ANALYSIS OF GROUNDWATER QUALITY AND IDENTIFICATION OF ABSTRACTION POINTS IN KAHAWA WENDANI, KIAMBU COUNTY.

By

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DECLARATION

This project is my original work, and has not been presented for award of any degree in any other university.

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C50/78031/2015

This project has been submitted for examination with my approval as the university supervisor.

Dr. Shadrack M. Kithiia-------------------------------------- Date----------------------------

(University Supervisor)

DEDICATION

I dedicate this project to my entire family; my mother Christine N. and Dad, James Makokha my brother and sisters.

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First and foremost I thank The Almighty God for His guidance, wisdom and providence. Secondly, I would like to thank my project supervisor Dr. Shadrack Kithiia for his constant assistance and guidance throughout my project. In addition, I wish to thank most sincerely, my family members, for their financial and moral support, Dr. I. A. Nyandega for his support and input in GIS Laboratory data analysis; Mr. Kaunda, Miss. Margret and Miss. Joy for Laboratory assistance, for their assistance to carry out my analysis. I cannot forget to thank my classmates, friends and colleagues, for their moral support and assistance and all the people who allowed me to take samples from their boreholes.

ABSTRACT

Surface water is not enough to meet the needs of the increasing populace, which has led to groundwater use as an alternative source globally. It therefore becomes essential to monitor groundwater levels and quality to enhance water resource management and protection (Foster, 2002).The main objective of this study was to assess the groundwater quality and position the abstraction points on the map of the study area.

Ground Water samples were collected from ten selected boreholes in Kahawa Wendani and each sample coded uniquely and systematically such as B1 for borehole one. The sampling period fell in the month of October, 2016 which was a hot and dry season. Sampling was by snowballing due to the unknown population size. Boreholes were identified and their geographical position shown on a map using ArcGIS software version 10.2.2.Two different samples (chemical/biological) were taken from each borehole. Samples for chemical analysis were collected in one litre plastic bottles prepared according to the WHO standard laboratory method. While those for biological analysis were collected in standard glass bottles well corked and with Aluminium foil reinforcement. The depth of the boreholes was also recorded. 19 parameters were selected for analysis, tested in accordance with the WHO Standard methods for the Examination of water and waste waters and their results compared to WHO drinking water standards. All the parameters measured in all the samples were within the required standards except fluoride and iron. Iron (Fe^{2+}) ranged from 0.1mg/l in three samples,1, 2 & 3 and 0.3mg/l in boreholes 5, 6 & 8 compared to the WHO standard value of 0.3 mg/l. Fluorides recorded the highest value of 1.92mg/l in borehole 1 compared to the WHO standard value of 1.5mg/l. Groundwater in Kahawa Wendani is suitable for drinking purposes. However, the levels of fluoride in boreholes 1 (1.92mg/l), 4 (1.54mg/l) & 5 (1.84mg/l), which were above 1.5mg/l, the WHO standard value, should be managed by the relevant authorities before they exceed this threshold to avoid risk to health. This implies that the aquifer in this site has fluoride deposits as the area falls in the hydrogeological zone made of volcanic rocks. The groundwater abstraction points were found to be clustered in distribution towards Matopeni and Booster areas of the study. Meaning more groundwater is abstracted in these particular positions in Kahawa Wendani. Further research should be done to achieve the trend in groundwater quality not only for this site but across the nation in order to have a reliable groundwater database.

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ABBREVIATIONS AND ACRONYMS

AWSD	Athi Water Service Board
DEWA	Division of Early Warning and Assessment
EAC	East Africa Community
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GPS	Geographical Positioning System
KEBS	Kenya Bureau of Standards
MDGs	Millennium Development Goals
RUJUWASCO	Ruiru-Juja Water & Sewerage co Ltd
SPSS	Statistical Package for social scientists
UNEP	United Nations Environment Programme
WHO	World Health Organization
WMA	Water Management Authority
WSP	Water Service Provider

CHAPTER 1: STUDY BACKGROUND

1.0 Introduction

Water quality is an indicator of health and is an area of chief alarm to environmentalists, because industrialization, urbanization and contemporary agricultural practices have an obvious effect on the water resources**.** Water is normally got from two major natural sources; superficial water such as fresh water lakes, streams and ground water from borehole and wells, (Gichuki and Gichumbi, 2012). Groundwater is abstracted for agricultural, industrial, household, leisure and environmental uses across the globe. In the study area groundwater is majorly abstracted for household purpose. The excellence of water is a major apprehension for man because it is unswervingly connected to human wellbeing and therefore the need for this study. Fresh water has developed into a rare resource because of too much consumption and pollution of water. Groundwater is normally said to be a 'safe source of fresh drinking water' (Lobina and Mercy, 2015), but the boreholes/wells are mostly considered to be prone to physico-chemical pollution caused by absence of compact surrounding drainage system. There are many ways in which groundwater is adulterated like applying fertilizers in cultivation and seepage from discharge bearing water body. Once the groundwater is contaminated, its worth cannot be restored by stopping the pollutants at the origin.

Kenya's geology has high concentrations of fluoride due to volcanic ash deposits in rocks and soil as well as in surface and groundwater. According to SIPA (2006), boreholes are not recurrently checked for water quality. The Kenya Bureau of Standards (2007) recommends a maximum of 1.5 milligrams of fluoride per liter (1.5 parts per million) in drinking water. This geological influence on groundwater is what prompted the researcher to carry out this research in Kahawa Wendani in Ruiru constituency to know if it's an issue of concern. From the findings, the fluoride levels in 3 of the samples need to be reduced and the others controlled since they are very close to the WHO standard value.

1.1 Statement of the Research Problem

The unforeseen and intensive use of groundwater has caused grave and growing complications of exhaustion and value weakening globally. Notwithstanding the increasing number of examples of declining groundwater conditions, knowledge on the status of groundwater resources is scattered and there is a lack of solid data (World Bank, 2012).

The extent of information on the occurrence and abstraction of groundwater resources is highly variable from one country to another. Global assessments of groundwater resources often do not have current data on the state of groundwater resources for several countries and efficient information on groundwater quality is even infrequent (World Bank, 2012).

Groundwater monitoring in Kenya is primarily conducted by WMA who try to physically get water level and quality developments periodically, and for the most used aquifers, water levels are examined every month. Kahawa Wendani is one forthcoming estate that has had increase in residency therefore also increasing the demand for water. The increase in number of residents is related to the benefits that the region has. The area is well situated beside the Nairobi-Thika super highway. The fast growth of institutions such as Kenyatta University has caused more students joining and searching for residency around the area. Given the fact that it is close to both Nairobi and Thika town, many people commute to their work places from here. This has led to a rise in residency and hence gravity on the accommodation and aquatic resources in that even the water service supplier is unable to meet the resident's need for water (Mugeraa, 2014). The water need can only be met up to 14% in Ruiru constituency (Obando, 2014). A majority of those in need have decided to the use of groundwater which is more dependable. Due to this it is not possible to get a clear picture on the extent of groundwater reduction and pollution. Population changes are expected to raise the groundwater use, with more boreholes being drilled and much deeper that have increased rates of use than in customary dug wells. This creates a necessity to know the present status of the groundwater quality in these areas and to relate the present groundwater storage versus the driving factors (demography and stratography). As well as to find the monitoring needs and introduce prime measures to safeguard the groundwater resources in the area. This is the main objective of the present study.

1.2 Research Questions

The research sought to answer the questions below.

i. Is the quality level of the selected groundwater parameters in Kahawa Wendani within the required WHO/KEBS standards?

ii. Which geographical position is groundwater drawn from in Kahawa Wendani?

iii. How suitable is groundwater in the Kahawa Wendani for drinking water purposes?

1.3 Objectives

The study had the main objective of determining the potability of groundwater Kahawa Wendani and showing their abstraction points geographically.

1.3.1 Specific Objectives

i. To determine the potability of groundwater in Kahawa Wendani by calculating the Water Quality Index (WQI).

ii. To analyse the water quality levels of selected groundwater parameters in Kahawa Wendani using the WHO standard method of water quality analysis.

iii. To develop a spatial distribution map of groundwater abstraction points for Kahawa Wendani area using ArcGIS 10.2.2.

1.4 Justification of the study

Groundwater quality is demarcated by a set of health and safety principles for domestic use. Groundwater abstracted for public domestic use must observe a stricter category of regulatory objectives for wellbeing and security than groundwater abstracted specifically for irrigation needs. The excellence of public water structures must be below the maximum contaminant levels (MCL's) for a standard set of constituents (Allan, 2006).

According to the hydro geological map of Kenya, the study area lies in the region that has poor groundwater capacity. In this regard and as a goal towards sustainable development, there is dire need to establish the quality and spatial distribution of groundwater abstraction points in Kahawa Wendani which does not have any available data at the moment. This will improve monitoring and present improved management approaches related to socio economic activities and natural resources by the relevant authorities.

This study focused on getting the quality of groundwater and mapping the geographical positions where groundwater is drawn from in the Kahawa Wendani and eventually proving if its quality is apt for domestic use. This will be beneficial to WMA officials and County authorities in putting up the right measures to tackle groundwater quality problems.

1.6 Scope of the study

The study was done in Kahawa Wendani estate of Ruiru constituency in the county of Kiambu in Kenya. Particularly focusing on areas where groundwater is abstracted for domestic purposes. These areas included a students' hostel in Matopeni, The Chinese Estate, Nakumatt flats, Githurai Mixed School at Booster, Coca Cola, a home near Dexta School, opposite PCEA, PCEA immediate neighbor, Apostolic and Booster stage. It was not necessarily within the administrative boundaries of Kahawa Wendani.

Based on resources obtainable at the laboratory and due to financial/time constrains this study was limited to a few selected water quality parameters as indicated in sections 1.6.1, 1.6.2 and 1.6.3.

1.6.1 The selected physical parameters

Physical parameters describe those features of groundwater that react to the senses of sight, touch, taste and smell. In this study the selected parameters were colour, turbidity and Total Hardness (TH).

1.6.2 The selected Chemical parameters included;

pH, Electrical conductivity (EC), Sulphates (SO_4), Nitrates (NO_3), Chlorides (Cl), Calcium (Ca), Iron (Fe),Total Dissolved Solids (TDS), Total Suspended Solids (TSS) and Fluoride,(F).

1.6.3 The selected biological parameter

For the microbiological test, coliform bacteria were analyzed because the occurrence of these bacteria in drinking water is reflected to be adulterated by human or animal fecal matter or sewage.

1.7 Study area

Kahawa Wendani falls to the north of Githurai and its geographic coordinates are 1° 11' South, 36° 55' East. Kahawa Wendani is an outskirt settlement navigating the Kiambu County and Nairobi County borders beside Thika superhighway. Regardless of its proximity to the city, most of its parts are administratively in Ruiru Constituency of Kiambu County.

The sub county of Ruiru is administratively distributed into four sub-locations namely; Kiuu, Theta, Mugutha and Ruiru. The sub county is extra distributed into eight wards according to

IEBC, 2009 report namely Biashara, Gitothua, Gatongora, Kahawa Wendani, Kahawa Sukari, Mwihoko, Kiuu and Mwiki.

Population and Land use

According to the KNBS, 2009, Kahawa Wendani has an approximate population of 16,711 people. Land use does not vary significantly in the area. Majority of the land is used for residential developments which entail construction of septic tanks and generation of both solid and liquid wastes. The residential facilities increase gradually as more people move in but the natural resources like water remain fixed.

1.7.1 Rainfall and Temperature

Table 1.1:Rainfall &Temperature

	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**
Average high in °C	26	28	27	25	24	23
Average low in °C	12	13	14	15	14	12
Av. precipitation - mm	50	44	103	242	192	46
	July	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average high in °C	22	23	25	26	24	25
Average low in °C	11	12	12	13	14	13
Av. precipitation - mm	24	33	32	69	150	80

Source: Ruiru County, (2016).

The temperature is generally high, the mean maximum temperature being 26°C while the mean minimum temperature being around 14°C. The average annual temperature is about 21°C. Rainfall is bimodal with long rains occurring from March to May while the short rainy period occurs from October to December.

1.7.2 Topography and Slope Analysis

Kahawa Wendani is generally plain but slightly sloping towards the Kiuu River. The area increases in altitude from the north western end of the sub county to the south western end. The area drops in altitute from the northwest to southeast. It is poorly drained since the soil is black cotton and the area is almost flat.

1.7.3 Geology and Soils

The rock structure of study area is made of tertiary volcanic rocks. The crucial volcanic rock being Nairobi stone which is used mainly for construction. Its appearance is underlain dark ashes and tuffs and is underlain by aggrometric tuffs, some of them welded. The Nairobi groundwater basin ranges from the region of north-south rift faulting west (with an elevation of about 2400 m ASL) towards the Athi river floodplain (with an elevation of 1500 m ASL) east of the city center. Volcanic action has determined the geomorphologic evolution of the rocks of the Nairobi basin mainly including a series of volcanic lavas and ashes (tuffs), whose thickness scopes some 400 m beneath and which eastward slowly combine into to the Tertiary residues of the Athi floodplain.

The volcanic rocks imply a broad extent of porosity and permeability and have advanced aquifer components divided by lower permeability strata. The aquifers chiefly include the Kerisha Valley Series and Upper Athi Series (transmissivity of 5-50 m2/d and low storativity).

The lithology in this area comes from volcanic rocks that steadily occur on levels between 1200 to 2000m beyond the sea level. The mutual outlook of the soils varies from shallow yellow/brown to red friable clays. These are undeveloped soils also known as cambisols that originate from erosion activities. However there are spots of black cotton soils. Soils occasioning from these rocks are dark reddish brown, well drained, friable and very calcareous. They are stony forming loam to clay loam, and in several places saline. There are also lithosols having calcic, xerosols boulding and saline phase and rock outcrops.

1.7.4 Hydrology and Drainage Systems

Kahawa Wendani area is a section of the greater eastern slopes of the Aberdare's Ranges. The land normally undulates with an overall drainage design towards the Athi river basin. In as much as the area is largely undulating, these features are observed in the main drainage channels in Ruiru, Theta, Gatharaini and Kamiti rivers that drain into the Athi basin. However, certain areas are ill drained for example portions of the CBD flood during the rainy season and are essentially unreachable for months after the rain (*RLPDP, 2009*).

Peak natural groundwater recharge happens on the slopes of the rift zone, where the volcanic rocks are carved by abundant watercourses linked to fault lines and disintegrated areas of the earlier terrestrial surfaces. The upstream zones of these watercourses become a significant basis of aquifer recharge. The thick foliage, porous soils and drainage design beside the upper parts of these watercourses deliver good recharge.

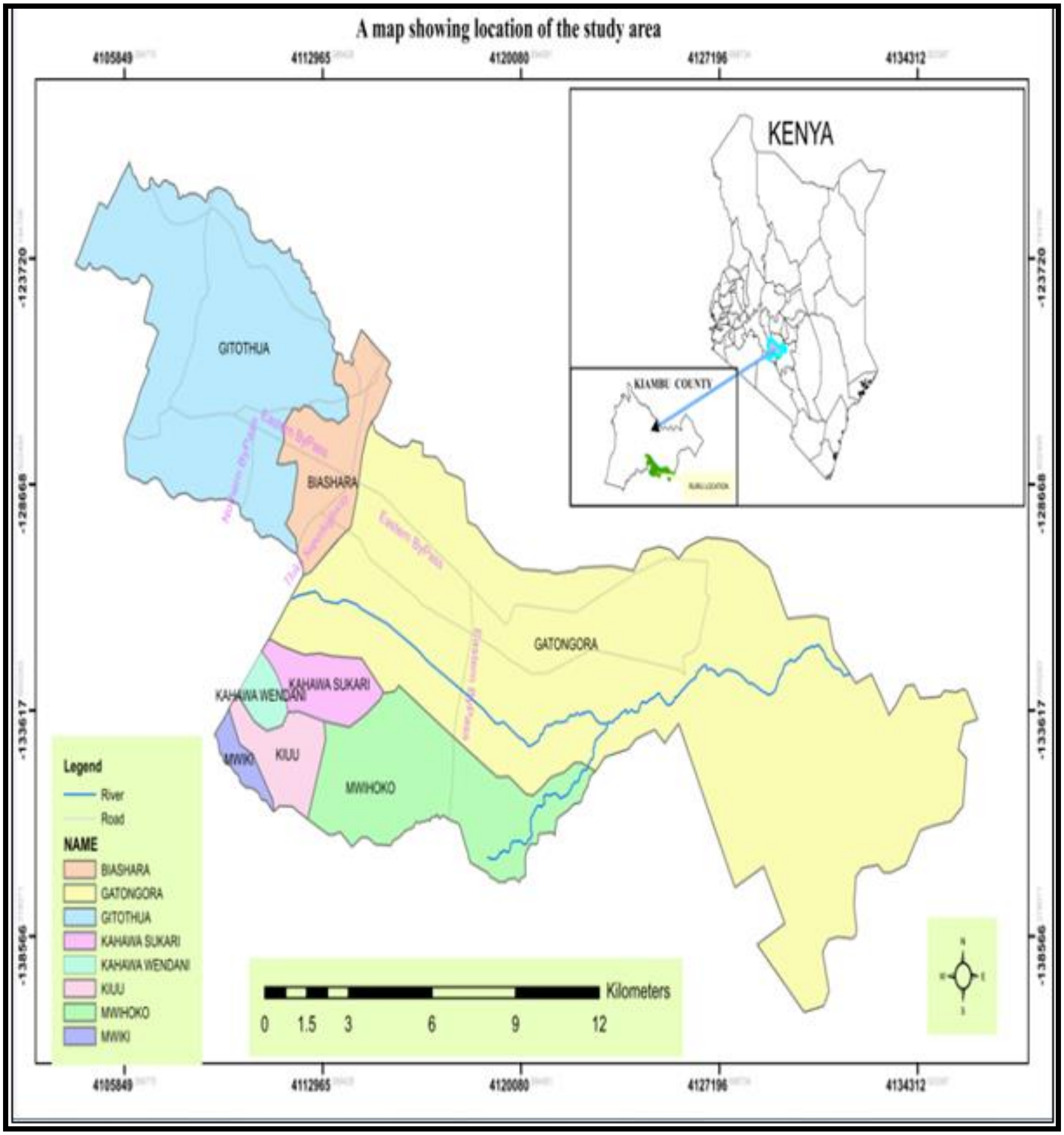

Figure 1.1: Location of the study area in Ruiru constituency Kenya.

Source: Ruiru Local Physical Development Plan **(**2009)**.**

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

Attaining nontoxic and enough water is a fundamental human necessity and is crucial to human welfare (UN, 2006). However, at the moment, almost a billion people especially those living in the emergent world do not have the reach to benign and enough water (UNICEF/WHO, 2012). One of the United Nations Sustainable Development Goals (SDG 6) precisely highlights the difficult of getting safe drinking water. The target of this goal was to half the percentage of people destitute of supportable reach to harmless water to drink. This has been attained on global basis, but Sub-Saharan Africa has not achieved it with only an advance of 16% since 1990 till 2012 (MDG Report, 2014). While groundwater is archaeologically believed to be void of bacteriological pollution, current studies show that groundwater may be polluted and this can simply lead to water related infections if taken minus earlier treatment (Momba and Mnqumevu, 2000; Momba, 2006). Water related vectors infect about 250 million individuals annually causing 10 to 20 million demises globally and Kenya is not excluded.

The World Health Organization (WHO) approximations that about 94 percent of the worldwide diarrheal problem and 10 percent of the entire illness problems are caused by insecure drinking water, reduced hygiene and weak aseptic norms (Prüss-Üstün and Corvalán, 2006). 80 percent of all ailments in emerging countries are connected to risky drinking water and insufficient cleanliness (Tebbutt, 1998). Nearly 6000 youngsters, maximum of them in emerging nations, lose their lives daily of sicknesses connected to insufficient hygiene and failure to get harmless drinking water (Louise, 2005). The great portion of the population in emerging nations is not sufficiently provided with clean water and is therefore forced to utilize groundwater from superficial wells and boreholes which are risky for household and intake because of high chances of pollution (WHO, 2006, 2011).Thus the need for this study.

In Kenya, the complete potential of groundwater is unidentified. Absence of scientific evidence about position and capacities imply only a predictable 5% of the total countrywide water benefaction. Meanwhile, the escalating use and need for water supply in Kenya shows its deliberate significance. Partial knowledge of groundwater resources and less monitoring systems, rainfall inconsistency, temporality of streams and absence of bulky reservoirs for water storage, all deter development.

In 2012 the vital demand to fight water shortage in the drought prone zone in east Africa following the 2011 drought in Somalia, pushed UNESCO with a group of global, regional, countrywide and native performers to start the Groundwater Resources Investigation for Drought Mitigation in Africa Programme (GRIDMAP).

2.1 Groundwater Quality

The word water quality is used universally to denote the state of water that reaches the universal Standards set for genuine and vital water usage at any level such as local, regional and international levels (WHO, 2000).

Groundwater is normally fresh under ordinary conditions, though not essentially of good chemical quality.

The major ordinary dissolved chemicals in groundwater include salts, irons and manganese, fluoride, arsenic, radio nuclide and trace metals. Calcium and magnesium ions cause water hardness (Hammer and Hammer, 2000). The inorganic content in water caused by installation from the air is raised by degree of evaporation. When the aridity and the ability of soil to retain water are high, then the degree of evaporation also raises. What is left will be turned into groundwater boost, which includes soil carbon dioxide from air movement at the roots of plants and carbon-based matter decomposing in the presence of oxygen. This gives bias to the soil and rock deposits to dissolve in the water. These renowned mechanisms (Appello and Postma, 1993; Custodio and Llamas, 1976) regulate groundwater quality standard (Edmunds and Shand, 2008).

For example on a global viewpoint, as stated by *Emilio,(2011-2014)* there are sections such as Tenerife, or in areas of the African Rift in Ethiopia, Somalia and Tanzania which have high fluoride content. The cause of the fluoride (F), is not well known, but in general is connected to the presence of F–rich sediments with Ca–poor groundwater. These sediments are majorly of acidic and intermediary volcanic origin in subducting parts of the Earth crust, such as that in the western side of the Americas or in eastern Asia, or triggered by volcanic processes associated to very advanced magmatic chambers. Acidic volcanic residues habitually have high F content, which are spread over great, far away areas, and are incorporated into other sediments, as is the case of great extents in Argentina and Bolivia. Renown regions subject to extra Arsenic in groundwater are in Blangladesh, West Bengal (India) and the “pampas” of Argentina. Vital research input have been carried out to know how and when Arsenic is existent (Smedley and Kinnibourgh, 2002).

According to the *Thematic Global Paper 1* on groundwater governance, (2011-2014), weakening of groundwater quality by contamination from inorganic oils, fuels, chlorinated solvents and other compounds that do not mix in water appears to reducing, in occurrence and strength, in several parts of the domain. This is due to upgraded machinery and standards to elude seepages and insecure disposal, extra enforcement of principles and developed monitoring. But this could not be the situation in emerging nations, where the gravity to monetary advance is leading in the scenario and is habitually followed by more point-pollution actions and aquifer quality worsening.

The major groundwater quality concern in Kenya is the existence of fluoride that is triggered by the volcanic powder deposits that extent over wide parts, (*Margat and van der Gun, (2012*). Volcanic rocks extend the central region of Kenya from south to north, happening in the bottom of the Rift Valley and on the peneplains west and east of the valley.

Disease causing bacteria like *Escherichia coli, Vibrio cholerae, Salmonella tyhimurium, Pseudomonas* species and *Klebsiella* species have been stated in groundwater sources (Momba, 2006). The major bacterial microbes to address in adulterated groundwater include *Salmonella sp., Shigella sp., Escherichia coli* (E.coli) and *Vibrio cholera* (Rajendran, 2006). The occurrence of fecal coliforms or E. coli has been broadly applied as an index for the occurrence of some of these water related disease causing microoorganisms (Ibe and Okplenye, 2005; Rajendran, 2006). In this study E. Coli was analysed and was found to be absent in all the samples. The World Health Organization (WHO) acclaims that in 100 ml of drinking water fecal coliform should be absent (USEPA, 2001). The aspects causing pollution are frequently unclear, however, they are regularly related to contamination by hygiene amenities in the vicinity, like pit latrines. Pit latrines have been recognized as a key source of pollution of groundwater (wells) with human waste (Molard, 1994; Pritchard, 2007).

Groundwater pollutants may be: (i) ordinary, caused by aquifer misuse; (ii) presented as an outcome of human action; or (iii) a mixture of both, *Groundwater governance, 2011-2014.*

Kenya is an arid nation categorized as recurrently water deficient since it has a fresh water capacity of only about 650m^3 per person. As stated by Wafula (2010), there is a possibility to reduce to 235 cubic meters annually majorly because of increased population. Referring to Marshall (2011), certain causes that make Kenya encounter serious water predicament are escalation in population, dry spells, pollution of aquatic sources, recurrent flooding, inappropriate water control and loss of vegetation. Hence, the problem of fast population upsurge and cost has caused potable water provision insufficient to satisfy the great need for water by the public. Groundwater can be quite an affordable substitute to limited water capitals. Groundwater is progressively becoming the basis of drinking water for residents of both nonurban and city dwellers because of erratic water scarcity that often strikes most parts of towns (Nyarko, 2008). A majority of the nonurban population do not get clean drinking water. With reference to the World Bank (2015), just 55 percent of the rural inhabitants in Kenya get clean water whereas 82 percent of the city dwellers get it, implying that groundwater use may be a substitute supply of water for household purpose, creating the essence to be examined. According to Rai and Sharman (1995), absence of sanitation, inappropriate waste disposal, defective well construction, and absence of source water safety enhances groundwater contamination. Therefore assessment of groundwater quality is crucial to safeguard both public health and the environment which is a chief objective in the present study. The study area is an emerging metropolitan residential estate with water provision that is inadequate. Some inhabitants have drilled boreholes and shallow wells to handle the low water provision.

According to UNESCO, 2013 Kenya groundwater report, there are many benefits associated with groundwater data. Programs were introduced in Turkana funded by the Japanese government to map groundwater potential and since then, many groundwater exploration initiatives have taken shape thus enhancing water availability given the fact that Kenya is a water scarce country. If similar initiatives are embraced nationwide then consistent groundwater data will be available to inform the relevant authority to plan well for water supply to address water shortage.

In Kiambu County, 25 percent of dwellers use poor water supply like ponds, straight from the rivers, insecure springs and from water merchants (KNBS and SID, 2013). Groundwater has been a vital supply of drinking water for the countryside and city societies (Singh, 2009). It is essential to boost the effort to advance the efforts of groundwater quality while bearing in mind the probable developments in water sources and hygiene in the nation and in the study area which is a key concern investigated in the study.

2.1.1 Groundwater quality attributes

Features of water quality are categorized as physical, chemical and biological. The quality of water is gauged by reliable standards. World Health Organization (WHO) has endorsed standard values for drinking water for developing countries, which are referred to as basis for developing the local values (Ramaraju, 2006 & WHO 1993).

2.1.1.1 Chemical characteristics of groundwater

Since groundwater mostly occurs in connection to rock constituents with ores that dissolve in water, higher levels of dissolved salts are usually anticipated in groundwater compared to surface water. The kind and quantity of salts is based on the geological nature, the origin and flow of the water (Ramaraju, 2006). The original chemical value of groundwater is usually good, but high concentrations of several constituents can lead to hitches to the water. For example, increased iron in groundwater is extensively noted from emerging countries, where it is mostly a crucial water quality issue. The condition is worsened in numerous areas by the corrosion of wells with iron linings and pump constituents (Ramaraju, 2006). The study area has high iron and fluoride levels.

According to the **(**Devendra *et al*., **(**2014), these groundwater quality parameters have been described as follows;

pH:

The influence of pH on the chemical and biological attributes of liquids renders its investigation very crucial. It is one of the very crucial factors in water chemistry and is demarcated as a negative logarithm $[H^+]$, and defined as strength of acidity or alkalinity at a range from 0-14,from 0 to 7 is acidic and 7 is neutral (Mumma, 2011).

The acceptable limit ranges from 6.5 to 8.5.

Turbidity: The disruption of penetration of light due to suspended matter is called turbidity. Turbidity is initiated by varied Suspended matter. Turbidity can be got either by its outcome on the penetration of light which is referred to as Turbidimetry or by its influence on the spreading of light which is called Nephelometry. It distorts the visual value of groundwater thus was chosen for analysis in this study.

TDS: Solids that can be filtered are established by the variance of total solids and suspended solids and referring to the procedure as stated in section 3.4.2.7. In water trials it can also be projected from conductivity figures. This variable was picked because water that has a lot of dissolved solids is usually tasteless and may encourage an unfavourable functional reaction in the user, (Mumma, 2011).

Electrical Conductivity: This is the ability of water to transfer an electrical current and differs both with amount and forms of ions the liquid holds. The conductivity of distilled water is low than 1umhos per centimetre. This conductivity is subject to the occurrence of ions, their overall concentration, kinesis, valence and comparative concentration and on the heat of the solution. Liquids of most mineral acids, bases, and salts are comparatively good conductors.

Total hardness: The outcome of hardness is scale in kitchenware and hot water structures in cisterns. This normally comes from dissolved calcium and magnesium from soil and underground ores made of granite. The mitigation of hard water is softener ion exchanger and inverse osmosis method. The extent of hardness is grouped with regard to the equivalent calcium carbonate concentration as follows: Soft - 0-60mg/l, Medium - 60-120 mg/l, Hard - 120-180 mg/l, Very hard - >180 mg/l. The acceptable limit is 500mg/l and below.

Sulphate: Normal water has sulphate ions and a great percentage of these ions also dissolve in water. Various sulphate ions are formed by way of addition of oxygen from ores. The technique to measure magnitude of sulphate is by UV Spectrophotometer.

Nitrate: Nitrate occurs in fresh water and predominantly in the form of N_2 complex. It is made from chemical and fertilizer plants, materials of living things, household and manufacturing discharge. The mode to enumerate nitrate is by UV Spectrophotometer.

Total alkalinity: This is the total of constituents in the water that habitually raise the pH to the alkaline. This describes the nature of the water, whether it forms scales, neutral or corrosive, rendering it a core variable for analysis. It is quantified by titration with standardized acid to a pH value of 4.5 and is stated frequently as milligrams per liter as calcium carbonate (mg/l as $CaCo_3$). Frequently present constituents in water that raise alkalinity are compounds of carbon, phosphate and hydroxides. Marble foundation and heavy deposits of icy till are noble causes of carbonate shielding. In this study the alkalinity was very low.

Chloride: All forms of ordinary and fresh water have chlorides. It originates from practices done in cultivated area, Industrial undertakings and from chloride deposits. Its concentration is great because of human undertakings. Only one sample indicated a level higher than the required.

Fluoride

Fluoride is a compound that is present by nature within numerous varieties of rock. Greatest of the fluoride found in groundwater is ordinarily present from the disintegration of rocks and soils or fragmentation and installation of atmospheric volcanic elements. Fluoride can also be a result of:

- Overflow and penetration of chemical nourishments in cultivated zones
- Septic and sewage handling structure releases in societies with fluoridated water sources.
- By-products from industrial supplies in solution form.

In minimal levels fluoride can decrease the danger of dental fissures. Introduction to advanced amounts of fluoride can lead to fluorosis of the teeth. In its slightest level this leads to dental discoloration, while serious teeth fluorosis comprises deformation of dental enamel and tooth cracks. Even advanced consumptions of fluoride consumed for an extended duration can end in alterations to bone, a disorder called skeletal fluorosis. This can lead to joint pain, limitation of movement, and perhaps raise the possibility of some bone breakages.

A study conducted on 513 junior school children in Nairobi with a focus to weigh the occurrence of cruelty of teeth fluorosis proved that the extent of fluorosis on children consuming river water was mild, (Nganga and Valderhaug 1982).

Nevertheless, in areas provided with borehole water, 48 percent of the teeth and 48 percent of the children had great dental fluorosis, thus encouraging this study. The study pursued to get the quality of fluoride in order to deduce if the level is of impact to abstractors. In the study area, the fluoride levels have exceeded the maximum required WHO standard in 3 samples and in some samples they are very close to the WHO standard value of 1.5mg/l hence should be controlled.

2.1.2 Biological characteristics of groundwater

Groundwater quality can be affected openly and indirectly by bacteriological activities, which can alter both mineral and organic components of groundwater. These biotic changes usually speed up geochemical progressions (Pusch *et al.*, 1998). Unicellular and multicellular entities have developed adaptation to consuming the dissolved particles and suspended matter in the water and solid substances in the aquifer for their body function. Later on, they discharge the biomechanical yields again in the water (Pusch *et al.*, 1998). The occurrence or lack of O_2 is therefore, among the very crucial aspects influencing microbial processes. For a microbe to develop and reproduce, nutrients must be provided in a suitable ratio, which gratifies C, energy,

N_2 and mineral necessities (Chapman, 1996).Several microbes develop on solid surfaces and therefore cover the grains of the soil. They connect themselves with multi-cellular polysaccharides, creating a defensive biofilm which can be so hard to eliminate (Chapman, 1996). Microbiological processes basically influence compounds of nitrogen and Sulphur and a number of the metals, essentially iron and manganese. Sulphate decline by obligate aerobes is among the very imperative biological activity in groundwater.

Chemical complexes containing Nitrogen are influenced by both nitrogen fixing and nitrogen reducing bacteria. Decrease of nitrate by reducing bacteria happens in the existence of organic matter in the absence of oxygen, causing the formation of nitrite which is then disintegrated further to basic nitrogen. The likelihood of improving natural reduction of nitrogen is now getting attention in connection to the difficult of nitrate in groundwater. In the presence of oxygen, ammonia (which may be made in the disintegration of organic substance) gets oxygenated and becomes nitrite and nitrate.

A major microbial worry in groundwater is the wellbeing risk caused by fecal pollution. Of the four types of the disease causing microbes confined in human waste, only bacteria and viruses are probable to be tiny enough to be transferred inside the soil and aquifer medium to groundwater bodies (Foster, 2000). The soil has for an extended time been identified as the most suitable shield from groundwater pollution by fecal microbes. Microbiological adulteration of groundwater stands as a key burden, particularly where many isolated, shallow dug wells or boreholes supply safe but unprocessed household water.

In summary, bacteriological activities may affect groundwater quality both in a good and bad way. The previous include decreasing nitrate and sulphate components of groundwater and elimination of carbon-based contaminants. The second include the creation of hydrogen sulphide and metals that dissolve in water, forming of gas and biofilm entangling of well screens and delivery pipes. Thus, the need to establish the organic makeup of groundwater in Kahawa Wendani with respect to the required WHO drinking water quality standards and assess the status of groundwater contamination and quality degradation.

2.2 Water Quality Index

Water quality index is one of the key suitable, simple and easily comprehensible implements to evaluate water quality for its aptness for numerous uses. In an effort to make water quality an indicator of groundwater in diverse areas, these indicators have now been established for

Haridwar district in Uttarakhand and Muzaffarnagar and Shamli districts of Uttar Pradesh in India, *Krishan et al. (2016).* This study in a similar attempt adopted the WQI for the study area.

“The WQI can be measured on a worldwide gauge in relations to Health Water Quality Index, (HWQI), Drinking Water Quality Index, (DWQI) or Acceptability Water Quality Index, (AWQI)” as stated by *Global Drinking Water Quality Index Development and Sensitivity Analysis Report, 2007.*

In as much as there is no universally recognized complex indicator of water quality, some nations and areas are applying collective water quality data in the improvement of water quality guides. Several water quality key variables depend on stabilizing data from one parameter to the other according to predictable concentrations and some explanation of ‘good’ versus ‘bad’ concentrations. Parameters are habitually then measured with regard to their professed importance to total water quality and the value is derived as the subjective mean of all attributes of concern (Tsegaye *et al*., 2006).

Furthermore, the Canadian Water Quality Index (CWQI) relates observed values against a standard, where the standard may be a water quality benchmark or zone specific contextual concentration (Lumb *et al*., 2006). The CWQI enumerates for one location, over a programmed interval (usually 12 months), the total variables that surpass a standard, the figure of records in a group of data that go beyond a standard, and the degree of exceedance of the standard. The index is bendable based on the standards applied for calculation, and is determined by the information needed from the index. For example, procedures for the safeguard of aquatic life may be used (when accessible) if the index being considered is to measure ecological health of the water, or drinking water quality procedures may be used if the concern in the index is in drinking water safety. On the other hand, facts unfolding natural background circumstances for a location or region may be applied as standards when attempting to measure nonconformities from natural settings. Spots at which water quality dimensions hardly surpass the benchmark have raised CWQI values (close to 100), while those areas that habitually have measured values that surpass standards have reduced CWQI values (close to 0).

Latest studies done by Global Drinking Water Quality Index Development and Sensitivity Analysis Report, © 2007, show that in Asia and Oceania, the water quality with regard to human health (HWQI) is steadily lesser than AWQI (and DWQI in Oceania). In Asia, the DWQI narrowly trails HWQI irrespective of AWQI, comparable to the configuration observed in the

Americas signifying that DWQI is intensely affected by wellbeing parameters other than acceptability parameters.

In India, the studies done by Sajal and Athar, (2016) in Greater Noida sub-basin,Uttar Pradesh, show deprived water quality in extremely industrial areas with figures extending from 53.69 to 267.85. Another study also did in Rajkot district, India by Krishan et al. (2016) show that 51.8 percent of water trial fell in the ‘good’ to ‘excellent’ water class. Conversely, 48.2 percent of water trials fall in the ‘fair’ to ‘poor’ class signifying that the water is not appropriate for straight intake and need treatment. Studies done in Kenya on WQI offered are on rivers: River Kibisi by Sindani, (2013) and Malakisi River by *Mwiluka, (2015)*.Another study has also been done on groundwater in Gatundu by *Ashun, (2014)* where a contrast between shallow wells and boreholes was done. In a related effort and for this specific study area, this project has been developed.

2.3 The use of Geographic Information Systems (GIS) in water quality.

Geographic Information Systems (GIS) is an electronic tool now applied to solve past and present water quality hitches. GIS applies an electronic database to accumulate enormous amounts of spatial and chronological data. This permits the incorporation of different forms of information into an arrangement that makes it potential to reflect diverse methods to land control and environmental difficulties prior to management resolutions. Spatial data is evidence that defines how a particular feature is positioned or spread in space, (Ramaraju, 2006).

In this respect, this project applied GIS to do a spatial dispersal map of the diverse abstraction points thus enriched groundwater database to make way for advanced research. The map produced by the GIS examination gave an overview of the spatial dispersal of groundwater drawing points in the area of this study as reference data for more research. GIS is a crucial instrument that is useful especially for prospect physical forecasting and monitoring as far as groundwater administration is concern.

Literature findings

Research on water quality index has been done broadly in India and Egypt and has been found to be the best method of analyzing drinking water quality. For groundwater the best parameter that has been used in most studies is Electrical conductance since it informs about the other parameters. From the studies in Kenya, the major parameter affecting groundwater is fluoride and this is due to the geological formation of the aquifer. It is found that deep boreholes tend to have high fluoride levels since the water is drawn from greater depths of the bedrock. The fluoride levels also are related to the type of aquifer, confined aquifers are said to have high fluoride levels because there is no direct mixing with water from the surface compared to unconfined aquifers. Another aspect that has been highlighted in previous studies is that shallow wells are more vulnerable to contamination by human waste compared to deep wells/boreholes. The samples were drawn from boreholes with depths ranging from 328 feet for borehole 6 as the deepest and 50 feet for borehole 7 as the shallowest. This study sort to know if the boreholes were contaminated with human waste. Most of these studies have been done over a long period to monitor the quality at different seasons. However, the sampling period for this study fell in the dry and hot season, in the month of October.

GIS has been applied in most of the recent studies to do mapping and relate the water quality to other ecological attributes. Hence, this study sorts also to build up on the GIS data for the study area. The research that has been done in other parts of Kiambu like Gatundu, Githurai Ruiru, Kikuyu and Kiambu town have captured; water supply as a health indicator, flooding, spatial distribution and quality, source of contamination and Fluoride levels of groundwater within Ruiru business centre only and not the entire Ruiru constituency. Other studies include urban sprawl and the impact on resource consumption. This definitely also implies that the population increase over the years since the Thika Super highway was constructed, is affecting water demand and sources, thus prompting this study.

Gaps

There is no comparison of groundwater changes over time that has been done in this study area. Also, the link between groundwater and ecosystems changes over time has not been done for this study area as well as monitoring the abstraction rates and their effects on the groundwater aquifers.

Right now, there is no documented study on the quality of groundwater in Kahawa Wendani located in Kiambu County, Kenya, which impelled this research to be initiated using water quality index and GIS so that reference data on groundwater quality is availed for the area. GIS is an obligatory tool to enrich prospect and auxiliary groundwater observation studies and physical design, so that whichever researcher can locate the specific site to pick up from the previous studies.

2.4 Theoretical framework

Conferring with the DPSIR structure there is a series of causative associations beginning with " '*driving forces*' (monetary divisions, social practices) through '*pressures*' (discharges, waste) to '*states*' (physical, chemical and biological) and '*impacts*' on bionetworks, human wellbeing and roles, ultimately causing partisan '*responses*' (prioritisation, goal establishment, indicators)". Illustrating the fundamental series from driving forces to impacts and responses is a composite undertaking, and needs to be fragmented into sub-tasks, by bearing in mind the pressure-state association.

2.4.1 Driving Force - Pressure Relationships

The environmental forces coming from human actions (abstraction of groundwater, waste production and land utilization) are a product of two sorts of parameters: (i) the degree of these actions, and (ii) the mechanism used in these actions. For instance a release of wastes from domestic activities is the product of the degree of that action and an emission factor, which mirrors the mechanism of the process under examination. Release of discarded water from household sources, for example, is subject to the magnitude of the populace and their intake (activity) and on the amount of population linked to sewerage system and diverse forms of discarded water treatment (machinery). The machinery variables are echoed by emissions aspects, resource utilization aspects or land utilization aspects. The parameters responsible for the degree of actions are of a fiscal nature, because they mirror the degree of production and depletion.

2.4.2 Water quality and DPSIR framework

Water accessibility hitches happen when the need for water surpasses the quantity accessible during a definite extent of time. Freshwater scarcities happen regularly in parts with little rainfall and increased population bulk and in zones with rigorous agronomic or industrial activity.
There are enormous space and time variances in the quantity of water accessible (***state***). In this study the state is limited freshwater source that causes drilling of boreholes and vending the water to the residents who are unable to drill their private boreholes. The selling is regulated by time, in that the sellers only start to sell from 2pm to regulate the rate of abstraction.

Additional ***pressures*** on water quality come from the key sectorial consumers of water such as agronomy, domestic, power production and industry. The periodic need from tourism is a substantial pressure.

In this study, the major pressure is domestic expenditure due to deficiency of other sources of water within their range. Rain water harvesting is very minimal and insignificant.

The ***impacts*** of excessive use of accessible water include reductions in groundwater heights that sequentially cause impacts on related water and land environments like wetlands. Furthermore, excess use of groundwater causes the interruption of saltwater into coastal aquifers. In the area of study, the key impact from the data collected is from the geological formation of the area. It is still not probable to know if there is over abstraction because the potential of the aquifers is not yet demarcated and further research should be done on this. But abstraction is controlled by some of the owners as stated earlier, by regulating the time of selling/supply. In addition, given the fact that the water is pumped by electric energy, it cannot be pumped just anytime .It is only pumped at specified time.

Responses to upsurge the quality of accessible water comprise the water treatment processes to secure the wellbeing of the consumers. Other precautions are focused at water analysis or monitoring plus waste controlling, borehole upkeep and decrease of chemical effluence in supply systems. In the area of study, measures include treatment of the water with water guard or chlorine and boiling it before drinking as individual initiatives. The boreholes are also well lined with cement and covered to increase the water security. However, most of the users presume the water to be safe enough to drink and do not treat. Other stake holders like government agencies need to come in handy and ensure continuous monitoring and control of fluoride and Iron levels. This will help eradicate the impacts which are a major point of focus in this study.

This model has many aspects which have added to its extensive application:

•Clearness and easiness, with 5 models which are freely clear to researchers and shareholders.

•Boosts exchange of information amongst researchers and participants by abridging the composite networks amid mankind and the ecosystem.

•Permits specific associations or connections to be singled out but holding conceptual significance to the greater system.

•Fundamentally mankind-oriented, pleasing to the people and resolution makers.

•Attractive to policy performers as it associates political objectives to ecological issues and shows pivotal affiliations between features (Smeets and Weterings, 1999).

•The fundamentals of DPSIR can be plotted onto other models, comprising the "Millennium Ecosystem Assessment (Hassan *et al.*, 2005) and Long Term Ecological Research Program."

2.4.3 Conceptual Framework

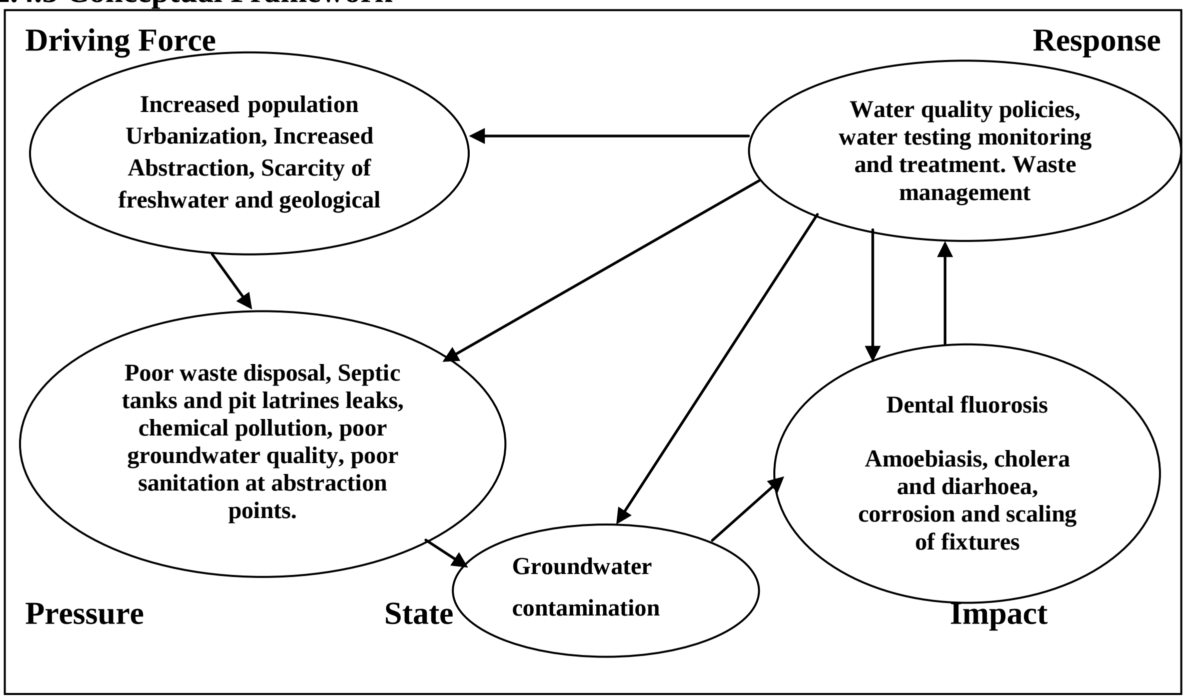

Figure 1.1: Conceptual model on Driving forces and outcomes of groundwater pollution.

*(Source: Amended and improved from DPSIR model in connection to water problems (Kristensen, 2004)***.**

This research embraced the Drivers Pressures State Impact and Responses (DPSIR) theoretical framework. The model explains the reasons of demeaning groundwater quality. Unevenness comes as an outcome of driving forces such as increased abstraction rates, increased population, urbanization and pressures like chemical intrusion, poor waste disposal as shown in Figure 2.1. The swift escalation in populace tied with reduced hygienic and sewerage structures plus the routine of septic tanks compromises groundwater excellence. When these pressures are exerted on groundwater sources, their levels reduce, quality decrease and if taken may cause impacts which are very numerous as follows. Dental fluorosis in case of high fluoride levels, amoebiasis, cholera and diarrhoea when the water has fecal coliforms. Corrosion and scale forming in boilers and water fixtures due to too much calcium and iron in the groundwater. Tastelessness, change in color from crystal clear to whitish or brown and oduor due to suspended solids and dissolved solids as well as increased alkalinity or acidity.

These impacts can be minimized only if the pressures influencing them are addressed. This happens when the relevant authorities and stakeholders come in with responses to mitigate the impacts and eradicate the pressures. Responses may include formulation of groundwater testing, monitoring and management programs, permits on abstraction and waste management policies to reduce contamination of groundwater.

Existing as an unified organization model, DPSIR has a great deal of probable parts in science forecasting, comprising recognizing major concerns, envisioning connections inside the structure, finding study openings, shaping information, establishing computational frameworks and finding signs.

CHAPTER 3: STUDY METHODOLOGY

3.0 Overview of methods and materials

Groundwater samples were gathered from ten selected boreholes by snowballing within Kahawa Wendani, Kiambu County. The 10 selected boreholes were located in the following named geographical positions;

Table 3.1: GIS Coordinates

NO.	AREA SAMPLED	X	Y
1.	Near Kimbo PCEA church	02707035	9867117
2.	Coca Cola	0270725	9867091
3.	Opposite PCEA church	0271209	9867272
4.	Next to Dexta School	0270393	9866846
5.	Githurai Mixed School	0270253	9867148
6.	Nakumatt	0269581	9868234
7.	Next to Apostolic Church	0270334	9867524
8.	Chinese Estate	0269193	9867814
9.	At booster stage	0270577	9867310
10.	Student hostel, Matopeni	0269617	9868193

Source: Researcher (2017).

The samples were gathered in the month of October, 2016. They were sampled in sterilized screw-sealed plastic bottles of one liter and each branded correctly, such as BI for borehole number 1, in that order up to B10. The samples were held at the field as per standard methods. Samples were drawn at the point of pumping, this is because all the boreholes are automatically pumped by electricity and no sampling can be done before pumping. The water samples from each borehole were scrutinized in terms of physical, chemical and biological contents using the Standard techniques of the American Public Health Association (APHA, 2005). The standard chemicals needed in the analysis were set using double distilled water. For the reasons of sustaining the legitimacy of the sample and to lessen probabilities of mixing and subsequent contamination, each sampling point was given a unique code from each other.

3.1 The Design of the Study

This study applied only numerical research technique. Given the unknown population size from which to draw the sample, snowballing was applied. The sample size was 10 boreholes, given the struggle of availability/suspicion of boreholes owners as well as lack of access to the current borehole register. The accessible register of 1950s has hardly any abstractors from Kahawa Wendani. Two separate samples were drawn from each borehole, one for biological and the other for chemical analysis. The depth was also recorded depending on the availability of information in regard to the borehole.

3.2 Generation of Abstraction points.

The sampled locations were positioned using a Global Positioning Systems device (GPS) to note the latitudes and longitudes as indicated in table 3.1. The site reading permitted the positioning of the boreholes in their individual locations. ArcGIS 10.2.1 software was used to produce the map of each of the boreholes in Kahawa Wendani area. This GIS version was used because it was the latest and available version then.

3.3 Laboratory Analysis

This constituted exposing the water samples for analysis in harmony with the Standard methods for the Examination of water and waste waters. The benchmark to define the concentrations of each parameter. The bottles were thoroughly cleaned with Hydrochloric acid and then washed with tap water rendered free of acid and then washed with distilled water twice and again rinsed with the water sample to be collected and then filled up the bottle with the sample leaving only a small air gap at the top stoppered and sealed the bottles. All the glassware, casserole and other pipettes were first cleaned with tap water thoroughly and finally with deionised distilled water. The pH meter, conductivity meter, spectrophotometer, flame photometer instruments were used to analyze the selected parameters.

3.3.1 Microbiological Analysis

The indicator microorganism particularly the number of *Escherichia Coli* were determined by the membrane filtration Method. This was chosen because its presence in water is an indication of fecal contamination (Umaru, 2012).

Procedure

Before the analyses, the incubation chamber for the analyses was thoroughly cleaned and disinfected with ethanol to avoid contamination from the field. 98% alcohol was used to sterilize the porous plate of the membrane filtration unit and the membrane filter forceps. The membrane filtration unit was set up with the grid side up and a sterile meshed funnel placed over the receptacle and locked in place. After this, the membrane filter was transferred onto the porous plate of the membrane filtration unit. The volume of groundwater samples analysed were 100 ml as the standard method, reporting for results of microbial analysis is the number of colony forming units per 100 ml volume analysed (Anon, 2000).

The groundwater samples were analysed for fecal coliform. The sample was filtered through the membrane filter under partial pressure created by a syringe fitted to the filtration unit. The filtrate was discarded and the funnel unlocked and removed. The forceps was used to transfer the membrane filter onto a labelled Petri dish containing the appropriate growth medium (m F.C agar for Fecal coliform). Fecal coliform counts were determined using the membrane filtration method with m-FC agar plates at 37 °C for 24 hours (Grabow *et al.*, 1991). After incubation, typical colonies were identified and counted. The colonies were counted three times with the aid of a colony counter and the mean recorded. Fecal coliform was detected as blue colonies on the M-FC agar. The total number of colonies appearing was counted for each plate.

3.3.2 Physical–chemical Analysis.

The parameters were tested in accordance with the Standard methods for the Examination of drinking water and waste waters. The pH and Electrical conductivity (EC) were measured using digital conductivity meter, Total Hardness (TH) as $CaCo_3$, calcium (Ca^{2+}) and Chlorides (Cl) were analysed by volumetric methods. Nitrates (NO_3), fluoride (F) by the Electrode method. Iron (Fe) by spectrophotometer, Sulphates (SO_4) was determined by Turbidimetric method (APHA, 2005). The results obtained were compared with both the WHO and KEBS drinking water standards in order to determine the quality of water and hence the suitability of the groundwater used in Kahawa Wendani. All the procedure and principles have been adapted from Pusch *et al*, (1998) and "Mumma *et al*, (2011).

3.4.2.1 Determination of pH.

Apparatus:

Electrometric method: Glass electrode, reference electrode (mercury/calomel or silver/silver chloride) and pH meter.

Procedure

The pH was measured in situ. The pH electrode of the pH meter was first calibrated against a pH buffer 7 and 9 at a temperature of 25^{o}C to adjust to the response of the glass electrode. The electrode was then immersed in the sample and stirred gently and stopped, allowing for 1-2 minutes for a stable reading to be obtained and recorded (SM 4500-H+.B APHA, 1998). *Pusch et al, (1998) and Mumma et al, (2011).*

Plate 3.1: pH measurement

Source: Researcher **(2017)**

3.4.2.3 Determination of Electrical Conductivity

Apparatus required: Conductivity meter

Conductivity (specific conductance) is the numerical expression of the water's ability to conduct an electric current. Conductance is defined as the reciprocal of the resistance involved and expressed as mho or Siemen (s). It is measured in micro Siemens per cm and depends on the total concentration, mobility, valence and the temperature of the solution of ions. Electrolytes in a solution disassociate into positive (cations) and negative (anions) ions and impart conductivity. Most dissolved inorganic substances are in the ionised form in water and contribute to conductance. The conductance of the samples gives rapid and practical estimate of the variation in dissolved mineral content of the water supply.

$$G = \frac{1}{R} \quad \text{.................} \textbf{Equation 1}$$

G – Conductance (mho or Siemens) and R – Resistance

Procedure

Electrical Conductivity was determined with the aid of an in situ conductivity meter. The conductivity cell was rinsed with at least three portions of 0.01M KCl solution. The temperature of the fourth portion was adjusted to 25.0 ± 0.1°C. The conductivity cells and beaker were rinsed with a portion of the sample. The beaker was filled completely with the sample. The conductivity cell was inserted into the beaker filled with the sample and the conductance read. It was recorded after a stable reading.

Plate 3.2: Measurement of Conductivity

Source: Researcher (2017).

3.4.2.4 Determination of Total Hardness

Principle:

In alkaline conditions EDTA (Ethylene-diamine tetra acetic acid) and its sodium salts react with cations forming a soluble chelated complex when added to a solution. If a small amount of dye such as Eriochrome black-T is added to an aqueous solution containing calcium and magnesium ions at alkaline pH of 10.0 ± 0.1, it forms wine red colour. When EDTA is added as a titrant, all the calcium and magnesium ions in the solution get complexed resulting in a sharp colour change from wine red to blue, marking the end point of the titration. Hardness of water prevents lather formation with soap rendering the water unsuitable for bathing and washing. It forms scales in boilers, making it unsuitable for industrial usage. At higher pH>12.0, Mg^{++}ion precipitates with only Ca^{++}in solution. At this pH, murexide indicator forms a pink color with Ca^{++}ion. When EDTA is added Ca^{++}gets complexed resulting in a change from pink to purple indicating end point of the reaction.

Apparatus required: Lab glassware-burette, pipette, conical flask and beakers.

Reagents:

•**Buffer solution**: 16.9 g of ammonium chloride and 1.25g of magnesium salt of EDTA was dissolved in 143ml of concentrated ammonium hydroxide and diluted to 250ml with distilled water.

•**Eriochrome black-T indicator**: 0.5 g of Eriochrome black-T indicator was dissolved in 100g of triethanolamine.

•**Standard EDTA titrant:** 0.01M or Ng AR grade EDTA was dissolved in distilled water and diluted to 1000ml and was standardised against standard calcium solution.

•**Standard Calcium Solution:** 1.0g of AR grade $CaCO_3$ was weighed into a 250ml conical flask, to which 1+1 HCl was added till all $CaCO_3$ dissolved completely. 200ml of distilled water was added and boiled to expel carbon-di-oxide, and diluted to 1000ml.

Procedure

100 ml of sample was pipetted into a 250 ml conical flask and 1ml of a buffer solution added to it to produce a pH of 10. A pinch of Eriochrome Black T indicator was also added to it. It was then mixed constantly and titrated with a standard 0.01M Ethylene Diamine Tetra Acetic Acid (EDTA) until the last trace of purple colour disappeared and the colour turned bright blue. The volume of the standard was read and the measured value calculated using the mole concept. *Pusch et al, (1998) and Mumma et al, 2011.*

3.4.2.5 Determination of Alkalinity

Reagents

Methyl Orange indicator

Standard 0.1M HCL (aq)

Apparatus Burettes, pipette, conical flask, beakers and droppers

Procedure

50ml of the sample was measured into a conical flask. Two drops of methyl orange indicator was then added. The resulting mixture titrated against a standard 0.1M HCl (aq) to the first permanent pink colour change at a pH 4.5 to get the measured value.(SM 2320 .A APHA, 1998).

3.4.2.6 Determination of Turbidity

Apparatus required: Nephelometer (It detects scattered light at $90^{o}$to the incident beam of light. It consists of a light source for illuminating the sample. One or more photoelectric detectors with a display unit indicate the intensity of light scattered at $90^{o}$to the path of incident light.), sample cells, lab-glass wares and Monopan balance.

Principle: Nephelometric measurement is based on comparison of the intensity of scattered light of the sample with the intensity of light scattered by a standard reference suspension (Formazin polymer) under similar conditions.

Reagents:

•**Distilled water and Stock primary Formazin suspension:**

Solution 1: 1.0 g Hydrazine sulphate is dissolved in 100ml of distilled water.

Solution 2: 10.0g of Hexamethylenetetramine was dissolved in distilled water and made up to 100ml in a volumetric flask.

•**Stock Turbidity Suspension:** 5ml of solutions 1 and 2 were mixed in a volumetric flask and allowed to stand for 24 hrs at about 25^{o}C (±3^{o}C) and diluted to 1000ml with distilled water to give a 400 NTU suspension.

•**Standard Turbidity Suspension**: 10ml of the stock solution was diluted to 100ml with distilled water to give a standard solution of 40NTU.

Procedure

Nephelometric Method was used to determine Turbidity. It was measured in situ using the Model -2100A Turbidimeter. The 25 ml of the samples were gently agitated and waited for air bubbles to disappear and then poured the sample into the cell. The turbidity was directly read from the instrument display (SM2130 .B APHA, 1998) to get the measured value.

Turbidity (NTU) = (Nephelometer readings) (Dilution factor)

Figure 3.3: Turbidity measurement

Source: Researcher (2017)

3.4.2.7 Determination of Total Dissolved Solids (TDS) Concentration

Principle: The difference in the weight of total solids and the total suspended solids expressed in the same units gives the total dissolved solids.

Apparatus: Glass-fiber filter disks, membrane filter funnel, filtration apparatus, suction flask and pump, drying oven and Grooch crucible.

Procedure: The difference in the weights of Total Solids (W_1) and Total Suspended Solids (W_2) expressed in the same units gives Total Dissolved Solids (TDS).

Calculation:

$$\text{Total Dissolved Solids (mg/L} = \frac{(W1 - W2) \times 1000}{\text{Sample volume (ml)}}$$ ....**Equation 2**

W_1 = Weight of total solids + dish

W_2= Weight of total suspended solids

Procedure

The determination of total dissolved solids was done using the gravimetric method. The samples were stirred with a magnetic stirrer and a measured volume transferred into a 100 ml graduated cylinder by means of a funnel onto a glass fibre filter with applied vacuum. The samples were filtered through the glass fibre filter under vacuum pressure for three minutes to ensure that water was removed.

The solid residue that remained on the filter paper was washed with deionised water and suction continued for three minutes. The total filtrate (with washings) was transferred to a weighed evaporating dish and evaporated to dryness in a drying oven at 180 ± 2 °C for hour, cooled in a desiccator and then weighed afterwards. The cycle of drying and weighing was repeated until a constant weight was obtained as the measured value (SM 2540 A. APHA, 1998).

3.4.2.8 Determination of Nitrate (NO3-) Concentration

Procedure

The determination of nitrate (NO3-) concentration was done using the Hydrazine Reduction Method. 10.0 ml of the sample was pipetted into a test-tube. 1.0 ml of 1.3 M NaOH (aq) was added and mixed gently. Nitrate is reduced to nitrite by heating (37°C) an aliquot of sample with 1.0 ml of hydrazine sulphate in alkaline media and mixed gently; this reaction is catalyzed by the addition of cupric ion. The resulting nitrite, together with the original nitrites, was reacted with sulphanil amide to form a diazo compound. This compound was then reacted with N-(1-naphthyl) Ethylene diamine dihydrochloride to form an azo dye in acid media. The absorbance of the light red azo dye is measured at 520 nm and the concentration of nitrate nitrogen plus nitrite nitrogen was determined by comparison with a similarly treated series of mixed standards. Nitrate may be calculated by subtracting the nitrite result from the nitrite plus nitrate result (SM 4500-NO3, Part E APHA, 1998).

3.4.2.9 Determination of Sulphates

Principle: Sulphate ions are precipitated in acetic acid medium with barium chloride to form barium sulphate crystals of uniform size. The scattering of light by the precipitated suspension (barium sulphate) is measured by a Nephelometer and the concentration is recorded.

Apparatus required: Nephelometer, magnetic stirrer, Nessler's tubes and lab glassware.

Reagents:

Conditioning reagent: 50 ml of glycerol was mixed in a solution containing 30 ml of conc. hydro chloric acid, 300ml distilled water (10% HCl), 100 ml of 95% ethyl alcohol or isopropyl alcohol and 75g NaCl.

Barium Chloride

Standard sulphate solution: 147.9mg of AR grade sodium sulphate was dissolved in distilled water and made up to 1000ml, to give 1ml = 100mg sulphate.

Procedure

Sulphate ion was converted to a barium sulfate in an acidic medium with barium chloride suspension under controlled conditions. The absorbance of the $BaSO_4$ suspension is measured by a spectrophotometer at 420 nm and the sulphate concentration is determined by comparison of the reading with a standard curve. 100 ml sample was measured into a 250 ml Erlenmeyer flask and exactly 5ml conditioning reagent was added and mixed with the stirring apparatus. A spoonful of barium chloride ($BaCl_2$) crystals was added while still stirring and commenced timing immediately for 60 seconds while stirring continued at a constant speed. After the stirring period, the solution was poured into the absorbance cell and turbidity measured at 30 seconds intervals for 4 minutes. A calibration curve was prepared using standard sulfate solution. The result was read directly from the calibration curve and expressed in mg/L. Reliability of calibration curve by running a standard with every three or four samples (SM 4500-SO42–E. APHA, 1998).

Calculation:

$$\text{Sulphate(mg/l)} = \text{(Nephlometric reading) (0.4) (Dilution Factor)}$$ …………**Equation 3**

3.4.2.10 Determination of Fluoride (F-) Concentration

Principle: The colorimetric method of estimating fluoride is based on the reaction of fluorides (HF) with zirconium SPADNS solution and the 'lake' (colour of SPADNS reagent), which is greatly influenced by the acidity of the reaction mixture. Fluoride reacts with the dye ‘lake’, dissociating (bleaching) the dye into a colourless complex anion (ZrF_6^{2-}). As the amount of fluoride increases, the colour produced becomes progressively higher.

Apparatus required: Spectrophotometer and lab glassware.

Reagents:

Standard fluoride solution.

Stock: 221.0mg of AR grade sodium fluoride was dissolved in distilled water and made up to 1000ml to give 1ml = 100mg of F^-

Working Standard: 100ml of the stock fluoride was diluted to 1000ml to give 1ml = 10mg of flouride.

SPADNS Solution: 958mg of SPADNS is dissolved in 500ml of distilled water.

Zirconyl-acid reagent: 133mg Zirconyl chloride octahydrate ($ZrOCl_2.8H_2O$) was dissolved in about 25ml of distilled water. 350ml of conc. HCl was added and diluted to 500ml with distilled water.

Zirconyl acid-SPADNS reagent: Equal volume of SPADNS and zirconyl acid reagent was mixed.

Procedure

The determination of Flouride (F-) Concentration was done using the SPADNS Spectrophtometric Method. This method relies on the fact that when fluoride reacts with certain zirconium dyes, a colourless complex anion and a dye are formed. The complex, which is proportional to the fluoride concentration, tends to bleach the dye which therefore becomes progressively lighter as the fluoride concentration increases.

50ml of the sample was measured with a graduated beaker into a conical flask and 5ml SPADNS (sodium 2- (parasulphophenylazo) -1, 8-dihydroxy-3, 6-naphthalene disulphonate) was mixed with 5ml of zirconyl acid reagent and added to the sample. The absorbance was read at 570 nm. The calibration curves were used to determine the concentration of fluoride in the sample. The results were expressed in mg/l F-. The procedure was repeated using standard diluted samples (SM 4500_F –D – APHA, 1998).

Figure 3.4: Measurement of Fluoride

Source: Researcher (2017)

3.4.2.11 Determination of Chloride (Cl-) Concentration

Principle: In alkaline or neutral solution, potassium chromate indicates the endpoint of the silver nitrate titration of chlorides. Silver chloride is quantitatively precipitated before the red silver chromate is formed.

Apparatus required: Lab glassware.

Reagents:

Potassium chromate indicator solution: 50g of potassium chromate is dissolved in minimum amount of distilled water and silver nitrate is added drop wise till a red precipitate is formed. The mixture is allowed to stand for about 12 hours and diluted to 1000ml with distilled water.

Silver nitrate solution (0.014N): 2.395g of silver nitrate is dissolved in distilled water and made up to 1000ml.

Procedure

50 ml of sample was measured and diluted to 100 ml. One milliliter (1 ml) of K_2CrO_4 indicator solution was added and titrated with standard $AgNO_3$ titrant to a pinkish yellow end point. Samples were directly titrated in the pH range of 7 to 10. The pH of the samples that were not in the range of 7 to 10 was adjusted with H_2SO_4 or NaOH. Reagent blank value was established by titrating 50 ml of distilled water with 1 ml of K_2CrO_4 dropped in it, against standard $AgNO_3$ (SM 4500-Cl - to get the measures value.(APHA, 1998).

3.4.2.12 Determination of Calcium and Iron.

Principle: When EDTA (Ethylene-diamine tetra acetic acid) is added to the water containing calcium and magnesium, it combines first with calcium. Calcium can be determined directly with EDTA when pH is made sufficiently high such that the magnesium is largely precipitated as hydroxyl compound (by adding NaOH and iso-propyl alcohol). When murexide indicator is added to the solution containing calcium, all the calcium gets complexed by the EDTA at pH 12-13. The end point is indicated from a colour change from pink to purple.

Apparatus required: Burettes, pipette, conical flask, beakers and droppers.

Reagents:

•**Sodium hydroxide (8%):**8g of sodium hydroxide is dissolved in 100ml of distilled water.

•**Murexide indicator (ammonium purpurate):**0.2 g of murexide is ground well with 100g of sodium chloride thoroughly.

•**Standard EDTA titrant, 0.01M:** 3.723 g of EDTA (disodium salt) is dissolved in distilled water and made up to 100ml with the same.

Procedure

In the Laboratory, the sample aliquots were digested in nitric acid, diluted appropriately, and aspirated. A blank solution was similarly prepared. The ion analyses were performed on an Atomic Absorption Spectrophotometer (Buck Scientific Model 240 VGP), using acetylene gas as a fuel and air as oxidizer. Calibration curves were prepared separately for all the metals by running suitable concentrations of the standard solutions. The digested samples were aspirated into the fuel rich air-acetylene flame and the concentrations of the metal ions were determined from the calibration curves. Average values of three replicates were taken for each determination. The absorbance of the blank was taken before analysis of the samples (APHA, 1998).

Calculation:

$$\text{Calcium hardness as Ca}\left(\frac{mg}{L}\right) = \frac{T \text{ X } 400.5 \text{ X } 1.05}{\text{Sample taken,ml}}$$ ………………..**Equation 4**

Where, T= volume of titrant, ml

T X 1000 X 1.05

3.4 Data Analysis

The data obtained from the physico-chemical and microbiological parameters were displayed on tables and graphically using excel and compared to WHO (International standards) and KEBs 2007 (guideline values) to check if they fall within acceptable limits. This data was also used in Arc GIS 10.2.2 version to generate spatial variability maps.

3.5 Determination of Water Quality Index, WQI

For computing ground WQI three steps are followed. In the first step, each of the parameters was assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes are shown in Table 3.1.The parameters are pH, Total Hardness, Ca, Mg, HCO_3, Cl, TDS, F, NO_3, and SO_4.The maximum weight of 5 has been assigned to the parameter nitrate, due to its major importance in water quality assessment. Magnesium which is given the minimum weight of 2 as magnesium by itself may not be harmful.

In the second step, the relative weight (Wi) was computed using the following equation:

$$Wi = \frac{wi}{\sum_{i-1}^{n} wi}$$ .... **Equation 5**

Where, W*i* is the calculated relative weight, w*i* is the assigned weight of each parameter and 'n' is the number of parameters. Calculated relative weight (W*i*) values of each parameter are given in Table 3.2.

Table 3.2: Calculated relative weight (Wi)

Chemical Parameter	Standard Value	Assigned Weight(wi)	Relative weight(Wi)
Ph	6.5-8.5	4	0.1333
Calcium Hardness	500	3	0.1
Chloride	250	2	0.0667
TDS	600	4	0.1333
Fluoride	1.5	4	0.1333
Nitrate	50	5	0.1667
Sulphate	250	4	0.1333
	Total	30	0.8666

Source: Researcher (2017)

In the third step, a quality rating scale (q*i*) for each parameter is assigned by dividing its concentration in each water sample by its respective standard (Equation 6) according to the guidelines laid down by KEBS (2007) and the result multiplied by 100:

$$qi = (Ci / Si)\ x\ 100$$ ……………………**Equation 6**

Ci is the sub-index of *i*th parameter; q*i* is the rating based on concentration of *i*th parameter and 'n' is the number of parameters. The computed WQI values are classified into a range from "excellent water" to "water, unsuitable for drinking"

$$WQI = \sum qiWi$$ ……………………..**Equation 7**

WQI=Water Quality Index and is gotten by the summation of the product of qi and Wi which are stated in equation 6 and table 3.2 respectively.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1Water Quality of Selected Groundwater Parameters in Kahawa Wendani

This is a tabulated summary of the measured values of each parameter of the selected borehole samples in the study area. The explanation of each is given herein below in form of graphs. The quality of water varies with time in a water body due to various natural and human induced factors. The monitoring has to be done in a way that records all the changes in the quality. Variations in water quality are mainly due to changes in the concentrations of the components of the water flowing into the water body. These variations can be man-made or natural and can either be cyclic or random.

Table 4.1: Results of Water Quality Analysis

	PARAMETER	B. Number	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
		Depth (ft) / Unit	76	-	58	180	230	328	50	-	-	300
1	pH	Scale	7.54	6.98	6.96	6.76	7.1	7.25	7.34	6.85	7.5	7.41
2	True Color ,	^{0}H	5	5	5	5	5	5	5	5	5	5
3	Apparent color,	^{0}H	5	5	5	5	5	5	5	5	5	5
4	Turbidilty,	N.T.U	0.7	0.5	0.8	0.6	0.5	1	2.7	1.9	3.5	0.6
5	Conductivity	µ/S/CM,mg/l	736	532	518	490	505	562	660	541	362	758
6	Calcium Hardness $CaCO_3$	mg/l,	86	88	78	70	56	82	100	76	48	58
7	Total Hardness,	$CaCO_3$mg/l	124	122	134	110	82	134	144	126	110	104
8	Total Alkalinity,$CaCO_3$	mg/l	330	343	345	334	270	370	170	336	124	516
9	Carbonate Alkalinity, $CaCO_3$	mg/l	0	0	0	0	0	0	0	0	0	0
10	Iron,	mg/l	0.1	0.1	0.1	0.2	0.3	0.3	0.2	0.3	0.2	0.2
11	Fluorides,	mg/l	1.92	1.45	1.47	1.54	1.84	1.18	1.6	1.19	1.4	1.43
12	Sulphates,	mg/l	10	2	0	0	2	0	0	5	5	10
13	Dissolved Oxygen,	p.p.m	5.8	5.3	6	6.4	6.1	5.6	5.6	5.7	5.5	5.6
14	Nitrates,	mg/l	8	2	1	1	1	2	6	1	6	0.5
15	Chlorides,	mg/l	186	64	48	40	74	56	42	68	103	290
16	Dissolved Solids,	mg/l	610	490	370	430	320	320	620	530	380	600
17	Total Solids,	mg/l	610	490	370	430	320	320	620	530	380	600
18	Coliform Plate	CFU/1ml	15	5	10	10	15	20	15	10	10	0
19	Total coliform	Per/100ml	5	0	0	0	3	10	5	0	5	0

Source: Researcher (2017).

4.2 Water Quality

In an overview, the sampled groundwater indicated a constant color that was normal at 5^0H for both apparent and true color. Carbonate alkalinity was also constant at 0 mg/l but the rest of the selected parameters varied from one sample to the other as elaborated systematically by graphs in this section.

Groundwater quality, conferring to Thomas (2003), includes the physical, chemical, and biotic attributes of ground water. Physical water quality parameters include Temperature, turbidity, color, taste, and odor. Generally, ground water is colorless, odorless, and deprived of precise taste, this study is most apprehensive with its chemical and biological merits. Spring water or groundwater yields are often sold as "pure," although their water quality is different from that of unpolluted water.

Logically, ground water comprises mineral ions. These ions gently dissolve from soil elements, deposits and rocks as the water moves along inorganic surfaces in the openings or cracks of the unsaturated region. They are called *dissolved solids.* Some dissolved solids may have come from the precipitation water or river water that refreshes the aquifer (Thomas, 2003).

Excluding natural organic material coming from top soils, all of these naturally arising dissolved solids are *inorganic* components. Mainly, trace elements present in such low quantities that they are not a danger to human health. In detail many of the trace components are regarded vital for the human metabolism.

High levels of trace metals can also be got in ground water near polluted origins which indicating serious health dangers. In this study none of the sources was found near a contaminated area. Some trace elements that are connected with industrial pollution, such as arsenic and chromium, may also be present in entirely virgin ground water at quantities that are extra ordinary rendering that water improper as drinking water (Thomas, 2003).

Microbial substances are also a natural component of ground water. Just as microbes are universal in the environment about us, they occur everywhere in the subsurface, comprising ground water. In this study the data exposed that there are no pathogenic microbes in the water samples. Thus the plate counts could be a suggestion of the naturally present microbes. "Hydrogeologists oftenly depend on these, for example for subsurface bioremediation of polluted ground water *(UC ANR Publication 8084, 2003)".*

Endeavors of men can change the natural structure of ground water by the dumping or spreading of chemicals and microbial substance at the land surface and into soils *(UC ANR Publication 8084, 2003).* In the area of study, the main land use activity is sprawl and very minimal animal and crop farming meaning they do not have a significant influence on the quality of groundwater in the study area.

4.2.1 pH

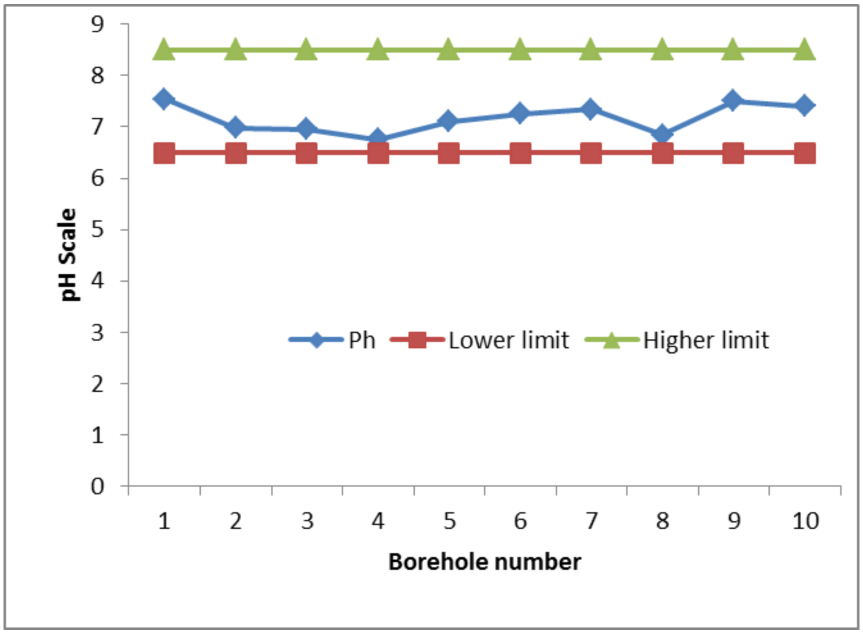

Figure 4.1: Measured pH values

Source: Researcher (2017).

The pH values for all the ten boreholes were found to fall within the required limits of between 6.5 -8.5. B1 had the highest value of 7.54 and B4 had the lowest value of 6.76.

The ability of the water to attack rock constituents is greatly influenced by acidity. Acidity also affects conduit fixtures, transport channels and infiltrate deadly trace metals into the water thus triggering visual difficulties like acid taste, fabric discoloration or blue-green blemishes in sinks and water system (WHO, 1993; USEPA, 2007). Finally, this renders it highly dangerous for mortal intake (Amfo-Otu *et al*., 2012). Acidic water, on the contrast, can be acclimatized with lime to produce water that has improved pH (McGuire, 2007). The acidity could be as a result of the existence of dissolved CO_2 and carbon-based acids in the soil region. Additional ordinary biogeochemical activities (Hounslow, 1995; Langmuir, 1997; Yankey *et al*., 2011) which are resultant from the rotting and cause percolation of vegetable constituents (Langmuir, 1997) also increase acidity. The sampled groundwater is contained in the essential standard limits and hence suitable for drinking. Nonetheless, assessment should be carried out at diverse seasons like during the rainy season to see if the quality is affected by rain. This study was conducted in a dry season. This could be an implication that during the dry season the pH of groundwater is within the required limits/the quality is good for drinking but could change during the rainy seasons.

4.2.2 Total Dissolved Solids

Boreholes 7 and 1 had the highest value of TDS of 610mg/l, followed closely by borehole 10 at 600mg/l. The least was boreholes 5&6 at 320mg/l. When groundwater has total dissolved solid levels lower than 500 milligrams per litre, it is regarded as suitable for consumption (WHO, 1984). Conferring to WHO (2004), the tastiness of water with total dissolved solid value less than 600 milligrams per litre is normally regarded to be suitable and turn out to be suggestively and gradually unpleasant at levels beyond a thousand milligrams per litre. The occurrence of high values of TDS in certain samples could similarly be hostile to users and can lead to extreme scaling in water conduits, heaters, boilers and domestic machines. Scaling in heaters and domestic machines is proof in the study area. In this study the TDS in 8 samples were way below the standard value of 600mg/l and 3 samples were at the standard value. This implies that the groundwater quality in terms of TDS is still within the required limits for drinking purposes in the study area.

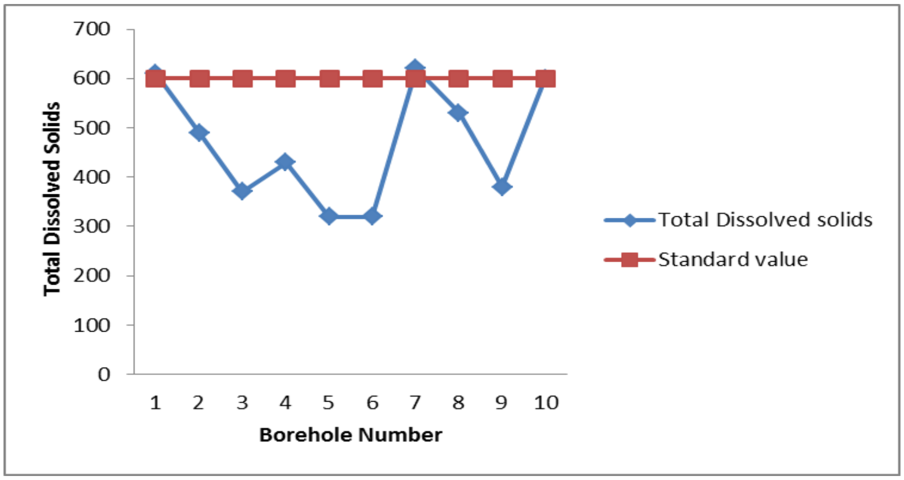

Figure 4.2: Measured TDS values

Source: Researcher (2017).

4.2.3 Turbidity.

Borehole 7 had the highest turbidity of 2.7 N.T.U and boreholes 2 &5 were least turbid with a value of 0.5 N.T.U. The standard value is 5 N.T.U, meaning that all the samples fell below the standard value of 5 N.T.U. The occurrence of suspended soil, sediment, carbon-based substance, inorganic material and other invisible living things enhance turbidity (DWAF, 1996). "The level of turbidity shows just a suggestion of the degree of pollution (Momba *et al.*, 2006)". Turbidity levels that are increased, when there are no fecal signifying bacteria suggests low defense from pollution. This could similarly mean that hygienic level is reduced (Momba *et al.*, 2006) and encourage the existence of microorganisms (DWAF, 1996). Since the samples were collected during the dry season, the turbidity is low. There was no siltation of soil and clay. In addition the sampled boreholes were all well-constructed with proper lining and cover, thus low chances of siltation and surface runoff mixing. Thus the sanitary integrity of the groundwater sampled is not compromised and there is high protection from contamination.

Compounds and disease causing organisms get adsorption positions on colloidal matter that may be dangerous to wellbeing or lead to unwanted taste or smell in drinking water (WHO, 1998). Disease causing entities stick on the small colloidal elements, if the water shifts beyond the 5 NTU standard value set by both NEMA (2006) and WHO (2004). This makes turbidity in water very important. This entails that the water should be safeguarded prior to consumption. The reduced turbidity similarly backs the reduced bacteriological adulteration and typical color in the illustrations, indicating suitable water quality for intake.

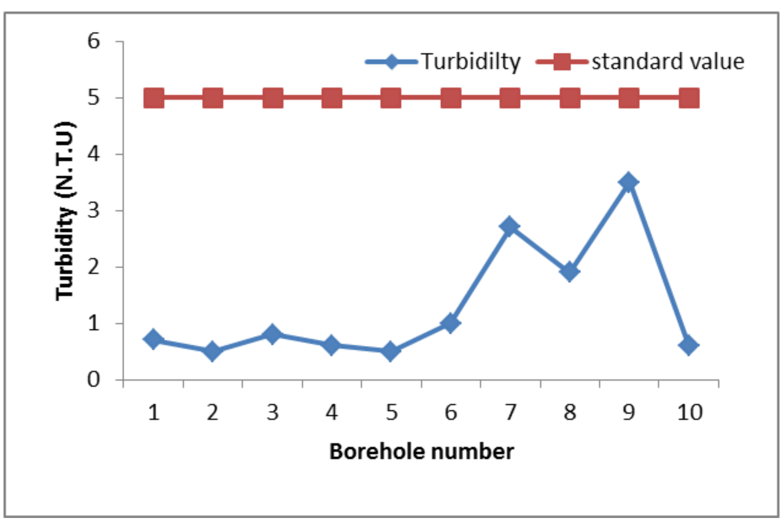

Figure 4.3: Measured Turbidity values

Source: Researcher (2017)

4.2.4 Total hardness

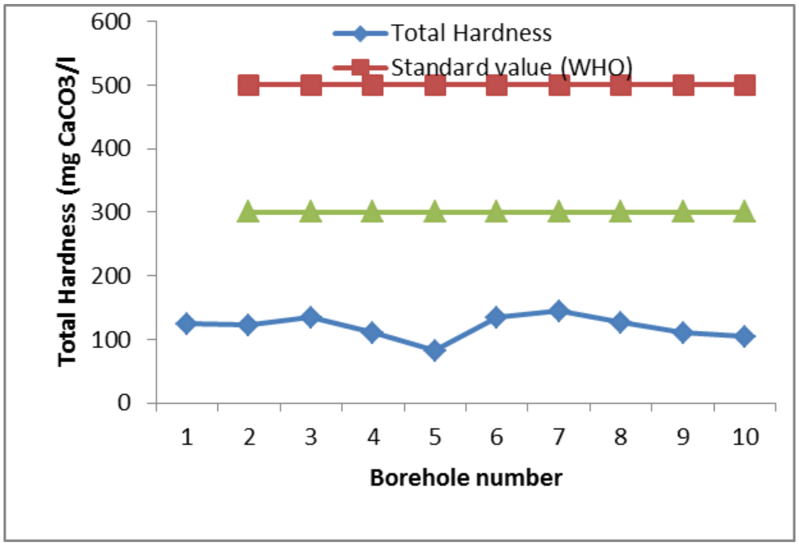

Figure 4.4: Total Hardness

Source: Researcher (2017)

The highest Total Hardness value was in borehole 7 at 144mg/l, the least was 82mg/l in borehole 5 and this was below the WHO (2004) guideline value of 500 mg/l. Referring to WHO (2004), the level of hardness of drinking water is grouped with regard to its calcium carbonate concentration are as follows: "Soft, 0 to 50 mg/L; Moderately Soft, 50 to 100 mg/L; Slightly Hard, 100 to 150 mg/L; and Moderately Hard, 150 to 200 mg/L, Hard, 200 to 300 mg/L and Very Hard above 300 mg/L". In this study and agreeing with this rating, the samples fall in the category of slightly hard water. This is because most of them were at around 100mg/l except for borehole 5 which falls in moderately soft category.

Positively charged ions with a valency of 2 such as Ca^{2+}, Mg^{2+}, and alkaline earth metal such as iron, manganese and strontium are the chief cause of hardness. The total of Ca^{2+} and Mg^{2+} concentrations both shown as $CaCO_3$ in milligrams per litre, describe total hardness. Short-term hardness is initiated by carbonates and bicarbonates of Ca^{2+} and Mg^{2+}. Permanent hardness is influenced by Sulphates and chlorides. From the findings, the implication is that the divalent cations and earth metals are present but not in very high concentrations. It also indicates low levels of sulphates and chlorides. Hence the quality of the groundwater in terms of total hardness is good for drinking purposes.

4.2.5 Calcium Hardness

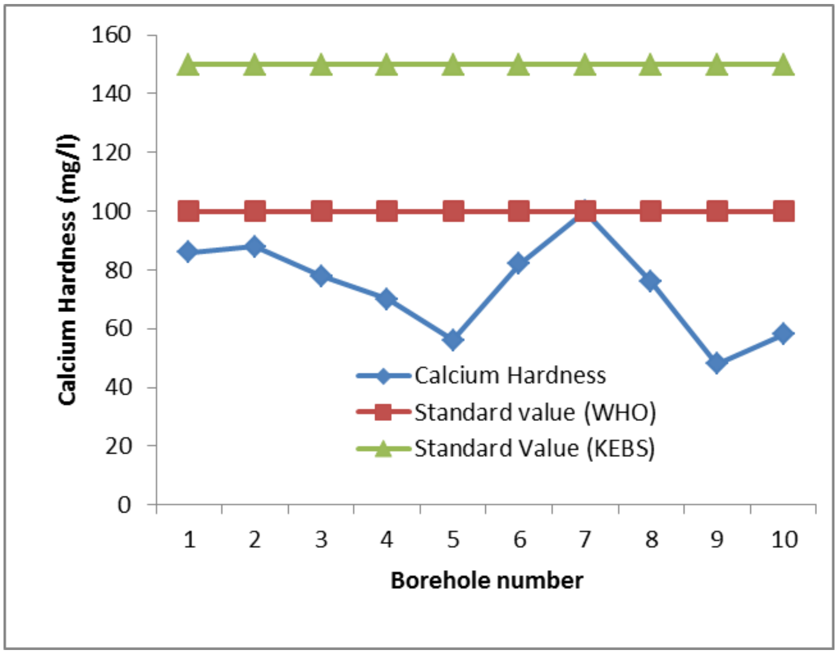

Figure 4.5: Calcium hardness

Source: Researcher (2017)

The levels of Calcium Hardness fell below the acceptable standards of 100 mgl except for borehole 7 which was at 100 mg/l, the least was at 45 mgl, borehole 10.

Calcium which is the 5th chief plentiful parameter in aquatic systems comes when water flow in or above residues of granite, dolomite, gypsum and any Ca yielding geology. The objective of this research was restricted to water quality and there is no evidence if the groundwater in this region passes over/through deposits of limestone, dolomite, gypsum and other iron yielding rocks. The total hardness of water is increased by Ca and is a vital micro-nutrient in water. This Ca is particularly required in great amounts by molluscs and animals with the vertebral column. It is assessed by Ethylene Diamine Tetra Acetic acid titrimetric procedure. Little levels of $CaCO_3$ inhibit decomposition of metal pipes by setting down a defensive coating. However, amplified amounts of calcium precipitate on heating to make detrimental patches in vessels, conduits and kitchenware. In the study area, the precipitates on heating are evident in as much as the levels fall below the acceptable limits. Cooking pans remain with a whitish stain after boiling the groundwater water, though it is not a major problem. The groundwater quality considering calcium hardness, is good for drinking in this study area.

4.2.6 Chloride

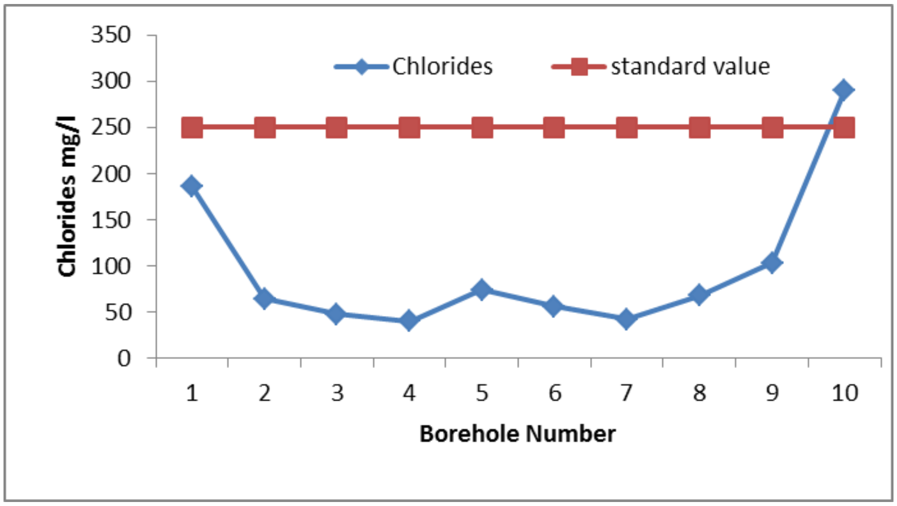

Figure 4.6: Chloride measured values

Source: Researcher (2017)

Borehole 10 recorded the highest measured Chloride reading of 290 mg/l which is above the standard value of 250mg/l. Borehole 4 had a small value of 40mg/l and the other samples fell below the standard value as demonstrated in the linear graph (figure 4.6). Chloride is a broadly spread component in all kinds of rocks in different states. Its attraction to Na is high. Consequently, its level is increased in ground waters, where the heat level is raised and rainfall is low. Soil permeability and absorbency also plays a major part in constructing the chlorides concentration (Ramakrishnaiah, 2008). Microscopic contamination is reflected by increased levels of Chlorides as a result of carbon-based waste of animal and human origin (Kumar, 2010). Fertilizer and vegetable nutrient use usually leads to chloride pollution of renewing shallow groundwater (Bohlke, 2002). In this study area, the high concentration of chloride can only be attributed to human pollution because there are no farming projects or stocks of animal that could enhance this. This also means that the soil absorbency and perviousness of the samples that had low concentrations does not permit the making up of chloride in the groundwater. Therefore the quality of the groundwater is good for drinking.

4.2.7 Fluoride

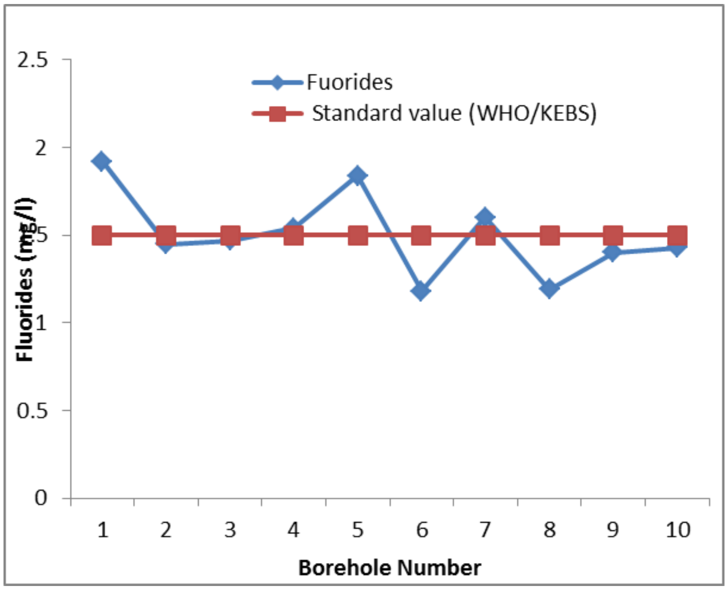

Figure 4.7: Measured Fluoride values

Source: Researcher (2017).

When Fluoride occurs in low levels of 0.8 to 1.0 mg/L it is of essence for fortifying of tooth surface. Yet, if taken in persistent amounts of fluoride over 1.2 mg/l leads to tooth fluorosis (Rao, 2006). Circumstances of thrilling skeletal flourosis (Dissanayake, 1991) have also been connected with cancer as a result of excessive fluoride intake (Edmunds and Smedly, 1996). Seven of the samples analysed indicated a high level of fluoride, the highest being borehole 1, at 1.92mg/l and the least was borehole 6 at 1.18mg/l. This definitely implies that there is a danger of dental fluorosis that may befall over time, especially to the young children who consume this water over time, if the current fluoride levels are not adjusted. The groundwater quality in terms of fluorides is not suitable for drinking. Measures should be put in place to mitigate these high levels.

4.2.8 Iron

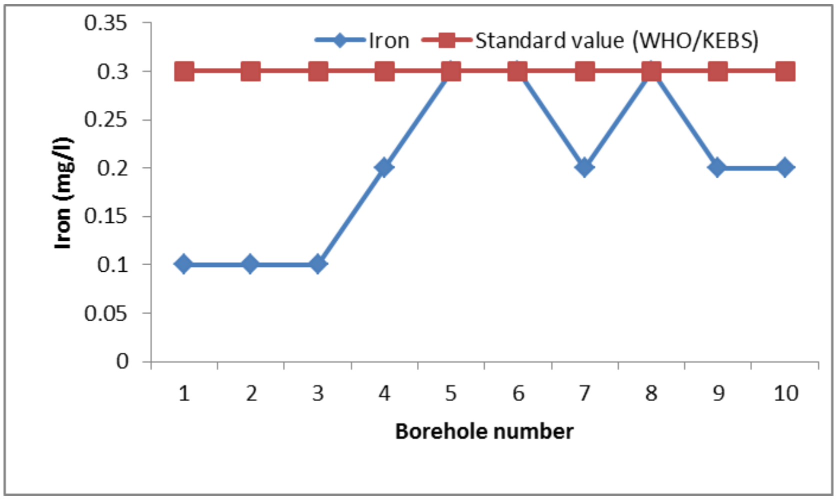

Figure 4.8: Measured Iron values

Source: Researcher (2017).

Three of the samples analyzed were at the maximum value of 0.3mg/l that is boreholes 5, 6 &8, followed by boreholes 4, 7, 9 &10 at 0.2mg/l and the others 1, 2 & 3 were at 0.1mg/l.

The basic origin of the Fe in groundwater in this study is geological. The increased iron intensities in these waters in this case are related to natural origin like the chemical processes in rocks and biological systems (Tay and Kortatsi, 2008). The suspension of Fe oxides in their aquifers also increase iron levels (Singhal and Gupta, 1999). In iron-producing rock formations, it is in great quantities. These minerals include goethite, haematite, and limonite.

When subjected to extra reducing environments, the levels of Iron in groundwater increase. This is because microbiological decomposition of biological substance which creates numerous humic and fluvic complexes (Applin and Zhao (1989).This increased degree of metallic iron could be accountable for the experiential turbid and brownish colour of the water when unruffled. This is caused by the oxidation of Fe 2+ to Fe 3+ which leads to trouble to fabric and sanitary facilities (Aiyesanmi *et al.*, 2004).

In as much as high iron concentrations may not create wellbeing danger to abstractors, the presence of the yellowish-brown colour can make that water to be refused by the public (Asante and Ansa A., 2001).

4.2.9 Total Alkalinity

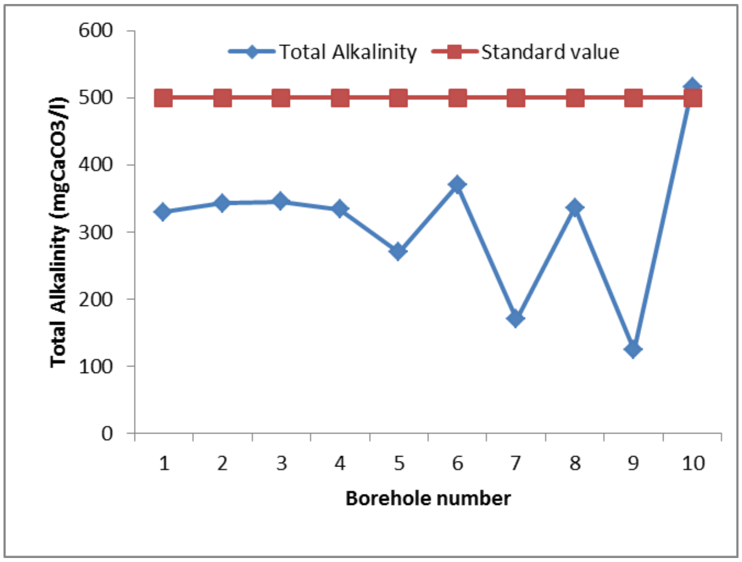

Figure 4.9:Total alkalinity

Source: Researcher (2017).

Nine of the samples analysed fell below the standard value by far except for sample 10 which had a Total Alkalinity value,516mg/l that is slightly above the standard value, 500 mgl. Borehole seven had the least value of 170mg/l.

Alkalinity in the water may be as a result of hydroxides, carbonates and bicarbonates.

Hydrogeochemical facies of groundwater

"Hydrochemical perceptions are important to clarify mechanisms of flow and transference in groundwater systems". "This reveals a collection of paleo environmental information" (Hem, 1992;Glynn & Plummer, 2005). The link between pH, alkalinity and water steadiness standard has been shown through Figure 4.11.The main aim of piper plots is to give water type of a region.

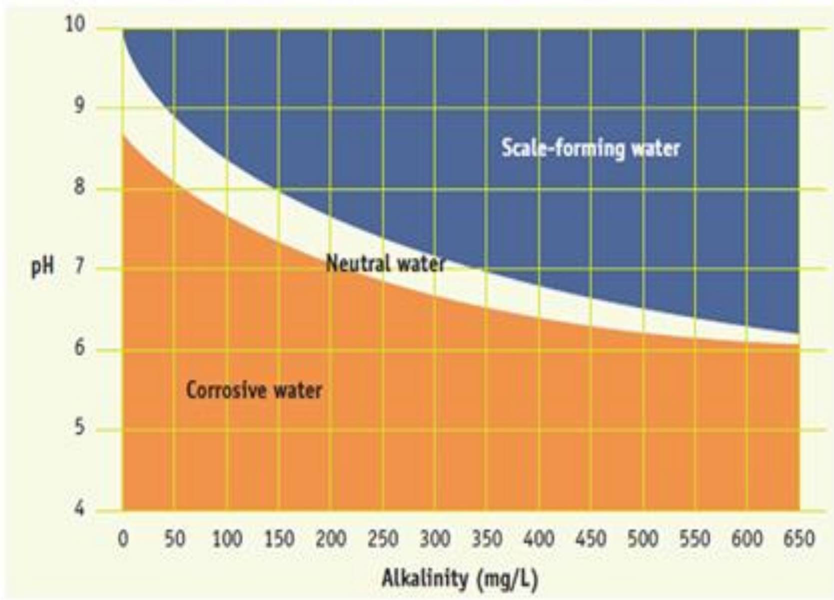

Figure 4.10: Water type

Source: Singh & Hussian, *Cogent Engineering* (2016), 3

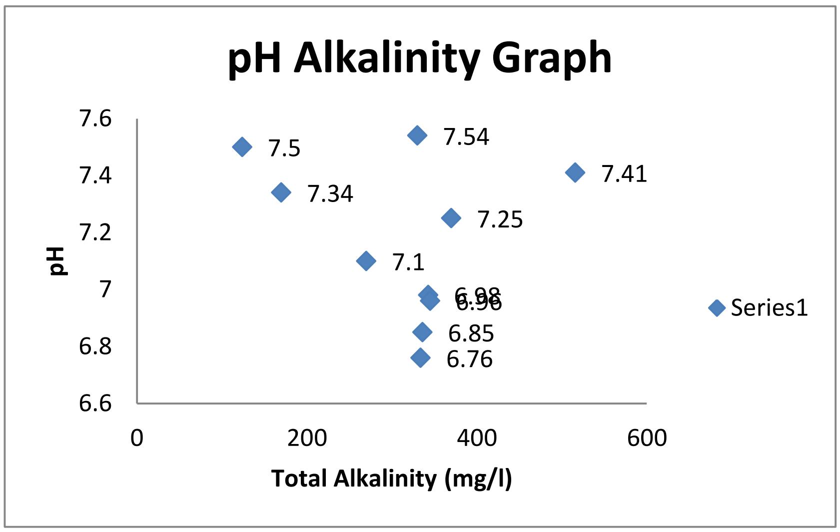

Figure 4.11: pH /Alkalinity graph

Source: Researcher (2017).

From the above graph by Singh & Hussian, it is shown clearly that pH and alkalinity are inversely proportional with the value of 350 mg/l and pH 7 falling at the centre. Meaning, for the water to be neutral, as alkalinity exceeds 350mg/l the pH value goes lower than 7 and when the pH value exceeds 7, the alkalinity should be lower than 350mg/l. Other values beyond this imply the water to be either corrosive or scale forming. Using this concept, the following classification has been developed to indicate the water type of the sampled boreholes.

Table 4.2: Water Types

Borehole No.	**Total Alkalinity**	**pH Value**	**Water Type**
1	**330**	**7.54**	**Scale forming**
2	**343**	**6.98**	**Neutral but almost scale forming**
3	**345**	**6.96**	**Neutral but almost scale forming**
4	**334**	**6.76**	**Neutral**
5	**270**	**7.1**	**Neutral**
6	**370**	**7.25**	**Scale forming**
7	**170**	**7.34**	**Neutral**
8	**336**	**6.85**	**Neutral**
9	**124**	**7.5**	**Neutral**
10	**516**	**7.41**	**Scale forming**

Source: Researcher 2017

4.2.10 Nitrates

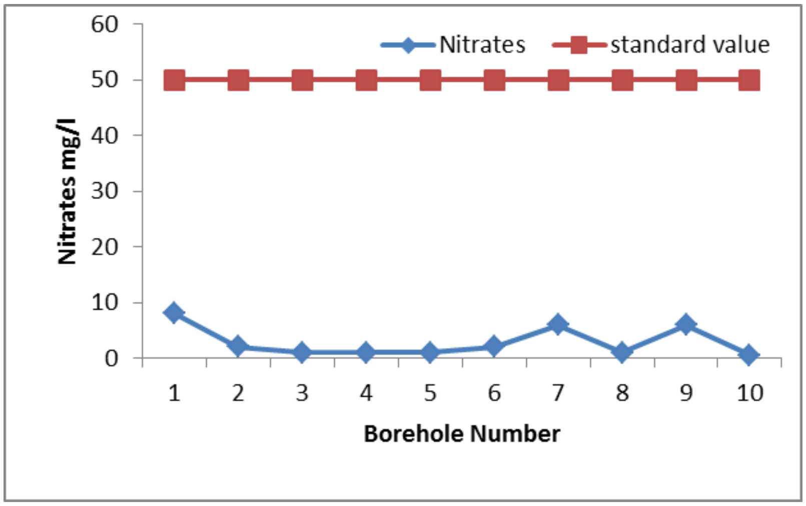

Figure 4.12: Measured Nitrate values

Source: Researcher (2017).

Nitrate measured values ranged from 8 mg/l as the maximum value in sample 1,follwed by 6mgl in samples 7 and 9. The other samples were at 2mg/l and 1mg/l, the least being sample 10 at 0.5mg/l.

According to "Singh & Hussian, (2016)". Nitrate (NO_3) is naturally occuring and is a crucial nutrient to vegetation. Leakages from normal plants may as well cause selected ground waters to have nitrate adulteration.

Nitrate becomes a wellbeing risk in potable water when it occurs in great amounts. By microbial activity, nitrate mixes with other chemicals like amines, amides, or other nitrogenous mixtures and become possible causes cancer. The extreme admissible nitrate level according to WHO for consumtion water is 45 milligrams per litre as Nitrate.

4.2.11 Conductivity

The Electrical Conductivity is way far below the standard value. The extent of water's ability to transfer electrical flow is called electrical conductivity. This capability is openly linked to the quantity of cations and anions in the water. These ions that transmit electricity originate from dissolved salts and inorganic matter such as alkalis, chlorides, sulfides and carbonate complexes. Electrolytes are those complexes that disintegrate into cations and anions. The further cations and anions available, the greater the conductivity of water. Purified water can be used as an insulator as it has a very reduced conductivity.

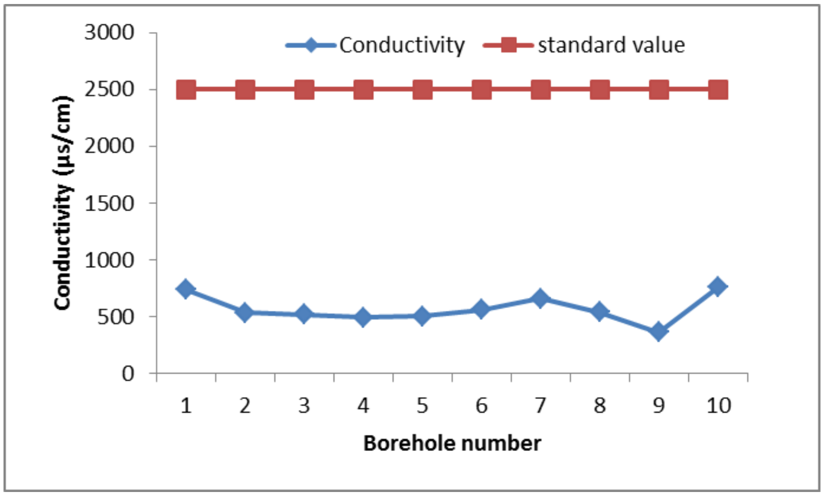

Figure 4.13: Conductivity

Source: Researcher (2017).

Sea water, on the contrary, is extremely conductive because it has many electrolytes.

This means that the salts that dissolve in water are at very minimal levels in these samples.

Conductivity, is one of the very beneficial and frequently assessed water quality parameters. Besides being the cause of major salinity and total dissolved solids calculations, conductivity is an primary pointer of variation in the aquatic structure. Most aquatic systems retain a impartially stable conductivity that may be applied as a foundation to compare to prospect measurements. Weighty variation, if caused by to usual flooding, evaporation or artificial contamination may be precisely injurious to water quality.

4.2.12: Sulphates

Boreholes 1 &10 had the highest value of 10 mg/l, while boreholes 8 & 9 had 5 mg/l and boreholes 2 & 5 had 2mg/l. The rest of the samples had 0mg/l. The most common form of sulphur in well aerated water is sulphate. Potable water can have evident flavor and escalated degrees of Sulphate which might produce a purging outcome to users. Taste benchmarks have been established to vary from 250 mg/l for sodium sulphate to 1,000 mg/L for calcium sulphate.

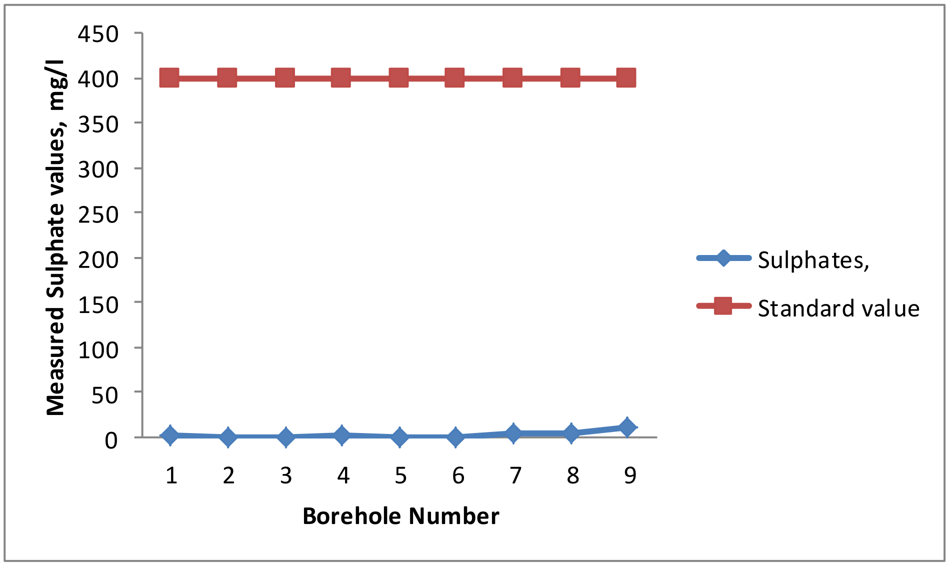

Figure 4.14: Measured Sulphate values

Source: Researcher (2017).

4.2.13: Dissolved Oxygen

All the samples fell within the required standard of >4 p.p.m. Dissolved oxygen (DO) levels in water are affected by numerous features such as water heat levels, salt content and atmospheric pressure. This implies that the salinity, temperature and atmospheric pressure of the groundwater is within the limits and the quality of the water is good for drinking purposes.

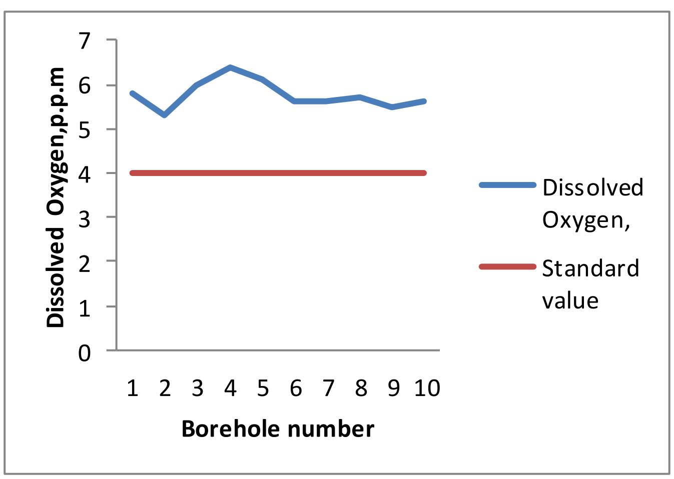

Figure 4.15: Measured dissolved oxygen values

Source: Researcher (2017).

4.2.14 Biological test

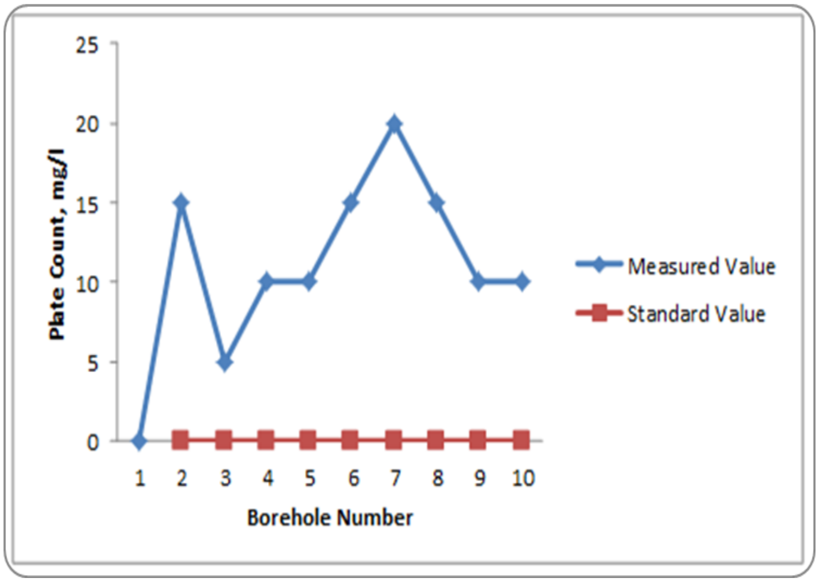

Figure 4.17: Coliform Plate Count

Source: Researcher (2017).

Borehole number 6 had the highest coliform count of 20 CFU/ml followed by borehole numbers 1, 5, & 7 at 15 CFU/ml. Borehole numbers 3, 4, 8 & 9 had 10 CFU/ml and borehole number 10 had a count of 0 CFU/ml. However, the test for E. Coli was negative for all the boreholes. This implies that the boreholes are free from fecal contamination given the fact that they were well constructed with proper cement lining and deeper than 100 meters hence the chances of fecal contamination are very minimal.

The assessment of drinking water sources for coliform microorganisms is crucial in establishing the quality of potable water as escalated amounts of coliform counts imply a polluted supply, insufficient treatment, or shortcomings after treatment (Mathew *et al.*, 1984). The colony forming unit (CFU) is a variable that shows the occurrence of coliform microbial contamination in the water. The occurrence of coliform similarly implies the likelihood of existence of extra disease causing entities and also implies the prospect of pollution of the water supply by sewage (Hosetti and Kumar, 2002).

The WHO (2004), NEMA (2006) and USEPA (2012) necessitates that no fecal coliform ought to be identified in a hundred millitres of any potable water sources. Discharges from entry points like septic tanks are frequently known as the key causes of adulteration of groundwater (Woods, 1990). In Pennsylvania and Maryland, USA is polluted by sewage dumping norms such as pit latrine, septic tank and soakage pit system as stated by Blueford *et al*., (1996).

The chief vital attribute of suitable water from the wellbeing perspective is evidently nonexistence of disease causing living entities (Richard *et al.*, 1977).

4.3 Spatial distribution of the boreholes

Table 4.3: Coordinates and Names of Sampled Boreholes

NO.	AREA SAMPLED	X	Y	Depth(ft)
1.	Near Kimbo PCEA church	02707035	9867117	76
2.	Coca Cola	0270725	9867091	-
3.	Opposite PCEA church	0271209	9867272	58
4.	Next to Dexta School	0270393	9866846	180
5.	Githurai Mixed School	0270253	9867148	230
6.	Nakumatt	0269581	9868234	328
7.	Apostolic Church	0270334	9867524	50
8.	Chinese Estate	0269193	9867814	-
9.	At booster stage	0270577	9867310	-
10.	Student hostel, Matopeni	0269617	9868193	300

Source: Researcher (2017).

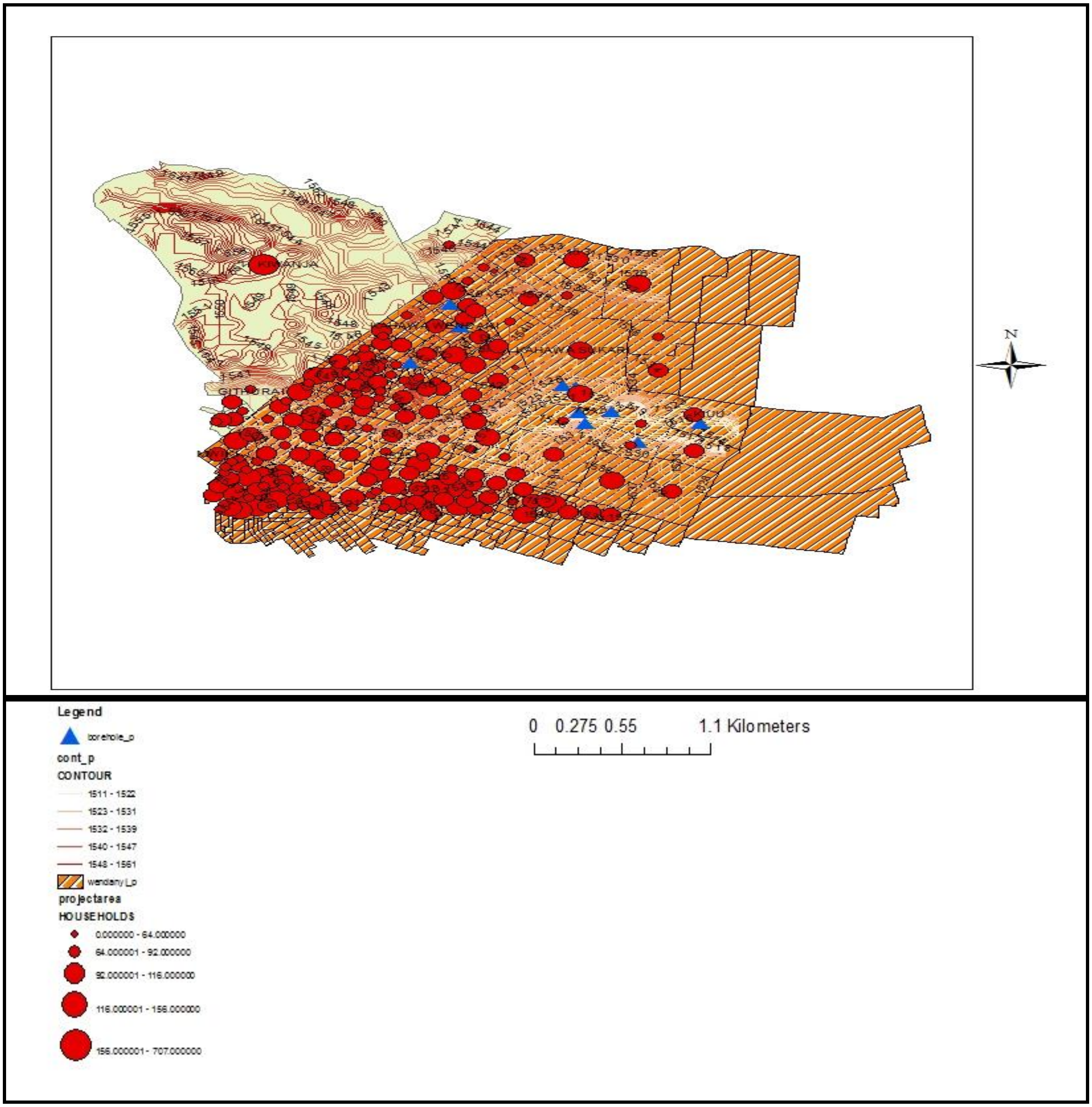

Figure4.17: Spatial distribution of Samples

Source: Researcher (2017).

4.4) Water Quality Index

Table 4.4 Relative Weight Values

Chemical Parameter	Standard Value	Weight(wi)	Relative weight(Wi)
pH	6.5-8.5	4	0.1333
Calcium Hardness	500	3	0.1
Chloride	250	2	0.0667
TDS	600	4	0.1333
Fluoride	1.5	4	0.1333
Nitrate	50	5	0.1667
Sulphate	250	4	0.1333
	Total	30	0.8666

Source: Researcher (2017).

Table 4.5: Calculated W.Q.I values for each parameter

Chemical Parameter	Standard Value	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	Totals	$\sum qiWi$
pH	6.5-8.5	88.7	82.12	81.89	79.53	83.53	85.29	86.35	80.59	88.24	87.17	843.41	112.42
Calcium Hardness	500	86	88	78	70	56	82	100	76	48	58	742	74.2
Chloride	250	74.4	25.6	19.2	16	29.6	22.4	16.8	27.2	41.2	116	388.4	26.02
TDS	600	101	81.67	61.67	71.67	53.33	53.33	103	88.33	63.33	100	777.33	103.61
Fluoride	1.5	128	96.67	98	103	123	78.67	106.67	79.33	93.33	95.33	1002	133.56
Nitrate	50	16	4	2	2	2	4	12	2	12	1	57	9.5
Sulphate	250	4	0.8	0	0	0.8	0	0	2	2	4	13.6	1.81

Source: Researcher (2017).

From this calculation of the WQI values, Fluoride has the highest value of 133.56, followed by pH at 112.42, then TDS at 103.61. The least and excellent parameter values are for sulphate followed by nitrate and chloride. Calcium hardness is fairly good at 74.2 as elaborate by table 4.5. These values are actually concurring with the water quality analysis as well as that fluoride is high above the standard value of 1.5 for drinking water.

Table 4.6: WQI Rating

WQI Value	Water Quality	pH	Calcuim Hardness	Chloride	TDS	flourides	Nitrates	Sulphates
<50	Excellent			√			√	√
50-100	Good		√					
100-200	Poor	√			√	√		
200-300	Very Poor							
>300	Unsuitable							

Source: Researcher (2017).

From this rating, it can be deduced that 42.86% of the WQI parameters indicate unsuitability of the groundwater for drinking, 14.29% good and another 42.86% excellent.

Spatial Distribution of the Boreholes.

From the spatial distribution maps, it’s evident that the abstraction points are clustered towards Booster area and Matopeni. Groundwater is mostly used in areas occupied by private owners but the area where there are rental houses hardly have boreholes. This implies that more groundwater is abstracted where boreholes have been drilled. This is baseline data that should be enhanced in future to provide a database for monitoring purposes.

CHAPTER 5: SUMMARY OF FINDINGS AND RECOMMENDATIONS

5.0 Introduction

Based on the objectives of this study the following conclusions have been made.

5.1 Summary of findings

Water Quality Analysis

From the results and as a comparison of measured values against the WHO (2004) and KEBS (2007) standard values, it is evident that the quality of groundwater in Kahawa Wendani is high in Iron and Fluorides in all the samples. Fluoride had the highest value of 1.92 mg/l in borehole number 1, 1.84 mg/l in borehole number 5 and the least value of 1.18 mg/l in borehole number 6 compared to the standard value of 1.5 mg/l. Iron recorded values at the standard value of 0.3 mg/l in borehole numbers 5, 6 and 8 while the least value was 0.1mg/l in borehole numbers 1, 2, 3 and 7.

Another major finding was that of alkalinity which indicated that most of the samples had neutral water but borehole numbers 1, 6 and 10 had scale forming water. No corrosive water was found from the samples.

The soil structure of the area is made of black cotton soil as the top soil and the underlying layer is made up of rocks. These two parameters are affiliated to the geological formation of the area, resulting from natural breakdown and weathering of rocks and soil. This is evident as well stated by the Ruiru Local Physical Development Plan (2009) that the geology of study area comprises of tertiary volcanic rocks, the most important being Nairobi stone. The Nairobi stone is a tertiary volcanic rock which is used mainly for construction. Its appearance is underlain dark ashes and tuffs and is underlain by aggrometric tuffs, some of them welded. The soils in this area originate from volcanic rocks that gradually occur on levels between 1200m to 2000m above the sea level. Chemical groundwater composition of groundwater is the result of climate-soil processes and lithological influences as explained by Kehew (1988) and Emilio, (2011-2014).

In terms of water type, boreholes 10, 6 &1 have scale forming water that need treatment. The rest of the samples are neutral and hence suitable for human consumption.

Water Quality Index

The groundwater in Kahawa Wendani is excellent for domestic drinking purpose based on the water quality index, in terms of chlorides, nitrates, calcium hardness and Sulphates, which are very lower than 100. Their WQI values were recorded as 1.81 for Sulphate followed by nitrate at 9.5, Chloride at 26.02 and Calcium hardness at 74.2 (fairly good). However, Fluoride had the highest WQI value of 133.56 and should be managed before it exceeds the threshold by the relevant authorities to avoid risk to health of the users. Defluoridation can be done using Fe 3+ modified bentine clay or using brick powder as an adsorbent. Other notable parameter followed by pH at 112.42, then TDS at 103.61.Microbial contamination in terms of E. Coli was absent though there were some coliforms recorded. This is because not all coliform are fecal, there are two types of coliform, fecal and non-fecal coliforms. Non fecal coliforms are not harmful but occur naturally in water. Follow up projects should be carried out to monitor the quality variability at different seasons and depths. The samples were collected from specifically drilled deep wells/boreholes.

Distribution of the boreholes

Spatially, the boreholes are clustered together in particular areas (Matopeni and Booster) of the study region and not evenly distributed. They are mainly in areas where piped water supply is scarce. Thus it is evident that more groundwater is abstracted for domestic use and not for other uses in these areas.

5.3 Recommendations

The following recommendations have been suggested to stakeholders such as.

Water Management Authority

Do groundwater quality analysis regularly to have a record on the trend in groundwater quality and especially on iron and fluoride for this particular study area. This will build up the data base on groundwater and provide room for informed decisions as far as groundwater management supply is concern.

Abstractors

Abstractors should comply with the set rules and regulation governing groundwater resource use. Especially on monitoring the trend in quality regularly to ensure the water in within the required standards for human intake.

Report changes in any of the physical parameters such as taste, color and turbidity which can be observed, to the relevant authorities to avoid health effects.

Researchers

The findings from this study are just an initiation of groundwater exploration in this site and so further research should be conducted at a more intensified wider level to ascertain the geological variations, potential and hydrochemistry of the aquifers which affect the quality of groundwater. Especially on iron and fluoride levels in the groundwater of Kahawa Wendani. This will enrich the groundwater data available for this study area to made credible conclusions and ensure potability of the water as well as the distribution of abstraction points is withing the legally required limits.

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APPENDICES

Appendix I: WHO & KEBS drinking water standards

PARAMETERS	UNIT	WHO STANDARDS	KEBS(KS 459-1:2007) STANDARDS
Ph	pH Scale	6.5-8.5	6.5-8.5
Colour	mgPt/l	Max 15	Max 15
Turbidity	N.T.U	Max 5	Max 5
Conductivity (25^0 C)	µS/cm	Max 2500	-
Iron	mg/l	Max 0.3	Max 0.3
Manganese	mg/l	Max 0.1	Max 0.5
Calcium	mg/l	Max 100	Max 150
Magnesium	mg/l	Max 100	Max 100
Sodium	mg/l	Max 200	Max 200
Total Hardness	$mgCaCO_3/l$	Max 500	Max 300
Total Alkalinity	$mgCaCO_3/l$	Max 500	-
Chloride	mg/l	Max 250	Max 250
Fluoride	mg/l	Max 1.5	Max 1.5
Nitrate	mgN/l	Max 50	Max 50
Ammonia	MgN/l		
Copper	Mg/l	Max 0.1	Max 0.003
Zinc	mg/l	Max 450	Max 400
Lead	MgP/l	-	-
Total Suspended Solids	Mg/l	-	-
Temperature	^0C	Max 1500	Max 1000
Cadmium	Mg/l	Max 10	Max10
TDS	Mg/l	1500	
Arsenic	µg/l	-	-

Source: KEBS (2007).

APPENDIX II: A comparison of measured values against the WHO and KEBS Standard values

	PARAMETER	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	WHO	KEBS
1	pH	7.54	6.98	6.96	6.76	7.1	7.25	7.34	6.85	7.5	7.41	6.5-8.5	6.5-8.5
2	True Color , ^{0}H	5	5	5	5	5	5	5	5	5	5	15	15
3	Apparent color, ^{0}H	5	5	5	5	5	5	5	5	5	5	15	15
4	Turbidilty,N.T.U	0.7	0.5	0.8	0.6	0.5	1	2.7	1.9	3.5	0.6	5	5
5	Conductivity,µ/S/CM,mg/l	736	532	518	490	505	562	660	541	362	758	2500	2500
6	Calcium Hardness $CaCO_3$mg/l,	86	88	78	70	56	82	100	76	48	58	100	150
7	Total Hardness, $CaCO_3$mg/l	124	122	134	110	82	134	144	126	110	104	500	300
8	Total Alkalinity,$CaCO_3$mg/l	330	343	345	334	270	370	170	336	124	516	500	500
9	Carbonate Alkalinity, $CaCO_3$mg/l	0	0	0	0	0	0	0	0	0	0	-	-
10	Iron,mg/l	0.1	0.1	0.1	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.3	0.3
11	Fluorides,mg/l	1.92	1.45	1.47	1.54	1.84	1.18	1.6	1.19	1.4	1.43	1.5	1.5
12	Sulphates,mg/l	10	2	0	0	2	0	0	5	5	10	-	-
13	Dissolved Oxygen,p.p.m	5.8	5.3	6	6.4	6.1	5.6	5.6	5.7	5.5	5.6	-	-
14	Nitrates,mg/l	8	2	1	1	1	2	6	1	6	0.5	50	50
15	Chlorides, mg/l	186	64	48	40	74	56	42	68	103	290	250	250
16	Dissolved Solids, mg/l	610	490	370	430	320	320	620	530	380	600		
17	Total Solids, mg/l	610	490	370	430	320	320	620	530	380	600		
18	Plate Count/1ml	15	5	10	10	15	20	15	10	10	0	0	0
19	Total Coliform/100ml	5	0	0	0	3	10	5	0	5	0	0	0

Source: Researcher, (2017).