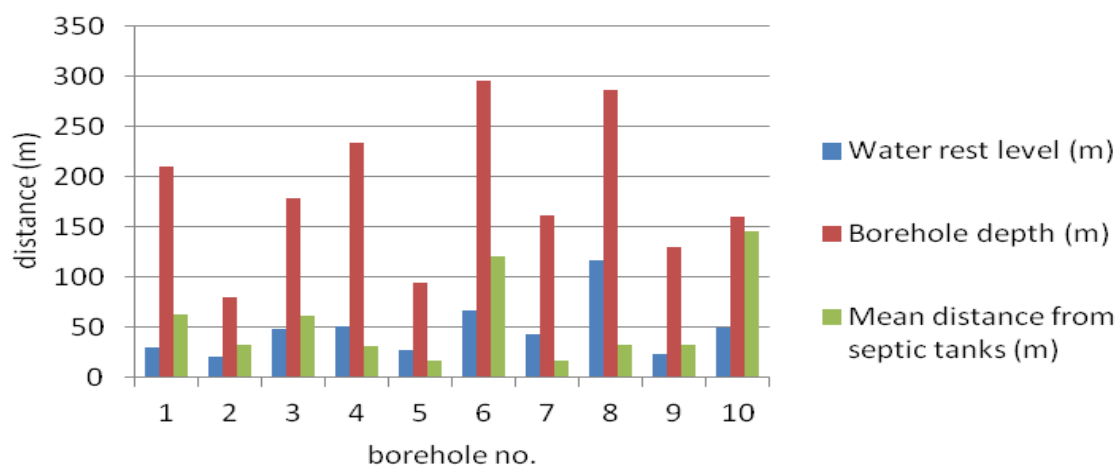

Figure 4.1; characteristics of the boreholes

4.2 Physical parameters.

The analysis of the physical parameters in dry and wet seasons gave three sets of results for pH, turbidity, alkalinity, electrical conductivity, and TDS levels (Table 4.2).

Table 4.2: Boreholes water physical Parameters

Borehole Site number		1	2	3	4	5	6	7	8	9	10	
Distance-ST (m)		63	33	60.8	31.4	16.2	120	16	33	32	146	Average
pH	b/line	8.3	8.2	6.8	7.6	8.4	7.3	8.4	8.5	8.5	7.7	7.97
	dry	8.4±1.19	7.4±0.44	7.8±0.25	7.8±0.31	8.6±1.10	6.5±1.26	8.2±0.14	8.5±1.03	8.5±1.03	7.8±0.95	7.95
	wet	7.9±0.33	7.5±0.21	7.6±0.20	7.8±0.31	8.4±0.40	6.5±0.4	8±0.52	8.6±0.53	7.6±0.20	7.7±0.11	76
Turbidity (NTU)	b/line	9	3.8	2	3.3	4.18	2.68	8	8.9	6.69	8	5.66
	dry	4.9±1.23	4.5±0.19	2.1±0.16	4.1±0.11	4.7±0.28	2.1±0.17	4.8±0.20	1.9±0.26	3.9±0.13	4.3±0.21	3.73
	wet	5±1.3	4.6±1.02	2±0.91	4.1±0.12	4.9±0.19	2.1±0.15	4.9±0.17	2±0.89	4.1±0.16	4.3±0.49	3.8
Alkalinity (mg/L)	b/line	134	129.2	117	123.6	143.3	142.1	146.7	151	122.8	177.2	138.7
	dry	125.7±0.21	130.2±0.34	116±0.31	130.2±0.22	143±0.20	137.8±0.15	145.2±0.35	156±0.21	126.1±0.22	187.1±0.81	139.73
	wet	126±0.88	134±0.32	161.1±0.64	131.1±0.21	152±0.50	136.6±0.39	149.1±0.28	145.7±0.20	126±0.54	186.9±0.92	144.85
TDS (mg/L)	b/line	467	801	353	539	869	534	180	675	518	675	518
	dry	513±0.43	788±1.10	412±0.91	766±1.33	840±1.42	477±1.03	174±2.41	709±1.58	598±0.42	709±1.58	598
	wet	611±0.67	890±1.45	422±1.04	770±1.33	896±1.98	480±0.69	180±2.21	702±1.63	592±0.78	702±1.64	592
Conductivity (µScm-[1])	b/line	840	1200	562	870	900	862	304	1220	806	1220	806
	dry	1265±1.32	1002±1.67	918±0.88	1222±3.15	812±0.53	830±0.66	318±1.43	1134±2.72	802±0.70.02	1134±1.11	802
	wet	1215±1.65	994±0.44	912±1.03	1218±2.97	808±0.31	840±0.91	315±2.12	1030±1.58	811±0	1030±2.10	811

b/line = baseline data obtained from the records of analysis results at the time of drilling the borehole, Distance-ST(m) = distance of borehole from septic tanks in metres, (-) = no data, (0) = below detectable limit (BDL).

4.2.1 pH values

In dry season the pH levels ranged from 6.5±1.26 to 8.6 ±1.10, while in wet season the levels ranged from 6.5±0.4 to 8.6±0.53, these values were not varied from the baseline data which ranged from 7.3-8.5 levels (Table 4.2).

The comparison of data results of water samples collected in the dry and wet season with the Historical Reference (baseline data) obtained from the Ministry of Environment, Water and Natural Resources with the study results is shown in Figure 4.2. This shows the variation of pH, from the baseline data values in relation to water from boreholes at 1m distances from septic tank systems and 1m water rest level.
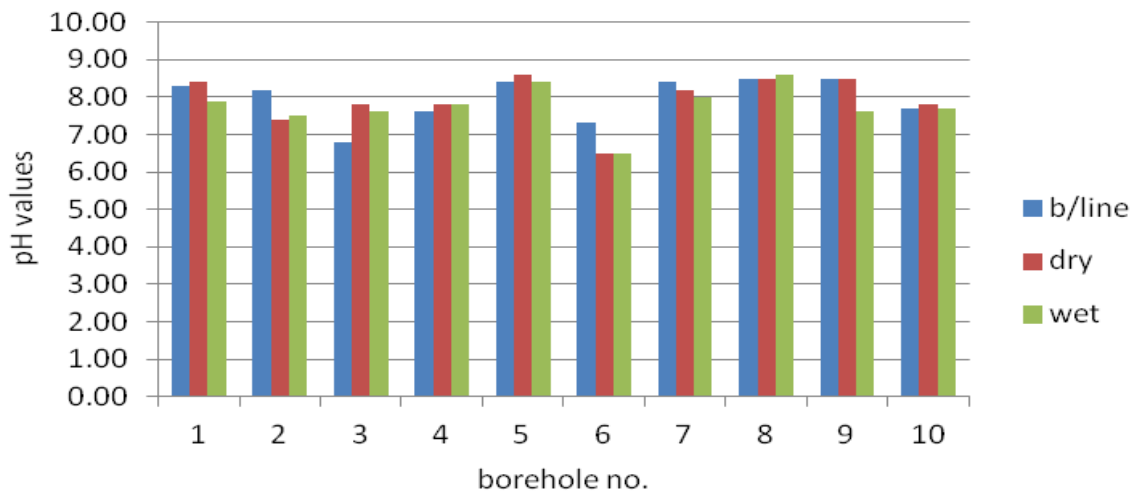

Figure 4.2: Variation of   pH levels in the borehole sites.

Water sampled from all the boreholes sites based at ≤ 146m mean distance from the septic tank and 30% of all the sites (Sites 3, 4 and 5) had higher pH than the baseline data and verage distances from 5 septic tanks of 60.8m, 31.4m, 16.2m respectively. in sites 4 and 6

there was no seasonal variation on pH. Sites 2, 6, and 7 had lower pH value in dry and wet seasons than the baseline data (Figure 4.2).

4.2.2 Turbidity values

Turbidity is caused by the scattering of light in all directions by un-dissolved substances. The values of the turbidity for the water samples from the ten borehole sites are shown in Table 4.1, Figure 4.3.
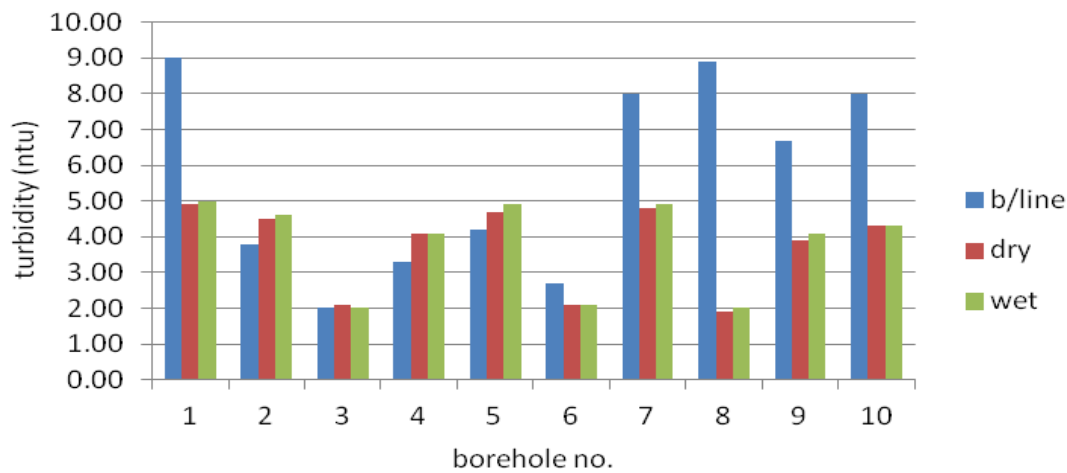
Figure 4.3: Variation of turbidity levels in the boreholes

In dry season the turbidity ranged from 1.9±0.26 to 4.9 ±1.23 NTU and ranged from 2.0±0.91 to 5.0 ±0.13 NTU in wet season. The baseline data ranged from 2.0-9.0 NTU. Site 1 showed the highest turbidity levels of 4.9±1.22 and 5.0 ±0.13 NTU in the dry and wet seasons respectively, this was followed by site 7 at 4.8 ± 0.20 and 4.9± 0.12 NTU in dry and wet seasons respectively. The water samples from 60% of all the boreholes sites based at ≤146m mean distance from the septic tank had lower turbidity and 30% of all the sites. Sites 2, 4 and 5 at an average distance of 33m, 31.4m and 16.2m respectively had higher turbidity than baseline data.(Figure 4.3). The baseline turbidity values are higher in some sites (Sites 1, 7, 8,

9 and 10) in samples analyzed in dry and wet season, (Figure 4.3). The selected borehole

turbidity data are within the WHO limit (WHO 2008) of 5NTU.

4.2.3 Alkalinity values

Total alkalinity values determined from the analysis ranged from 116 ±0.31 to 187.1±0.81

mg/l in dry season and 126 ± 0.88 to 186.9±0.92 mg/l in the wet season, with the baseline

data ranging from 117-177.2 mg/l, indicating an increase over time period (Table 3), in wet

and dry seasons. The values are above the limit of 5 − 125 mg/l (John, 1997), Table 4.2.
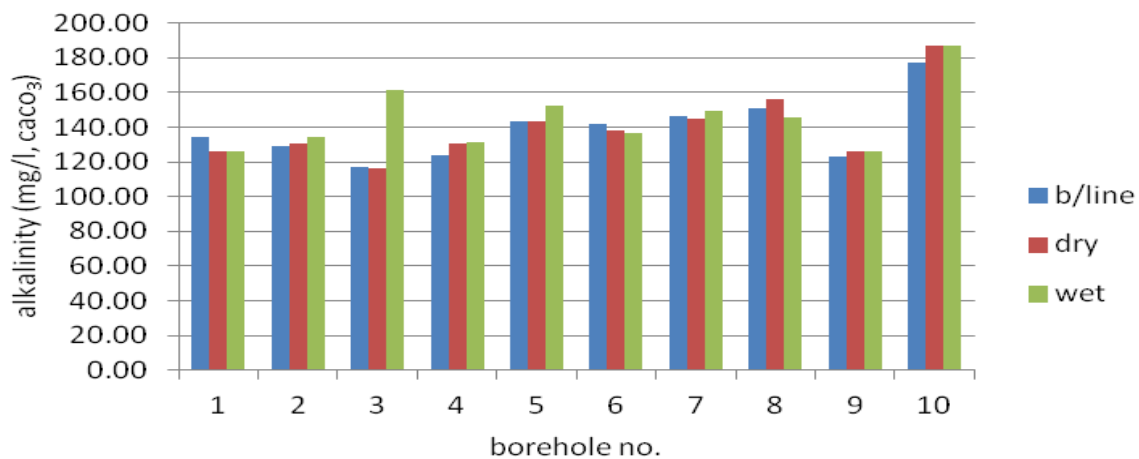
Figure 4.4: variation of alkalinity levels in.

The values are above the limit of 5 − 125 mg/l (Gleeson, *et al*, 2012). The high values are

because of anthropogenic influences on the sub surface environment, including precipitation

leading to leaching of lime from the soil and CO_2 (Gleeson, *et al*, 2012). Alkalinity is a

function of bicarbonate, carbonate and hydroxyl ions which have dissolved from chemical

compounds from rocks and soils. Out of all the samples collected, Sites 1 and 2 had carbonate

/ bicarbonate alkalinity since pH was ≥ 8.3.

Site 10 had the highest alkalinity values in the wet and dry seasons (Figure 4.4). Alkalinity in water has no health significance but high levels makes water unpalatable and may affect the efficiency of certain water treatment processes such as coagulation where treatment is needed (WHO, 2008). According to the set standards, all the analysed samples fall within range and satisfy alkalinity requirements.

The wet season groundwater samples have alkalinity values that are higher than the dry season samples. Interestingly, samples from site 10 have a relatively higher alkalinity even though it is deeper and far from the septic tanks (mean distance of 146 meters away). This could be due to other environmental factors other than the proximity to the septic tanks. The groundwater samples are within the WHO (2008) limit range of 100-300mg/l limit for total hardness in water (Figure 4.4)

4.2.4 Electrical Conductivity values

The standard unit of electrical resistance (R) is the Ohm. The standard unit of electrical conductance is its inverse. The electrical conductivity of water is related to its concentration of dissolved mineral matter (TDS)
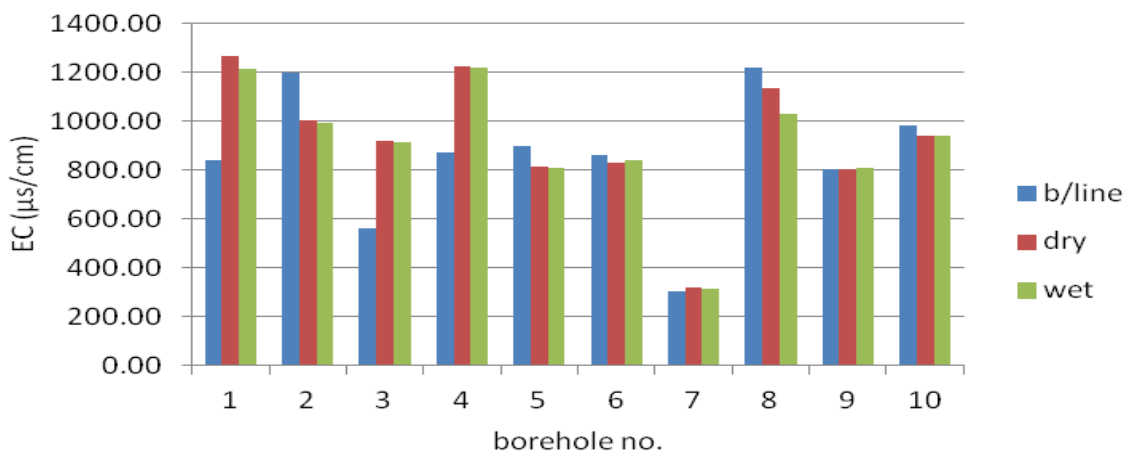

Figure 4.5: Variation of Electrical Conductivity of the boreholes.

Electrical Conductivity in the sampled water varied from 318±1.43μS/cm to 1265±1.32 μS/cm (Table 4.2). The mean conductivity of the samples was 802μS/cm in the dry season and 811 μS/cm in the wet season. The baseline data had values ranging from 304μS/cm to 1220μS/cm, and an average value of 806 μS/cm. Higher conductivity greater than 1000 μS/cm is observed in polluted water or those waters which receive large quantities of land rum-off (Pedro *et al*, 2007). Conductivities arise from high dissolved mineral matter in water, (Table 4.2). High conductivities were obtained from sites 1, 3 and 4, (Figure 4.5) which are very close to septic tanks A, B and C, (Table 2) at mean distance from the septic tanks, of 63m, 60.8m and 31.4m respectively. Conductivity is dependent upon the presence of ions and thus serves as an indicator of TDS in water. As the concentration of dissolved salts, of sodium, calcium and magnesium, bicarbonate, chloride and sulphates, increases in water, conductivity increases. Electrical conductivity also relates to salinity of water and this was confirmed for samples 1, 3 and 4, which had saline taste. The guideline given by WHO (2008) stated a maximum of 2500 μS/cm. Sites 2, 5, 6, 8 and 10 had lower conductivity in water samples during wet and dry seasons than the baseline data. While sites 1, 3, and 4 had higher values of conductivity in dry and wet seasons than baseline data.

Electrical conductivity of the borehole water samples generally decreases with increasing distance from septic tanks. The conductivity of the groundwater samples is not consistent in both wet and dry seasons. However there is a decrease in electrical conductivity during the wet season. The decrease of electrical conductivity and sodium with distance from ST-SAS was more pronounced than chlorides. Suggesting that Electrical conductivity and sodium concentrations were reduced by sediment solution interaction (eg sorption) in addition to dilution of leachates with ground water and chloride moved without being sorbed.

4.2.5 Total Dissolved Solids (TDS) values

The TDS values obtained from the tested samples ranged between a minimum value of 174 ± 2.41 mg/l and a maximum value of 788 ± 1.10 mg/l, Figure 4.6.
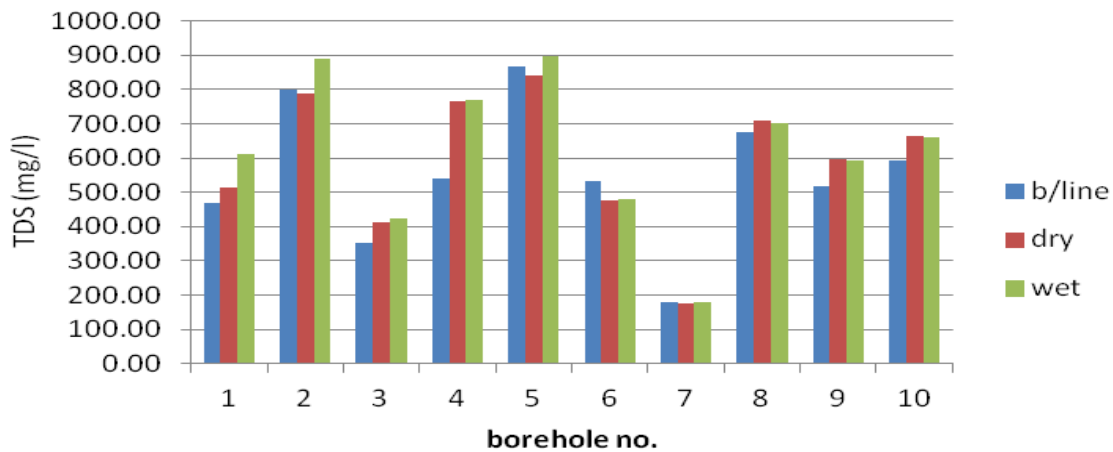
Figure 4.6: Variation of total dissolved solids.

The mean total dissolved solids (TDS) of the analysed water is 598 mg/l in the dry season and 592 mg/l in the wet season; hence the seasonal variation is not very high. Total Dissolved Solids (TDS), is the total amount of mobile charged ions including minerals, salts or metals dissolved in a given volume of water. TDS thus includes anything present in water other than the pure water molecules and suspended solids. TDS concentration is thus generally the sum of the cations and anions in water. Some dissolved solids come from organic sources, silt and industrial waste and sewage. Other sources come from runoff of fertilizers and pesticides used on farms along some of the sources where sampling was done. Site 7 is closest to septic tanks. Dissolved solids also come from inorganic materials such as rocks and air that may contain calcium bicarbonate and other minerals that is present in precipitation during recharge. Site 7 had the least of the TDS (174 ± 2.41 mg/l) and Site 10 had least seasonal variation, this was due to its depth and distance from built up areas, (Table 4.2).

There is a reduction in the Total dissolved solids (TDS), with increase in distance from the septic tanks, Site 5 which is nearest to the five septic tanks shows greatest seasonal influence, probably due to high volume of leachates from the surrounding septic tanks. Total dissolved solids in the samples are higher during the wet season than the dry season (Figure 4.6). The TDS increases in the wet season could be attributed to weathering intensity and the increased percolation through the septic tanks leachate in the event of groundwater recharge WHO (2008). The WHO (2008) tolerance limit for drinking water is 1000 ppm, all the samples are within this limit. The high value of TDS could be as result of other ionic impurities like iron according to a report by S.Odhiambo, (University of Nairobi) on the quality of water supplied by water vendors in Ongata Rongai, 2014. Changes in the total dissolved solids could be a reflection of the additions of chemicals to the septic tanks, from activities within the house, that cause changes to the solubility of inorganic compounds in the effluent and from the degradation of organic molecules into soluble salts, that move into groundwater.

4.3 Chemical parameters.

Table 4.3 shows the levels of chemical parameters; chlorides, nitrites, ammonia, nitrates and sodium in the ten borehole sites.

Table 4.3: Variation of chemical parameters in borehole water samples in wet and dry seasons with the baseline data

Borehole Site number		1	2	3	4	5	6	7	8	9	10	Ave'
Distance-ST (m)		63	33	60.8	31.4	16.2	120	16	33	32	146	
Chlorides	b/line	40	71.7	24	43	98	49	77	120.4	32	93	64.81
(mg/l)	dry	94±0.75	130±1.8	34±2.24	126±1.31	130±1.42	51±1.44	108±0.67	119±0.96	39±2.61	96±0.34	92.7
	wet	113±1.56	144.4±3.21	35±3.91	126.8±2.03	156.3±3.24	51.5±26.4	128±2.24	119±1.77	39±2.82	96±7.93	101
Nitrite	b/line	0.05	0.03	0.01	0.03	1.2	0.01	0.1	1.4	0.01	4.2	0.7
(mg/l)	dry	12.31±0.6	11.62±0.32	4.44±1.65	9.88±0.81	8.8±0.24	4.12±1.52	7.83±0.97	10.9±1.20	6.62±0.78	5.57±1.03	8.21
	wet	15.1±1.82	16.8±2.17	4.42±3.74	9.74±0.89	13.4±1.02	4.14±3.22	13.7±2.18	11±0.99	6.7±2.64	5.73±3.44	10.1
Nitrate	b/line	0	1.23	1.5	4.3	0.04	0.45	0.6	0.86	0.1	0.91	1
(mg/l)	dry	6±0.14	6.03±1.22	3.89±0.77	4.85±0.96	5.21±2.02	5.53±2.31	5.93±2.65	2.17±1.10	3.05±2.81	2.44±1.46	4.51
	wet	6.69±0.23	7.07±0.31	3.7±0.93	4.8±1.28	5.83±2.64	5.1±3.12	6.62±3.44	2.23±3.21	3.8±2.90	2±1.90	4.78
Ammonia	b/line	0.01	-	-	-	-	-	-	-	-	-	-
(mg/l)	dry	0.6±0.1	0.2±0.1	0±0.0	0±0.0	0.1±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0
	wet	0.8±0.17	0.5±0.05	0±0.0	0±0.0	1.4±0.1	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0.27
Sodium	b/line	206.1	19.2	111	-	188.3	184.5	134.8	131.3	200	96.5	141.3
(mg/l)	dry	215±1.12	159±0.51	102±0.39	212±1.83	192±2.77	8±23.81	142±0.31	130±0.02	203±0.97	102±0.42	130
	wet	217±1.24	160±0.6	102±3.22	146±2.72	219±0.69	192±2.42	143.8±0.5	130.5±1.8	202.8±0.1	103±3.32	5.2

b/line = baseline data obtained from the records of analysis results at the time of drilling the borehole, Distance-ST(m) = distance of borehole from septic tanks in metres, (-) = no data, (0) = below detectable limit (BDL).

4.3.1 Chloride values

The minimum chloride level was 34±2.24 mg/l at site 3 and a maximum of 156.3±3.24mg/l at site 5, with average value of 92.7 mg/l and 101mg/l in dry and wet seasons in sites 3 and 5 respectively. Sites 1, 2, 3, 4, 5, 7 and 9 had higher chloride levels in dry and wet seasons than the baseline data, indicating an increase over time (Table 4.3).
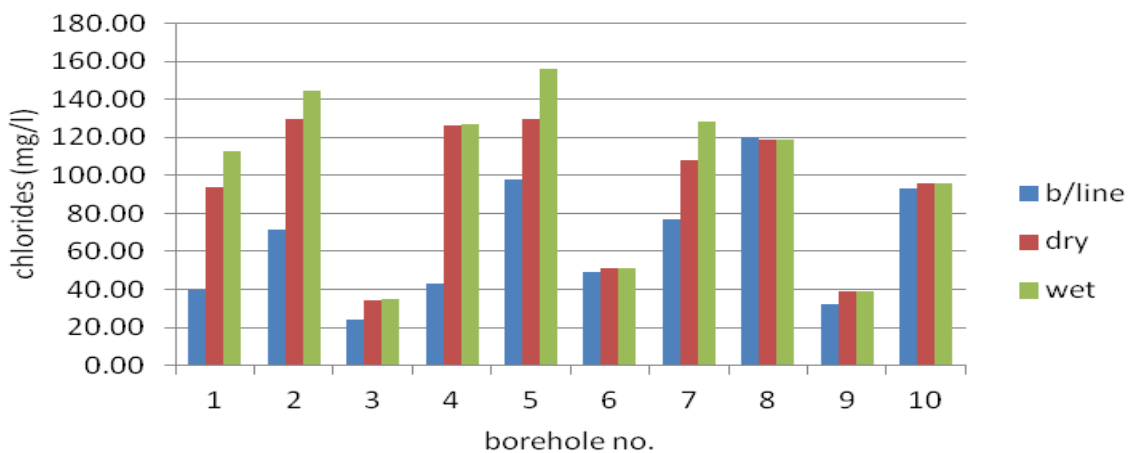
Figure 4.7: Seasonal variation of chloride levels in for the boreholes

Site 5 had the highest value of chloride, which was followed by site 2 and 4 in wet and dry seasons (Figure 4.7). The values are below the maximum value recommended by WHO (2008) standards of 300 mg/l (Table 1a, appendix A). The level of chlorides increase with decreased distance from septic tanks and is higher during the wet season than the dry season. Site 5 with the highest chloride level of 130±1.42 mg/l to 150±3.24 mg/l is close to all the five septic tanks at distances of 9 – 30 m (Table 4.3). This could be due to leaching through the soil media as precipitation percolates to recharge the ground water (Pilgrim *et al*, 1979).

4.3.2 Nitrite values

The baseline data from sites 1, 2, 3, 4, 6, 7 and 9 had very low levels of nitrates in the range of 0.01 to 0.05mg/l (Table 4.3).

The nitrite levels in the groundwater samples were initially low, from the baseline data, and higher in the samples in the study sites (Table 4.3).
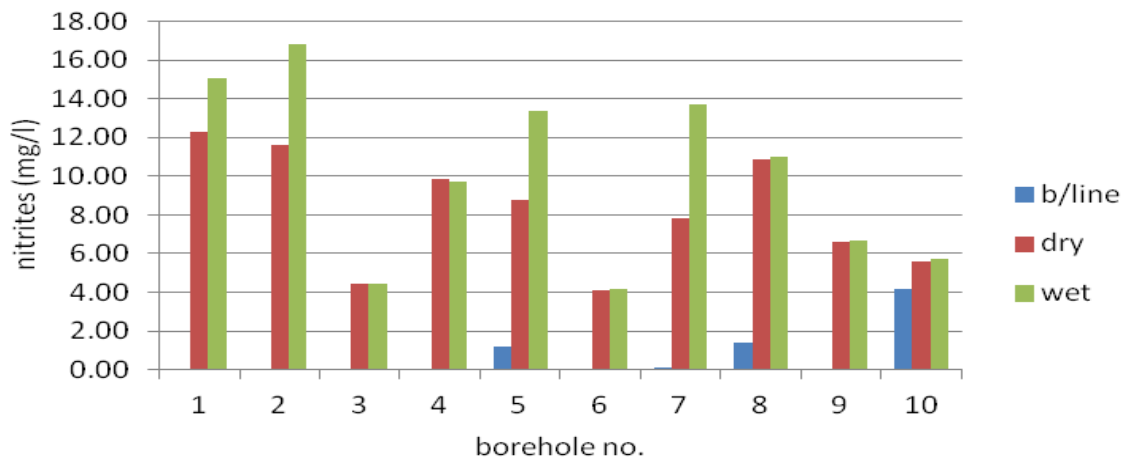
Figure 4.8: Seasonal variation of nitrites levels for the borehole sites compared to baseline data.

The wet season average (10.1mg/l) being higher than the dry season average (8.2mg/l). However, the concentration of nitrite (wet season) is higher in sites 1(15.1 ± 1.82mg/l), 2 (16.8 ± 2.17mg/l), 5 (13.36 ± 1.02mg/l), 7(13.7 ± 2.18mg/l) and 4 (15.4 ± 1.12mg/l) (Table 4.3). These values were within the WHO (2008) guideline limits of 45mg/l, (Table 1a, Appendix A). This could be due to their distances (vertical and horizontal) from the septic tanks soak pits or due to heavy use of fertilizers or disposal of animal waste in sites 1 and 7 (Table 2.1),

which had a horticultural farm and a slaughter house nearby, as sources of nitrogen to the sub soil. Sites 2 and 1 had the highest nitrites levels in the wet and dry seasons respectively (Figure 4.8).

4.3.3 Nitrate values

Nitrate level determined from the various sample points ranged from a minimum value of 2.1± 0.1 mg/l in dry season to a maximum value of 7.0 ±1.23 mg/l in the wet season in Sites 8 and 2 respectively (Table 4.3).
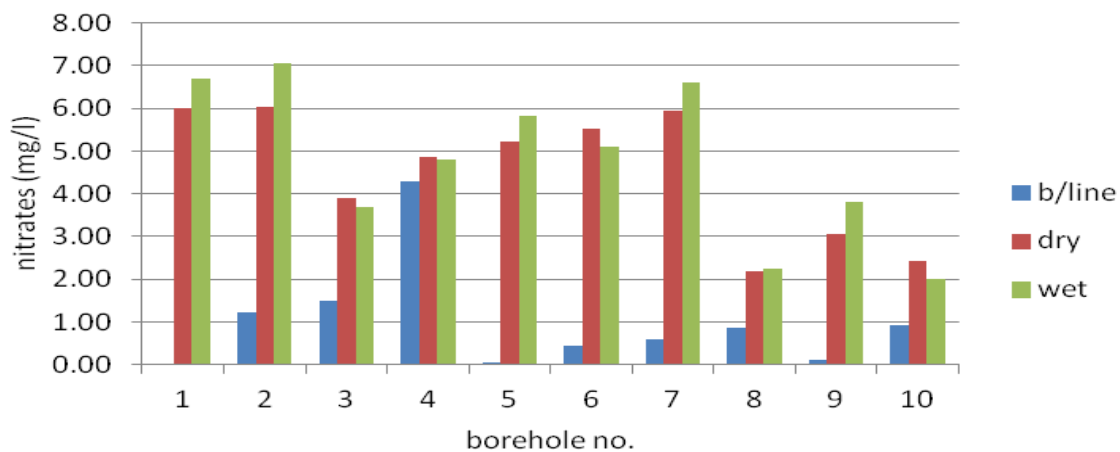
Figure 4.9: Seasonal variation of nitrate levels in the boreholes.

Sites 1, 2, 4, 5 and 7 had nitrate values above the Standards advised by WHO (2008) and KS (2007) standards of 10mg/l. Baseline data, ranged between a minimum value of 0 mg/l and a maximum value of 4.3 mg/l and had a lower average mean compared to values obtained from the sampled sites. This could be an indication of contamination of the sub-surface environment over time. High Nitrate levels may indicate pollution from fertilizers, feedlots or septic tanks systems (Table 2.1). Nitrate in water interferes with the body's capacity to absorb oxygen (Twort, 1962). However, the concentration of Nitrates in the water samples was found to be within the acceptable limits of a maximum value of 10 mg/l, as specified by the

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KS (2007) and WHO (2008) Standards. Nitrates concentrations for the different boreholes have a relatively large range probably due to many factors e.g different concentrations of water solutions in the soil at different periods of time (Pilgrim et al 1979) and different patterns of human behavior. The nitrate levels in the groundwater samples are higher during the dry season (Figure 4.9), this could be due to the reduction in groundwater recharge resulting from low precipitation, higher temperature and evaporation during the dry season. Primarily, obligate autotrophs transform ammonia to nitrate (Foncht and Verstreate, 1977) which is readily leached to the ground water. The ammonia in effluent (>80%) is mostly converted to nitrate. The highest value is associated with close proximity to sources of nitrogen from the sub-surface, including septic tanks (Foncht and Verstreate, 1977).

4.3.4 Ammonia values

Baseline data for ammonia levels was not available for the boreholes water samples (Table 4.3).
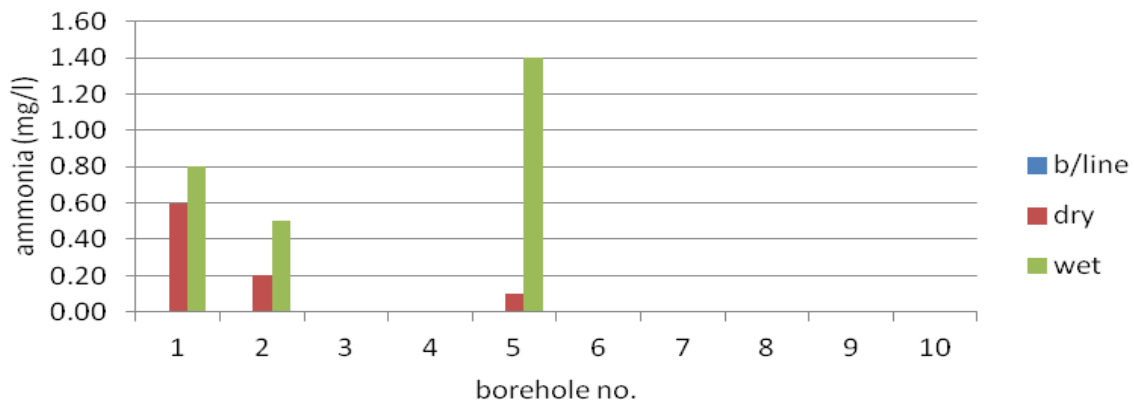

Figure 4.10: Seasonal variation of ammonia levels in the boreholes.

Major sources of nitrogen are human excreta which contains many ammonia derivatives e.g creatine, creatinine, uric acid, urea, bile pigments, undigested protenaceous foods and bacterial cells. In the septic tanks, microbial enzymes such as proteases, ureases and

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deaminases hydrolyse and degrade these compounds with liberation of ammonia. Most of the organic nitrogen is converted to inorganic nitrogen in soils before reaching ground water, and retained in the clogging layer formed in the infiltrative surface. Nitrification was the key reaction beneath septic systems for ammonia and nitrate. The concentration of nitrogen contamination is higher as distance from septic systems decreases and rises in wet season due to percolation through saturated sub-soil environment that is favorable for conversion of ammonia. Ammonia was detected in Sites 1, 2, and 5 (Figure 4.10) only and this could be due to the site's close proximity to the septic systems effluent and /or other anthropogenic activities like heavy use of fertilizer. The values of ammonia at sites 1, 2 and 5 had highest values of ammonia in wet season than the recommended levels by WHO (2008).

4.3.5 Sodium values

Sites 1, 4, 5 and 9 had sodium levels $\geq$ 200 mg/l (Table 4.3).
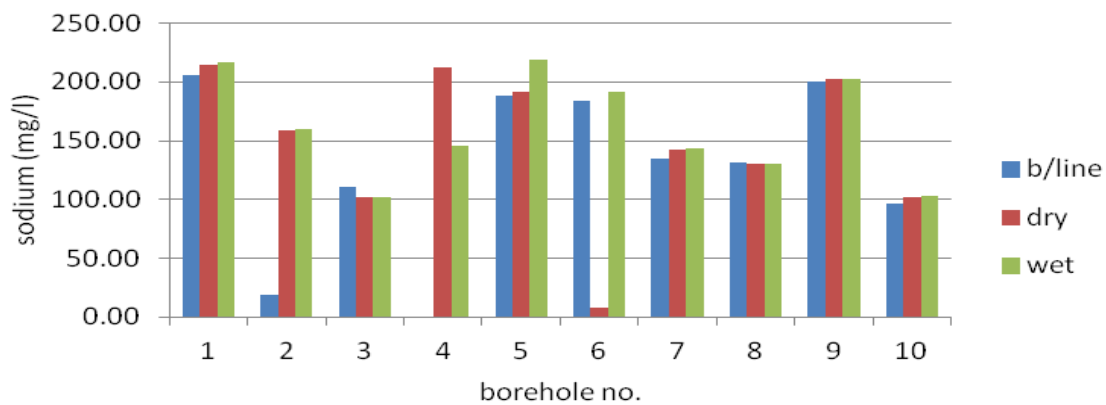

Figure 4.11: Seasonal variation of Sodium levels in the boreholes.

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The pattern of pollution decreases with distance from the septic tanks for Sodium similar to chloride levels (Figure 4.11), probably because in most home use of sodium chloride salt is common in food.

4.4 chemical and bacteriological parameters

Table 4.4*:* Results of chemical and bacteriological parameters in borehole water samples.

Borehole Site number		1	2	3	4	5	6	7	8	9	10	Average
Distance-ST (m)		63	33	60.8	31.4	16.2	120	16	33	32	146	
phenol (mg/l)	b/line	-	-	-	-	-	-	-	-	-		-
	dry	0.15±0.03	0.2±0.02	0±0.0	0±0.0	0.1±0.03	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0.05
	wet	0±0.0	0.2±0	0±0.0	0±0.0	0.2	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0.04
COD (mg/l)	b/line	-	-	-	-	-	-	-	-	-	-	-
	dry	75±1.0	20±0.3	5.5±0.1	10±0.1	19±0.33	9±0.30	16±0.89	6±0.44	12±1.11	10±0.7	18.25
	wet	6.5±0.32	18±0.71	4±0.67	8±0.21	16±0.88	7.5±0.46	14±0.01	4.5±0.78	10±0.94	8.5±0.02	9.7
E.coli	b/line	-	-	-	-	-	-	-	-	-	-	-
	dry	0±0.0	0±0.0	0±0.01	0±0.0	1±0.1	0±0.0	3±1.05	0±0.01	0±0.01	0±0.01	0.4
	wet	0±0.2	1±5.02	0±0.2	0±0.2	2±3.00	0±0.2	3±1.00	0±0.0	0±0.0	0±0.0	0.6
surfactants (MBAS, mg/l)	b/line	-	-	-	-	-	-	-	-	-	-	-
	dry	0	0	0	0	0	0	0	0	0	0	0
	wet	0	0	0	0	0	0	0	0	0	0	0
sulphates (mg/l)	b/line	50	61.6	3.7	8.6	12.3	0.3	44.9	60.3	0.3	77	32.52
	dry	198±1.50	193.5±1.64	68.4±0.43	74.2±0.91	81.7±1.44	70.7±0.23	99.5±0.22	82.2±1.00	66.7±3.56	81.1±0.87	80.32
	wet	184.5±1.66	182±1.69	68±0.21	74±0.03	93±1.58	69.9±0.99	97.5±0.34	82.4±1.50	77.4±4.89	80.8±0.88	83.5
phosphates (mg/l)	b/line	-	-	-	-	-	-	-	-	-	-	-
	dry	0.12±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0.01
	wet	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0±0.0	0.01

b/line = baseline data obtained from the records of analysis results at the time of drilling the borehole, Distance-ST(m) = distance of borehole from septic tanks in metres, (-) = no data, (0) = below detectable limit (BDL).

4.4.1 Phenol values

Phenol does not naturally occur in ground water and therefore the presence of phenols in the sites 1, 2 and 5 (Figure 4.12) could be as a result of contamination by household chemicals that contain phenolic compounds in their formulations.
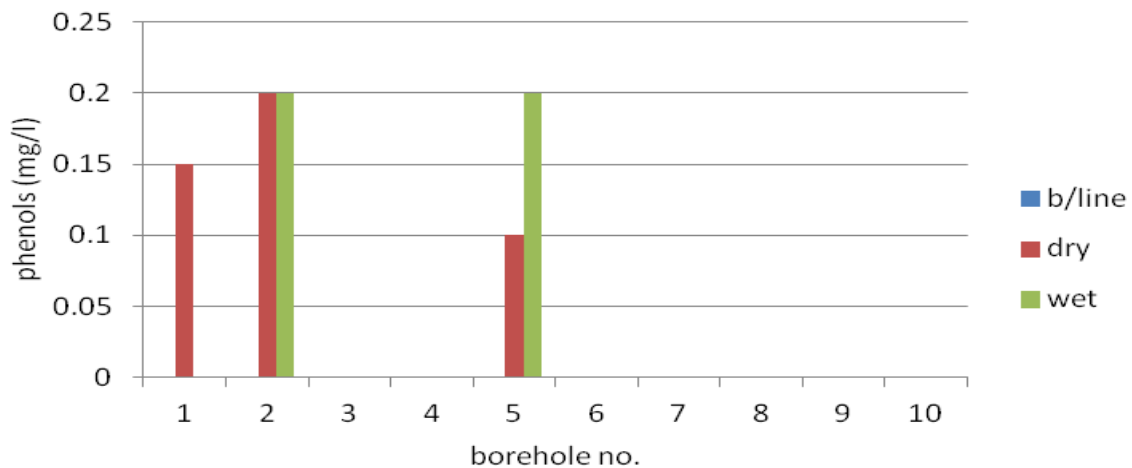

Figure 4.12: Seasonal variation of phenol levels in boreholes.

Site 5 shows greatest vulnerability to contamination by virtue of its distance from built up areas and septic tanks (Table 2.1). Site 5 shows highest level of contamination by phenols by virtue of its distance from built up areas and septic tanks (Table 2.1). Site 5 shows seasonal variation in phenol concentration, confirming that it could be due to environmental pollution from the septic tanks, (Figure 4.12). There was no baseline data available for comparison. Sites 1, 2 and 5 show high level of phenols in both dry and wet seasons compared to the WHO (2008) recommended levels (Table 5, Appendix A)

4.4.2 Chemical Oxygen Demand (COD) values

The Chemical Oxygen Demand (COD) was done on the samples The COD levels of borehole water samples were higher as distance from septic tanks reduced, especially high for boreholes with a high water rest level during the dry season and slightly lower during the wet season (Figure 4.13).
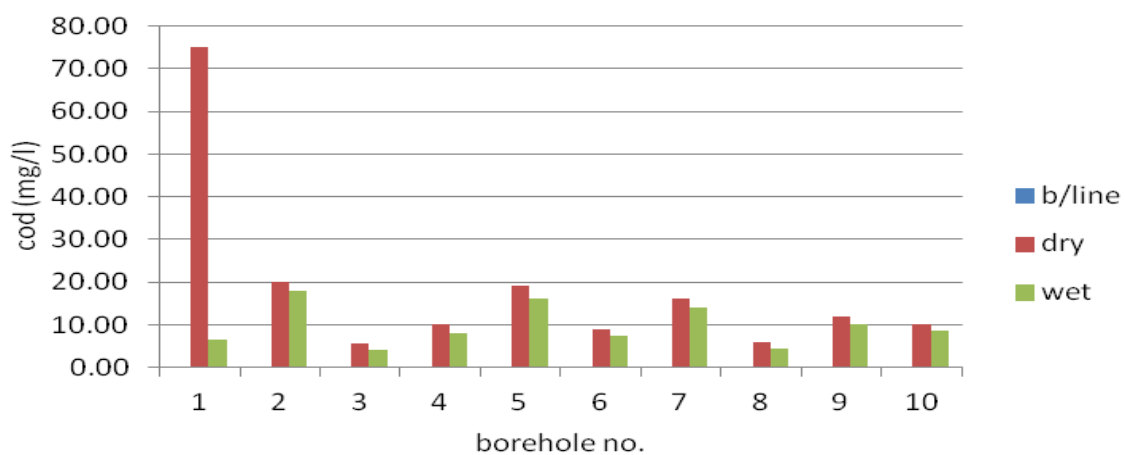
Figure 4.13: Seasonal variation of COD levels in the boreholes.

The high COD during the dry season could be due to the decreased groundwater recharge. All the boreholes water samples had COD with levels which are higher than the WHO (2008) >1.0 mg/l permissible limit.

4.4.3 E.coli values

Biological characteristics were determined by carrying out tests on the water samples with a special emphasis on E.coli. Baseline data was not available for comparison (Figure 4.14).

Figure 4.14: Seasonal variation of E.coli levels in the boreholes.

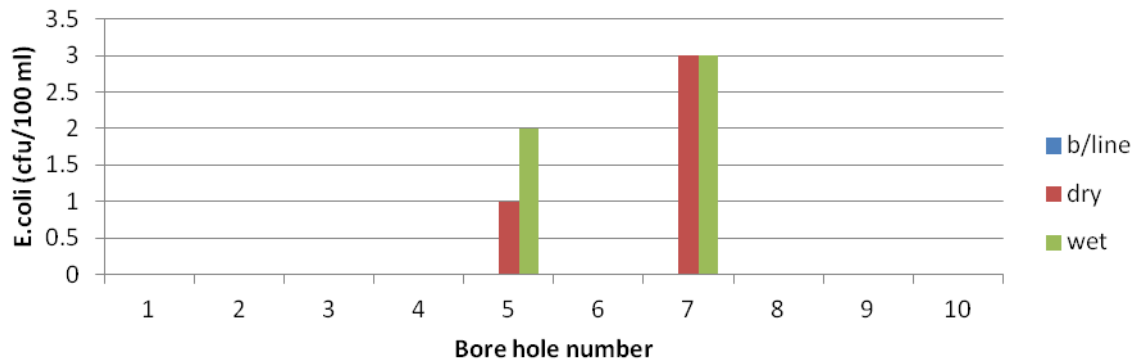Microbiological parameters can have an immediate and significant impact on human health and must therefore be analyzed more frequently. For bacteriological tests, coliform tests were used to show the presence of bacteria. Upon confirmation, the samples were subjected to a faecal coliform test. Thus for this study, biological characteristics were determined by carrying out tests on the water samples with a special emphasis on E.coli. Baseline data was not available for comparison. Sites 2, 5 and 7 tested positive for faecal coliform. Sites 1, 3, 4, 6, 8, 9 and 10 tested negative (Figure 4.14).

It can thus be concluded that sample water from sites 2, 5 and 7 was polluted by wastes from septic tank systems. Generally, most of the sampled points tested negative for faecal coliform, thus it can be concluded that the water sampled from those boreholes was safe for use in various domestic purposes. Total coliforms were detected from sites 2, 5, and 7 (Figure 4.14), out of all the samples analysed, the rest had a most probable number index (M.P.N) of zero. According to the KS (2007) guidelines, coliforms should not be detected in water. E.coli is present in borehole water samples that are closer to septic tanks and even higher during the wet season. The absence of e.coli in the other samples could be due to the distance from septic tank systems (Table 2.1). The levels of e.coli are higher than the WHO (2008) recommended 0 cfu/100ml for the water samples.

4.4.4 Sulphate values

The distance from septic tanks has no influence on sulphate level, in the borehole water samples (Table 4.4).
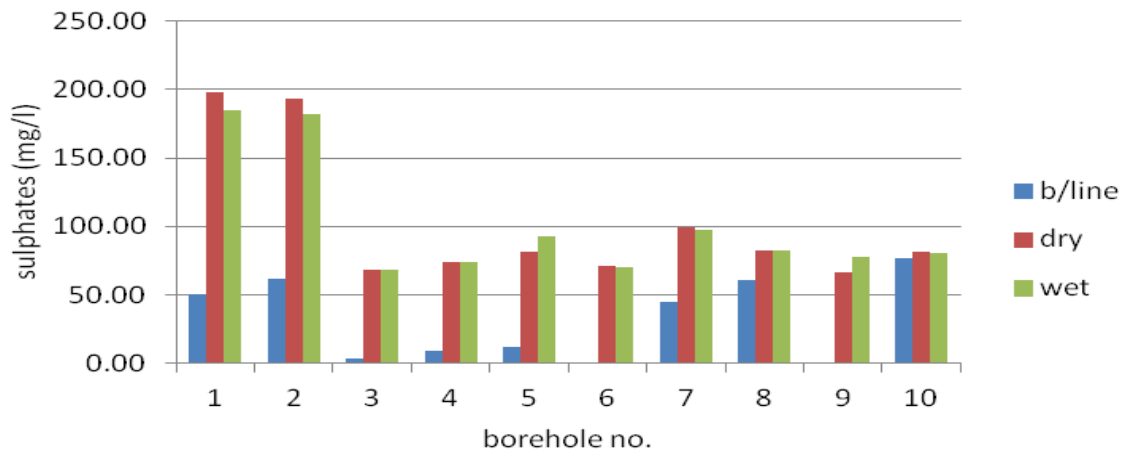
Figure 4.15: Seasonal variation of sulphate levels in the boreholes.

The sulphate levels in the borehole water samples are higher in the dry than in the wet season (Table 4.4). This is because of dilution during the wet season. The sulphate values are within the WHO (2008) guideline limit of 250 mg/l. Site 6 has the lowest level of 66.7 mg/l while site 1 the highest value of 198mg/l. The baseline data has a lower average level in all the seasons (Table 4.4), an indication that the sulphates are not naturally occurring but could be as a result of contamination (Figure 4.15), either from other non-point sources or due to the geologic make up of the aquifer that could be releasing the sulphates slowly over time.

4.4.5 Phosphate levels

Phosphate was detected significantly in only in site 1 and 5 (Figure 4.16).

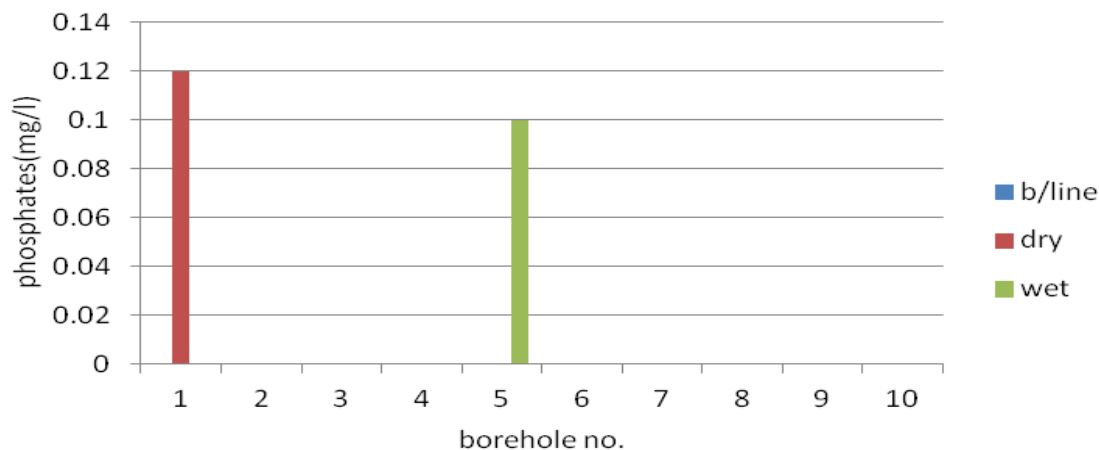Figure 4.16: Seasonal variation of phosphate levels of the boreholes.

This could be either because it is naturally occurring or due to other influences other than as a result of athropogenic activities affecting the sub surface environment. Most likely Phosphate detected was not from the septic system and could be from other back ground sources. The insignificance of phosphates as a contaminant in ground water was probably because soils and sediments under septic systems were highly efficient in removal of effluent phosphate found in some detergents, etc. Baseline data was not available for comparison in this study (Table 5).

4.4.6 Surfactants (as Methylene Blue Active Substances- MBAS)

The detergents used mainly contained only linear alkylbenzene sulphonate (LAS) that was likely to be degraded chemically (Wayman *et al*, 1956) or adsorbed into soil and sediments (Freeze and cherry, 1979). Measured as methylene blue active substances (MBAS), surfactants from all sites studied (Table 4.4), were either biodegraded or adsorbed and did not reach ground water. There were no surfactants detected in all the water samples. Detergent residues, measured as methylene blue active substances did not pass un-decomposed through

the septic systems. No detergent allowed entry of phosphorous to ground water in concentrations > 0.1mg/l. The absence of methyl blue active substances (MBAS) was confirmed in all samples (Table 4.4).

Another factor to consider when septic tanks are ineffective, is that the flooding that my result due to failure, can be carried to other surface water as run-off which eventually may contaminate the ground water. When a septic tank soil absorption field fails, serious pollution to ground and surface waters may result (Botkin *et al* 1987).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study provided data on the parameters previously analysed at the time of drilling (baseline data), water rest levels, borehole depths, yield (m^3hr^{-1}) and septic tanks distance for ten sampled boreholes selected.

When septic tanks are close to the boreholes, within 15 – 40 m, the impact of the contamination levels is higher during the wet season due to the increased amount of groundwater recharge which results in soil saturation and consequently resulting in reduced filtration.

Septic tank systems are sources of nitrates, chlorides, sodium, sulphates, e.coli and COD to borehole water in Ongata Rongai

The septic tank systems did not have effect on the pH values on the borehole water. Borehole sites with septic tank distances of ≤15 m length to the borehole had high turbidity. The septic systems do not contribute to ground water pollution by phosphates, surfactants despite proximity to boreholes and seasonality. Most of the organic nitrogen in effluent (>20%) is converted to inorganic nitrogen in soils or retained in the clogging layers at the soils' infiltrative surfaces and some of it reaches ground water. Septic tank systems are sources of nitrates, chlorides, sodium, sulphates and e.coli to borehole water samples. When septic tanks are close to the boreholes (15 – 40 m), the impact of the contamination levels is higher during the wet season due to the increased amount of groundwater recharge which results in soil saturation and consequently resulting in reduced filtration.

The results reveals that parameters such as turbidity and total dissolved solids, phenols and sulphates have no significant variation in all the sites and are not necessarily an impact on the septic tank distance location. Further, the presence of Cl^-, NO_3^-, NH_4^+, Phenol and COD can be used as tracer with relation to leachate percolation. As there is no natural or other possible reason for high concentration of these pollutants, it can be concluded that leachate has significant impact on Sites 1, 5 and 7 in Ongata Rongai.

The effect of septic tank distances have been confirmed since the concentration of the pollutants reduces with longer distance from the septic tank systems at ≤ 63 m , the pollution levels were higher in wet season. Sites 1, 2, 5 and 7 water samples are not within WHO (2008) drinking water standards for e.coli, phenol, ammonia, and have marginally high levels of nitrates, chlorides, sodium, COD and TDS and therefore the most polluted borehole sites in ongata Rongai sub-county.

5.3 Recommendations

1. The determination of pollutants levels in the other Ongata Rongai borehole water sites should be conducted, so as to get more accurate analyses reports, on septic tanks distances and concentrations and quality of effluent being discharged from septic systems.

2. There is need for the environmental assessment to include aspects of subsurface environments and ground water when constructing domestic on-site effluent treatment and disposal facility.

3. Efforts should also be made by the regulatory agencies such as National Environmental Management Authority and the county governments to meet and

enforce the international standards and recommendations for the location of onsite effluent disposal systems.

4. Other pollution levels of heavy metal ions and pesticide residue levels in water samples from boreholes close to septic tanks in Ongata Rongai should be analysed

5. The contaminated boreholes should be treated as follows; reduce the pH of Sites 5 and 8; reduce the TDS of Sites 1, 2, 4, 5 and 8; reduce NO_2^- and NH_3 in Site 6; reduce phenol in Sites 1, 2 and 5; reduce COD in Sites 1 – 10; disinfect Sites 5 and 7 due to presence of E.coli.

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Parameters for water quality characterization and standards for domestic water supplies compiled from different sources; USPH (2001), WHO (2008) and KS (2007)

Table 1a Water quality Characterization and standard for domestic water supplies

Parameter	USPH(2011)	WHO (2008)	KS (2007)
Colour, odour, taste	Colourless, odourless, tasteless	Colourless, odourless, tasteless	Colorless, odourless, tasteless.
pH	6.0- 8.5	6.5 – 9.2	6.5 – 8.5
Specific conductance (µ mho cm-1)	300	-	-
Dissolved oxygen (ppm)	4.0 - 6.0	6	-
Total dissolved solids	500	500	1500
Suspended solids	5	-	NIL
Chloride	250	500	250
Sulphate	250	-	400
Nitrate and nitrite	<10	45	-
Phosphate	0.1	-	-
Ammonia	0.5	0.5	0.5
COD	4	1.0	-
Methyl blue active substances	0.5		-
Phenols	0.001	0.002	0.002
Surfactants	200	-	-
Coliform cells/ 100ml	10	10	NIL
Total bacteria count/ 100ml	0	0	NIL

Sources: Kenya Bureau of Standards (2007), 05-459, Part 1; and the official journal of European committees (2011).   WHO (2008).   Note that all the units, except otherwise mentioned and pH and specific conductance are in parts per million (mg/l).

Table 2a: Water samples preservation methods (De, 2011).

Parameter	Minimum sample size (ml)	Container	Preservation
pH	100	polythene	Measurements within 0-4hrs
COD	500	polythene	Add H_2SO_4 to pH 2.0; refrigerate
Ammonia	500	polythene	Analyzed as soon as possible; 0.8 ml conc. H_2SO_4 /l is added
Nitrate + Nitrite	500	polythene	Add 40 mg $HgCl_2$ /l and refrigerate
Sulphide	500	polythene	Add 1ml of 2N $Zn(CH3COO)_2$ and 2ml of 1M NaOH; stir and refrigerate
Phosphate	500	Polythene/ glass	Add 40mg $HgCl_2$ /l and refrigerate.
E-coli/total bacteria/actenomycetis	100	Glass bottle	Sterilize the bottle in autoclaved at 121˚C at lb/inch-1 pressure for 15 min, sample collected in the sterilized bottle and refrigerate immediately
Algae and other biological organisms	500	Glass bottle	5ml formalin per 100 ml sample is added and refrigerate immediately.

Table 3a: Questionnaire interviews templates used for the study.

Residents' / borehole water consumers questionnaire			
Questionnaire number			comments
Interviewer			
date			
location			
Do you know the quality of water you consume from boreholes	YES	NO	
Do you think onsite effluent disposal systems can have an impact on the boreholes water quality nearby due to disposal system location	YES	NO	
Have you heard of any complaints from other residents, on the quality of water as a result of seasonal changes	YES	NO	
How safe is this area for us to walk during the day for field work?	YES	NO	

Table 4a: Borehole owner and water supplier questionnaire

Borehole owner/ water supplier questionnaire			
Questionnaire number			comments
Interviewer			
date			
location			
Do you test the quality of your water regularly?	YES	NO	
Is the water treated prior to supply to consumers?	YES	NO	
Have you heard of any complaints from your customers as a result of seasonal changes?	YES	NO	
Can we access the borehole sites and sample water for laboratory analysis today and during the next season?	YES	NO	

Table 5a: Questionnaire for staff members at Ministry of water, environment and natural resources

Ministry of water, environment and natural resources questionnaire			
Questionnaire number			comments
Interviewer			
date			
location			
Do you have records of boreholes from 30 years to date showing results of physico-chemical and biological parameters, water rest level, yield and locations, which we can access?	YES	NO	
Do you think onsite effluent disposal systems can have an impact on the ground water quality if not well located?	YES	NO	
Have you heard of any cases of borehole contamination in ongata Rongai as a result of onsite effluent disposal methods?	YES	NO	
Do you think EAI assessments should consider aspects of boreholes and onsite effluent disposal systems?	YES	NO	