

Seasonal variations of physico-chemical and microbiological characteristics of groundwater quality in Ruiru, Kiambu county, Kenya

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Abstract- A study was conducted to assess seasonal variation in physicochemical and microbiological quality of groundwater in Ruiru, Kiambu County in Kenya. A total of 109 well water samples, 51 boreholes and 58 shallow wells during 2 different seasons, viz. dry and wet season were collected during the year 2015 and analyzed for temperature, pH, colour, electrical conductivity, turbidity, total hardness, calcium, magnesium, Sulphates nitrate, fluoride, iron, manganese, coliform count and Escherichia coli. Significant difference between seasons was observed in all parameters studied except, for sodium and magnesium. The results were compared with WHO guidelines, 2009 and Kenya Bureau of Standards 2006 water guidelines to ascertain its suitability for domestic use.

Index Terms- Groundwater quality, microbiological, physico-chemical, Ruiru, seasonal variation.

I. INTRODUCTION

II. Background Information

Water is life and sound management of water resources is an integral component of the new paradigm for sustainable development i.e. one that allows the steady improvement in living standards without destroying the fragile natural resources of rivers, marine and groundwater system (1). Groundwater comprises 97 percent of the world's readily accessible freshwater and provides the rural, urban, industrial and irrigation water supply needs of 2 billion people around the world (2). As the more easily accessed surface water resources are already being overused and heavily polluted, pressure on groundwater is growing. Kenya has a water resource endowment of 21 billion cubic meters a year with a per capita available water currently being at 650m³/year (3). This figure is far much below the global accepted value of 1000m³. There is a perception that groundwater is an inexhaustible resource (4). This perception is caused by poor knowledge of groundwater resources, general weakness in institutional capacity, limited technical capacity that is not appropriately deployed and weak political commitment at the senior policy-making level.

Water resources in Kenya are under pressure from agricultural chemicals (fertilizers and herbicides) and urban and industrial wastes, as well as from use for hydroelectric power. Thus, increase in demand for water resources for various uses is

likely to cause many constraints and lead to the pollution of the available water resources. Groundwater pollution occurs when surface water makes its way into the ground. Surface water contains various contaminants such as organic chemicals, inorganic chemicals that occur naturally in the soils, sediments and potential pathogens which may degrade the groundwater quality (5). It is reported that 80% of all illness in developing countries is related to water and sanitation (6).

Problems of water scarcity and poor sanitation issues account for approximate 10% of all deaths relating to water-borne or sanitation-related diseases in Kenya (7). The eminent scarcity in water as a resource has population growth as one of the major causes. Ruiru is one upcoming towns which, in recent passed has experienced a rise in population. The increase in population is attributed to the advantages that the area enjoys. Being strategically positioned along the Nairobi - Thika super highway, Ruiru is also served with a railway which provides relatively cheap transport to the city. The area is also sandwiched between two institutions of higher learning; Kenyatta and Jomo Kenyatta Universities. The rapid expansion of Kenyatta University has seen more students enrolling and looking for residential places for settlement around the area. Due to its proximity to both Nairobi and Thika town, the area has attracted large numbers of people who commute to their work places. This has resulted to over population and hence pressure on the housing and water resources to an extent that even the water service provider can no longer meet the habitants demand for water. The water service provider in Ruiru is Ruiru-Juja Water and Sewerage Company (RUJUWASCO) and is only able to meet 14% of the water demand (8). Most people have resorted to the use of groundwater which is more reliable. As an upcoming area in terms of industrial set up, more people have moved in to provide cheap labour to the industries. This has led to unplanned settlements and sprawling slum area. Majority of the people who can't afford a well-constructed well resort to hand-dug shallow wells. Overcrowding in slum areas has resulted to poor sanitation since the area lacks an elaborate sewage system and it is therefore dominated by pit latrines and the use of septic tanks and soaks pits (9).

Currently, Ruiru lacks an adequate solid waste management system and this has resulted to the Murera dumpsite located in the area (9). These conditions pose a threat on the groundwater quality. The area is also an Agricultural base dominated by coffee plantations and flower farms which use pesticides, fertilizers and herbicides in the farms; this may contaminate the groundwater through infiltration. However people have

continued to use this water without testing, mainly due to ignorance or lack of awareness to all these risks surrounding the resource. More so, there are no policies or strategies to guide the management of groundwater resources (10).

This study is therefore aimed at determining the quality of groundwater in the Ruiru and therefore establishing its suitability for domestic use. This will assist Water Resources Management Authority (WRMA) officials and County authorities in developing strategies to address groundwater quality problems. To safeguard the health of inhabitants of Ruiru it is imperative that the quality of the water be assessed and ascertained. This research therefore aims at identifying the groundwater status of the area and hence assist the relevant functions in coming up with mitigation measures which will ensure provision of safe water to the residents.

The study was carried out in Ruiru, Kiambu County in central Kenya. The town is geographical located at 1° 9' 0" South, 36° 58' 0" East and covers an area of 292 km² (113 sq. m) with a population of 238, 858 inhabitants in 2009 (11). It is strategically located from Thika town and Nairobi city with good road network connections making it easily accessible. Ruiru has a typical tropical climate with warm and temperate characteristics. There is much less rainfall during the cold seasons than during the hot season. The average annual temperature in Ruiru is 19.5 °C with an average annual rainfall of 797 mm. The rainfall distribution pattern is bimodal with long rains falling from March to May and short rains from October to December.

Ruiru is located on the slopes of the Aberdare Range and the land is generally undulating with a general drainage pattern towards the Athi River basin. The geology of Ruiru comprises of tertiary volcanic rocks, the most important being what is termed as Nairobi Stone. The Nairobi stone is a tertiary volcanic rock used extensively for building purposes. The soils in the study area are derived from volcanic rocks and tend to be dark reddish brown, well drained and friable.

It is an agricultural area dominated by coffee and flower production and well covered with industries that have not only provided employment but also contributed to economic growth in the town (11). As such the area is divided into three groups namely; lower, middle and upper class. The lower class forms a huge part of the population followed by middle class whereas the upper class consists of a small percentage.

III. MATERIAL AND METHODS

A. *Sample Collection and Preservation*

A total of 109 groundwater water samples collected from 51 boreholes and 58 shallow wells in the study area (figure 1). The field sampling was done during the dry season (January to February, 2015) and the wet season (April to May, 2015) in order to cover overall variation in groundwater quality during the two seasons. Samples were collected according to methods described by APHA (2005). Position of each sampling point was recorded by GPS (Global Positioning System).

Samples for microbiological analysis were collected aseptically in sterilized glass sampling bottles, and carried in a cool box packed with ice bags. In the case of boreholes, the outlet tap was opened to the full to splash out water and then it was wiped using spirit before sterilizing it using a flame. For the shallow wells, a clean bucket tied with a rope was used to obtain water from the well. All samples were properly labeled with details of the source, date of sampling and time of sampling. The samples were transported to the laboratory for further analysis within 24 hours from the time of collection. Samples for physico-chemical analysis were collected in 1 litre plastic bottles pre-cleaned with detergent and rinsed with distilled water. The bottles were rinsed with the sample before sampling. The samples were then transported to the laboratory for further analysis.

Borehole and Shallow well distribution

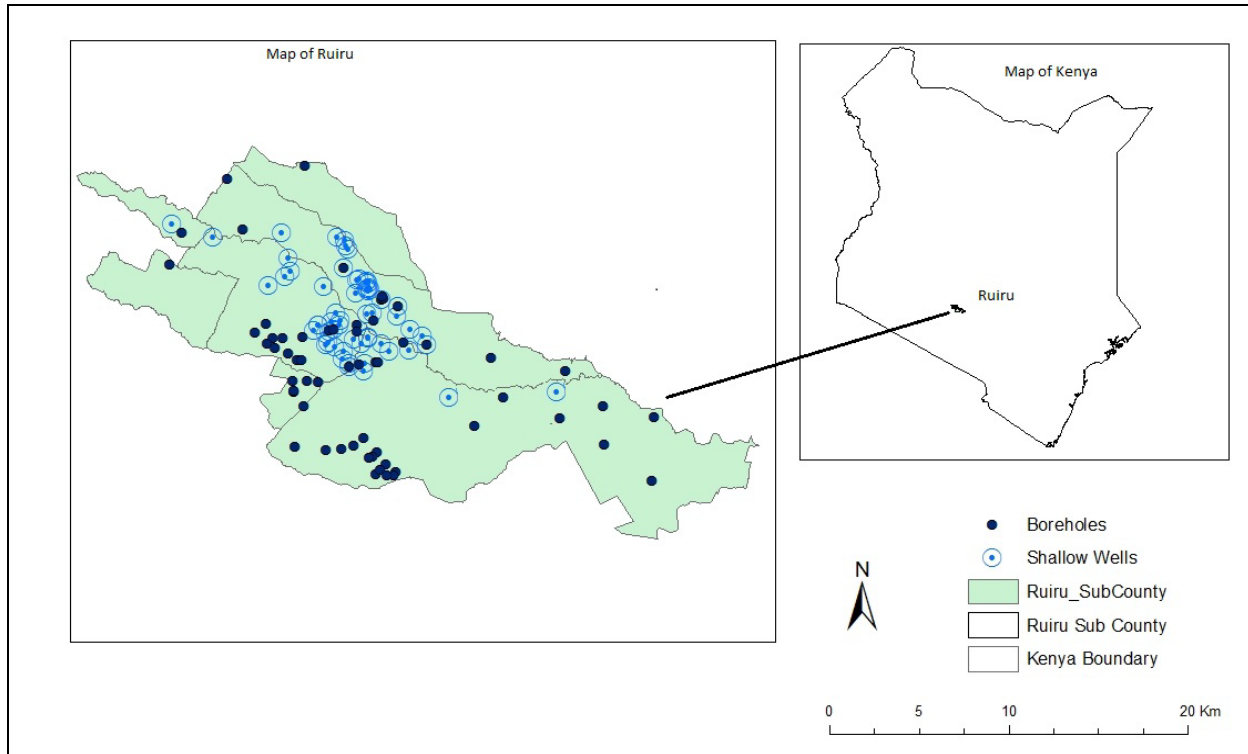


Figure 1: Map showing the distribution of sampled locations in the study area.

B. Physico-chemical Analysis

Samples of groundwater were characterized in terms of electrical conductivity (E.C.), turbidity and pH, colour, fluoride, chlorides, total hardness, calcium, magnesium, potassium, sodium, Nitrates, Iron and Manganese. Parameters like pH, temperature, Electrical conductivity and Total dissolved solids were measured *in-situ* at the point of sample collection; a thermometer was used to determine the temperature of the samples, E.C was measured with a portable conductivity meter (Model Con 200, SensoDirect), pH was determined using a portable pH meter (Winlab Dataline, Windaus Labortechnik) while Turbidity was measured with a portable turbidity meter (Model 6035, JENWAY). Each instrument was duly calibrated before use. Color was measured using Colour comparator (Lovibond). Total Hardness, Calcium and Magnesium contents were determined by titrimetrically, using standard (EDTA). Sulfate concentrations were determined by Turbidimetric method. Chloride (Cl) by Argentometric titrimetric method while Total Alkalinity was estimated by neutralizing with Sulphuric acid, Sodium (Na) and Potassium (K) were determined by flame photometer, Nitrate (NO₃), fluoride (F) were determined by Electrode method while Iron, Manganese were determined by colorimetric method using the standard methods as suggested by the American Public Health Association (12)

C. Microbiological Analysis

Before and during analysis, hands and working surfaces were disinfected using 70% Isopropyl alcohol. Two indicator

microorganisms (total coliforms and fecal coliform (*E.coli*) which indicate faecal contamination (Umaru et al., 2012) were target in this study. The bacterial counts were enumerated using the defined substrate (13) method. This method detects both bacterial species simultaneously. The substrate Colilert-18[®] contains two nutrient-indicator; o-nitrophenyl- β -D galactopyranoside (ONPG) and 4-Methylumbelliferyl- β -D-glucuronide (MUG) utilized as the major sources of carbon. During growth, the ONPG is metabolized by enzyme β -galactosidase found in the total coliforms changing it from colorless to yellow. Similarly *E. coli* use β -glucuronidase to metabolize MUG and create fluorescence. Since most non-coliforms do not have these enzymes, they are unable to grow and interfere. 100 ml of the water sample was measured into a sterile Duran bottle. One snap pack of the Colilert-18 (IDEXX) was transferred into the sample and dissolved by gentle shaking. This content was mixed by shaking gently until it dissolved. The mixture was then transferred into a Quanti-tray, 97 well (97 well, IDEXX) taped gently to expel the trapped air and then left for a few minutes for the foam to dissipate. Using a pre-heated Quanti-tray sealer, the tray was sealed and incubated at a (35°C to 37 °C \pm 0.5) for 24 hours. The most probable number (MPN) of coliforms in the water sample was estimated by the number of positive wells corresponding with standard MPN statistical table and recorded as MPN/100ml. The total coliforms and *E.coli* were determined by the number of yellow wells and fluorescence wells under a UV light (6 watts, 365nm) respectively.

D. Statistical analysis

The data obtained was analysed using statistical package for social sciences (SPSS-Version 20) for mean, standard deviations (SD), standard error (SE) and student's t-test. The mean and SD were used to determine the deviation of the water quality parameters from WHO and KEBS standards. The student t-test was used to test the formulated hypotheses to establish the seasonal variations in the water quality parameters within the boreholes and shallow wells or between the boreholes and shallow wells.

IV. RESULTS AND DISCUSSION

The analytical results of the water quality attributes of the boreholes and shallow wells for different seasons from study area are presented in Tables 1 -9. Increasing trends are noticed towards the dry season for most of the ions in boreholes while in shallow wells, the increase is recorded towards the wet season. The study analysis was obtained in three categories; physical, chemical and microbiological water quality attributes. The physical attributes considered in this study included; Temperature, pH, Colour, Electrical Conductivity, Total Dissolved Solids and turbidity. The chemical attributes of interest included; Total Hardness, Total Alkalinity, Calcium, Magnesium, Chloride, Sodium, Potassium, Fluoride, Nitrate, Sulphate, Iron and Manganese while the microbiological attributes of concern were Total coliforms and *E.coli*.

A. Season variations in water quality characteristics between Boreholes and Shallow wells

i. Variations in the physical characteristics

The majority of the elements in the boreholes are lower than those of the shallow wells except for the pH. The shallow wells exhibited higher mean temperatures in both seasons with mean values of 25.23 °C and 23.49 °C against 23.03 °C and 21.81°C for the boreholes in the dry and wet season respectively (Table 1 and 2). The mean temperature for boreholes and shallow wells are significant ($p \leq 0.01$) in the dry season but the difference is not significant ($p \leq 0.05$) in the wet season (Table 3). The higher mean temperatures in the shallow well could be attributed to the fact that most of their depths are closer to the surface and tend to have the sun's direct influence as compared to the boreholes which tend to be deep and therefore their waters tend to be cool. Temperature affects physical, chemical and biological processes in water bodies. As water temperature increases, the rate of chemical processes generally increases and the solubility of gases in water such as oxygen, carbon dioxide, Nitrogen and others

decrease (14). This eventually impact on the taste, colour and odour and thus the acceptability.

The mean pH values for boreholes are 7.88 and 8.01 in the dry and wet season respectively while shallow wells recorded comparatively lower values of 5.06 in dry season and 7.59 in the wet season (Table 1 and 2). The mean pH values of boreholes and shallow wells are significantly different ($p \leq 0.01$) in both dry and wet season (Table 3). Results showed that the borehole water samples gave pH values within the permissible range of 6.5-8.5 for both WHO and KEBS standards (Table 1). The boreholes have higher pH as compared to the shallow wells in the study area. Thus the boreholes are more of alkaline type while the shallow wells show slightly acidic trends. The low values of water pH can be attributed to the release of carbon dioxide, ammonia and methane during decomposition of the waste materials, which percolate through the aquifer to the groundwater via leachates (15). Similar trends have been reported in previous studies by (16). The high pH in some of the wells can be attributed to the influence of fertilizers like ammonium Sulphates and super phosphate in agriculture and to some extent the sulphur and amino acid compounds from human and animal excreta (17).

Turbidity values over the two seasons showed some remarkable differences. The mean turbidity values for the boreholes and shallow wells are 3.63 Nephthometric turbidity units (NTU) and 12.26 NTU for the dry season and 4.31 NTU and 14.03 NTU for the wet season (Table 1 and 2). From the mean differences, the shallow wells have higher turbidity in both seasons as compared to boreholes Previous studies by (18) confirms the same. The mean turbidity values of boreholes and shallow wells are significant ($p \leq 0.05$) in both seasons (Table 3). Comparatively higher levels of turbidity were recorded in shallow wells and could be attributable to soil erosion, increase in the influx of surface runoff into the water (19). The high turbidity is often associated with higher levels of disease causing microorganisms such as bacteria and other parasites (20). Turbidity directly influences the colour of water and there is a general increase in colour with increasing turbidity values. The turbidity values recorded in the dry season for the shallow wells almost doubled in the wet season. This can be attributed to increased infiltration into the aquifers during the raining season leading to increased dissolution of substances that made the ground water turbid. However in the dry season when there is virtually no infiltration into the aquifers, most of the dissolved substances settle down leading to a reduction in the overall turbidity of the water. Turbidity in water causes problems with water purification processes such as flocculation and filtration which normally increases the cost of water treatment. High turbidity values may also increase the possibility of microbiological contamination (21).

Table 1: Physical characteristics of boreholes and shallow wells in dry season and their comparisons with WHO and KEBS standards

Water Quality Parameter	Units	Borehole		Shallow well	
		Mean± Std. Error	Mean± Std. Error	WHO (2009)	KEBS (2006)
Temperature	°C	23.03±0.06	25.23±3.39	—	—
Colour	mgPt/l	12.55 ±5.04	7.49 ± 0.12	15	15
pH	-	7.88 ±0.04	5.06 ± 0.17	6.5 -8.5	6.5 -8.5
Electrical conductivity	(µS/cm)	533.04±22.42	647.94 ± 53.27	2500	2500
Total dissolved solids	(mg/l)	341.03±15.47	393.21 ± 33.43	1500	1500
Turbidity	NTU	3.63 ±1.04	12.26 ± 3.84	5	5

Note: Number of samples is 109,

Electrical conductivity (EC) indicates the presence of dissolved solids and contaminants especially electrolytes but does not give information about specific chemical. There is a significance difference ($p \leq 0.01$) between the mean EC levels of the boreholes and shallow wells in both seasons (Table 3). The electrical conductivity of the water sample is completely proportional to the TDS value and thus increases with increase in EC. Potable water should not have high electrical conductivity. Boreholes have electrical conductivity with mean values of 533.04 µS/cm and 497.04 µS/cm in the dry and wet seasons

respectively. Shallow wells contain comparatively higher mean levels of Electrical conductivity of 647.94 µS/cm in dry season and 718.24 µS/cm in the wet season. Electrical conductivity in shallow wells are noted to be higher in the wet season than the dry season and vice versa for boreholes. The high EC in boreholes during the dry season is due to concentration build-up of the minerals associated with low water volumes. This may also be traced to the local environment of the water points in terms of geology, soil and land use activities (22).

Table 2: Physical characteristics of boreholes and shallow wells in the wet season and their comparisons with WHO and KEBS standards

Water Quality Parameter	Units	Borehole		Shallow well	
		Mean ± Std. Error	Mean ± Std. Error	WHO (2009)	KEBS (2006)
Temperature	°C	21.81 ±0.03	23.49 ± 0.09	—	—
Colour	mgPt/l	14.02±5.12	36.64±9.23	15	15
pH		8.01±0.04	7.59±0.08	6.5 -8.5	6.5 -8.5
Electrical conductivity	(µS/cm)	497.04 ±23.80	718.24±56.34	2500	2500
Total Dissolved Solids	(mg/l)	308.16 ±14.76	457.3±37.44	1500	1500
Turbidity	NTU	4.31±1.66	14.03±4.04	5	5

Note: Number of samples is 109; WHO-World Health Organization; KEBS-Kenya Bureau of Standards.

Total dissolved solids (TDS) are a measure of the total amount of dissolved minerals in water. Essentially, TDS represents the sum of concentrations of all dissolved constituents in water. Water in contact with highly soluble minerals will probably contain higher TDS levels than water in contact with less soluble minerals. TDS content is usually the main factor, which limits or determines the use of groundwater for any

purpose (14). A total dissolved solid (TDS) is an indicator of polluted water and determines the water’s palatability and acceptability. From the mean differences, the shallow wells exhibit higher mean values of total dissolved solids with mean values of 393.21mg/l (dry season) and 457.3mg/l (wet season) against 341.03mg/l and 308.16mg/l for boreholes in dry and wet season respectively (Table 1). There is significance difference

($p \leq 0.01$) between the mean TDS values of the boreholes and shallow wells in both seasons (Table 3). Season wise the mean values show that the concentrations are high during dry season in boreholes while that of shallow wells is high during the wet season. The TDS increases in the wet season could be attributed

to weathering intensity; and the increased amount of groundwater recharge (23) especially from surface run-off. These findings are similar to that of (24) in study on the groundwater in India.

Table 3: Independent Samples t-test of means of the physical characteristics of Boreholes versus shallow wells in the Dry and Wet Season

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

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

ii. Variations in the chemical characteristics

In natural waters, the probable sources of chloride comprise the leaching of chloride-containing minerals (like apatite) and rocks with which the water comes in contact, inland salinity and the discharge of agricultural, industrial and domestic waste waters (25). The mean chloride concentrations of sampled boreholes are 15.20mg/l in dry season and 16.86mg/l in the wet season. The shallow wells exhibited higher mean concentration of 55.54mg/l and 50.10mg/l in dry and wet seasons respectively (Table 4 and 5) but there is a decrease in the concentrations during the wet season. Previous studies by (16)observed similar trends. There is a significance difference ($p \leq 0.01$) between the mean chloride values of the boreholes versus shallow wells in the dry and wet season (Table 6).

Shallow wells exhibit higher mean chloride values as compared to boreholes. The sources of chlorine in natural water may be from drainage waste and from dissolving rocks. The high value in shallow wells is due to leachates from the surface runoff. An increase in the mean value of chloride content of water may indicate possible pollution from human sewage, animal manure or industrial wastes (26) . Chlorides can get in groundwater from solid waste when it comes in contact with rain water and then gain entrance into aquifer. Chloride in small concentrations are not harmful to humans in drinking water, and with some adaptation, the human body can tolerate water with as much as 200 mg/l chloride ion. However, above a concentration of 250 mg/l chloride, the water may taste salty (27).

Table 4: Chemical characteristics of boreholes and shallow wells in dry season and their comparisons with WHO and KEBS standards

Water Parameter	Quality	Units	Borehole	Shallow well	WHO (2009)	KEBS (2006)
			Mean± Std. Error	Mean± Std. Error		
Total hardness	as	(mg/l)	74.41 ±6.98	139.38 ± 18.35	500	500
Calcium		(mg/l)	19.7±1.95	32.99 ±5.76	100	150
Magnesium		(mg/l)	6.12±0.77	16.02 ± 2.52	100	100
Sodium		(mg/l)	79.08 ±3.43	78.44 ±7.8	200	200
Potassium		(mg/l)	13.04 ±1.14	13.47 ± 4.45	50	50
Total Alkalinity	as	(mg/l)	133.37±13.48	184.19 ± 17.66	500	500
Chloride		(mg/l)	15.2 ±2.24	55.54 ± 8.63	250	250

Fluoride	(mg/l)	2.27±0.23	1.41 ± 0.27	1.5	1.5
Nitrate	(mg/l)	2.37 ±0.42	12.12 ± 2.68	10	10
Sulphates	(mg/l)	3.28 ±0034	18.39 ± 2.42	450	450
Iron	(mg/l)	0.19 ±0.05	0.36 ± 0.10	0.3	0.3
Manganese	(mg/l)	0.50 ±0.06	0.09 ± 0.03	0.1	0.5

Note: Number of samples is 109; WHO-World Health Organization; KEBS-Kenya Bureau of Standards

Sulphates occur naturally in numerous minerals. Gypsum (CaSO₄.2H₂O) and anhydrite (CaSO₄) are generally the common sources of sulphate. The mean sulphate values of the boreholes are 3.28 mg/l and 3.95mg/l in the dry and wet seasons respectively while those of shallow wells are 18.39 mg/l in dry season and 17.25mg/l in the wet season (Table 4 and 5). Sulphates in boreholes and shallow wells are significant (p ≤0.01) in both season (Table 6).Shallow wells exhibited higher values than boreholes in both season. On seasonal variability, the wet season values are higher as compared to the dry season values. Sulphate gets into ground water through the dissolution of rocks containing sulphur and drainage waste. On the other hand, this may be as a result of high-level combustion of sulphur containing hydrocarbon fuels in the study area (28).Water with sulphate levels above the recommended can have a laxative effect until an adjustment to the water is made. Increased sulphate levels can cause deficiencies in trace minerals which can contribute to a depressed growth rate and infertility in herd. The most serious is thiamine deficiency (14).

Nitrogen fertilizers are widely used in agricultural practice, organic nitrogen is present in number of waste products, notably sewage effluents, animal excrement and manure and municipal wastes. The mean nitrate levels of boreholes and shallow wells are significant (p ≤ 0.01) in both the seasons (Table 6). The mean nitrate values for the boreholes for the dry season are 2.37mg/l and 2.70 mg/l in the wet season. Shallow wells had mean values of 12.12 mg/l and 12.87 mg/l in dry and wet seasons respectively (Table 4 and 5). Shallow wells exhibited higher values than boreholes while season wise, the high nitrates were exhibited during the wet season. The mean values of nitrates for boreholes are within the permissible guideline values of 10mg/l for both WHO and KEBS standards. Being loosely bound to soils, nitrate is expected to be more in runoff and hence its concentration

increases during wet seasons especially in shallow wells. These findings are consistent with that of (16). The higher nitrate levels can be attributed to leachates from nitrogen fertilizers widely used in agricultural practice, waste, notably sewage effluents, animal excrement and manure and municipal waste (29). Nitrate concentration above the recommended value of 10 mg/L is dangerous to pregnant women and poses a serious health threat to infants less than three to six months of age because of its ability to cause methaemoglobinaemia or blue baby syndrome in which blood loses its ability to carry sufficient oxygen (14).

From the mean difference, boreholes have high mean values of fluoride as compared to shallow wells (Table 6). The boreholes recorded mean fluoride values of 2.27mg/l in the dry season and 1.77mg/l for the wet season while shallow wells show decreasing values of 1.41 mg/l and 1.10mg/l in dry and wet season respectively (Table 4 and 5). The Means of fluoride for boreholes and shallow wells are not significant (p ≤ 0.05) in the dry season but are significantly different (p ≤ 0.01) in the wet season (Table 6).The high fluoride levels in boreholes can be attributed to the fact that fluoride in groundwater is associated with the fluoride bearing rock which as reported earlier, the dissolution of fluoride bearing minerals may be contributing to the high percentage of fluoride in borehole samples. The low fluoride levels observed in the shallow wells is due to the dilution effect from the rain water (30).The reduction of fluoride during the wet season is due to the dilution effect of the rechargeable aquifers which leads to increase in water table. Lack of fluoride in children nutrition can lead to failing of healthy teeth and bones production which may result to tooth decay or dental caries (31). Whereas, high fluoride concentrations in water, may results to dental or skeletal fluorosis and exhibit with mottling and yellowish or brownish teeth (32).

Table 5: Chemical characteristics of boreholes and shallow wells in wet season and their comparisons with WHO and KEBS standards

Water Quality Parameter	Units	Borehole	Shallow well	WHO (2009)	KEBS (2006)
		Mean ± Std. Error	Mean ± Std. Error		
Total hardness as CaCO ₃	(mg/l)	66.48 ±7.58	197.72±56.18	500	500
Calcium	(mg/l)	17.78 ±1.69	37.93±6.80	100	150
Magnesium	(mg/l)	5.41 ±0.84	31.25±11.66	100	100
Sodium	(mg/l)	74.07 ±3.89	68.08±7.34	200	200
Potassium	(mg/l)	13.06±1.1	15.54±3.22	50	50

Total Alkalinity as CaCO ₃	(mg/l)	121.18 ±13.48	203.16±16.77	500	500
Chloride	(mg/l)	16.86±2.66	50.10±7.01	250	250
Fluoride	(mg/l)	1.77±0.16	1.10±0.21	1.5	1.5
Nitrate	(mg/l)	2.7±0.39	12.87±2.69	10	10
Sulphates	(mg/l)	3.95±0.41	17.25±2.37	450	450
Iron	(mg/l)	0.26±0.06	0.58±0.15	0.3	0.3
Manganese	(mg/l)	0.05±0.01	0.08±0.02	0.1	0.5

Note: Number of samples is 109

Water hardness is the traditional measure of the capacity of water to react with soap, hard water requiring considerably more soap to produce lather. Hard water often produces a noticeable deposit of precipitate (e.g. insoluble metals, soaps or salts) in containers, including “bathtub ring” (33). It is not caused by a single substance but by a variety of dissolved polyvalent metallic ions, predominantly calcium and magnesium cations, although other cations (e.g. aluminum, barium, iron, manganese, strontium and zinc) also contribute (34). The mean hardness values for the sampled boreholes are 74.41 mg/l and 66.48 mg/l in the dry and wet season respectively while those for shallow wells are 139.38 mg/l for the dry season and 197.72mg/l for the wet season (Table 4 and 5). Water containing calcium carbonate at concentrations below 60 mg/l is generally considered as soft; 60–120 mg/l, moderately hard; 120–180 mg/l, hard; and more than 180 mg/l, very hard (35).

According to this classification, borehole water was found to be moderately hard while that of shallow wells was found to be hard in the dry season tending towards very hard in the wet season. The climate and geology of the area plays a very important role in contributing to the total hardness. The leaching of calcium (Ca) and magnesium (Mg) from these rocks adds to the hardness. Further, the agricultural activities directly or indirectly affect the concentrations of a large number of inorganic chemicals in groundwater such as nitrates, chlorides, Sulphates, phosphates, potassium, magnesium and calcium levels (12). Total hardness in water samples as shown by the analyses have concentrations all within the WHO guide value of 500mg/l and 300mg/l for KEBS for drinking water in the wet and dry seasons. From the mean concentration of total hardness, concentrations in water is higher in wet season than in the dry season. This is even more pronounced in shallow wells than in boreholes. This is obvious because of the solvent action of rainwater coming in contact with soil and rock is capable of dissolving calcium and magnesium that promote water hardness. This effect is more pronounced in shallow wells by the agricultural activities directly or indirectly which affect the concentrations of a large number of inorganic chemicals in groundwater such as Nitrates(NO₃⁻), chloride(Cl⁻), sulphate (SO₄²⁻), hydrogen(H⁺), phosphates(PO₄³⁻), carbon (C), potassium(K⁺), Magnesium(Mg²⁺), Calcium(Ca²⁺) etc. (30). Water hardness has no harmful effects on human health it can affect the taste of water as well as reacting with ordinary soap to form scum, plume solvent, scale formation in boilers and in hot water systems.

Most of the alkalinity of natural waters is caused by bicarbonates, carbonates and hydroxides. The seasonal means for the boreholes and shallow wells are 133.37 mg/l and 184.19 mg/l in the dry and 121.18mg/l and 203.16 mg/l in the wet season (Table 4 and 5). Shallow wells have higher mean concentration as compared to the boreholes in both seasons. On seasonal variability, shallow wells exhibited increasing trends towards the wet season. This results confirms the findings of (30). All the boreholes and shallow wells exhibit alkalinity values below the permissible limit of 500 mg/L for both WHO and KEBS.

It may also be noted that in polluted waters, other negative ions like phosphates and nitrates may contribute to alkalinity. The primary source of carbonate and bicarbonate ions in groundwater is the dissolution of carbonate minerals in the study area. The decay of organic matter present in the soil releases carbon dioxide (CO₂). Water charged with CO₂ dissolves carbonate minerals, as it passes through soils and rocks to give bicarbonates. Total alkalinity mean values of the boreholes and shallow well water is significant (p≤ 0.01) in both dry and wet season (Table 6).

The mean calcium (Ca) values for boreholes and shallow wells are 19.7mg/l and 32.99mg/l for the dry season and 17.78 mg/l and 37.93mg/l in the wet season respectively (Table 2 and 5). Shallow wells exhibit higher values and on seasonal variability, the wet season higher concentrations especially in shallow wells while in boreholes there is a reduction. The increase in the Ca and Mg in the shallow wells during the wet season can be attributed to the surface run-off which contains different types of substances that may result to their increase. For the boreholes the decrease exhibited during the wet season is due to the dilution effect from the rain water through infiltration to the ground water. However all the mean concentrations are within the WHO and KEBS calcium permissible limits of 100mg/l and 150mg/l respectively. High concentration of Ca is not desirable in washing, laundering and bathing. Although the sources of Ca in groundwater resources are mainly the crystalline limestone associated with khondalitic rocks, the prolonged agricultural activities prevailing in the study area may also directly or indirectly augment the mineral dissolution in groundwater (23). The content of Mg is comparatively less than that of Ca. with mean value of 6.12mg/l and 16.02 mg/l for borehole and shallow wells in the dry season while those for the wet season are 5.04mg/l and 31.25mg/l. The boreholes show lower concentrations as compared to shallow wells. Previous studies by (16) showed similar trends. The geochemistry of the rock types may have an influence in the concentration of Mg in groundwater. There is significance difference (p≤ 0.01) between

the mean concentrations of the boreholes and shallow wells in both season. .

The mean Iron values for the borehole and shallow wells are 0.19mg/l and 0.36mg/l for the dry season and 0.26 mg/l and 0.58 mg/l in the wet season (Table 4 and 5). The shallow wells have higher Iron concentrations as compared to boreholes whereas on seasonal variability, the wet season exhibit higher values than the dry season. The boreholes water samples fall within the permissible limits of 0.3mg/l of both WHO and KEBS but the shallow wells values exceed the limits. However, no significance difference ($p \leq 0.05$) between the mean values of Iron for the boreholes and shallow wells in the dry season but the difference is significance ($p \leq 0.01$) between iron values of boreholes and shallow wells in the wet season (Table 6). This confirms the study of (36) which observed that high iron concentration is mostly associated with relatively shallower wells (less than 40 m deep). This high concentration of metallic iron may be responsible for the observed high colour and turbidity in shallow wells during the wet season. The high iron levels in these waters could be attributed to due to the distribution of laterite soil, containing excess iron natural sources such as the geochemical and biochemical processes (37) and the dissolution of iron oxides within their aquifers.

This high concentration of metallic iron may be responsible although high iron concentrations may not pose health hazards to users, the occurrence of the yellowish-brown coloration may cause rejection of such waters by the communities (38). The high values of iron concentration in the water have the potential of staining laundry and scaling in pipes. The major disadvantage of the presence of iron in water is that it increases the hazard of pathogenic organisms because most of these organisms need iron to grow (39). Iron in ground water may originate from a variety of mineral sources; and several sources of iron may be present in a single aquifer system. Oxidation-reduction potentials, organic matter content, and the metabolic activity of bacteria can influence the concentration of iron in ground water. Pyrite (FeS_2) oxidation may also contribute iron to unconsolidated aquifer systems. Iron is also present in organic wastes and in plant debris in soils (40). Low concentrations in some of the bedrock systems may be explained by precipitation of iron minerals from activity of reducing bacteria or by the loss of iron from cation-exchange processes occurring in confining clay, till or shale overlying the bedrock (40).

Table 6: Independent Samples t-test of means of the chemical characteristics of Boreholes versus shallow wells in the Dry and Wet Season

Chemical parameters		Borehole versus Shallow well (Dry season)		Borehole versus Shallow well (Wet season)	
Water parameter	quality	p-value	Mean Difference	p-value	Mean Difference
Total Hardness	(mgCaCO ₃ /l)	0.000 ***	-72.89	0.034 **	-123.31
Calcium	(mg/l)	0.014 ***	-15.20	0.012 ***	-18.24
Magnesium	(mg/l)	0.000 ***	-10.61	0.036 **	-25.13
Sodium	(mg/l)	0.611	-4.36	0.189	11.01
Potassium	(mg/l)	0.822	-0.42	0.486	-2.48
Total Alkalinity	(mgCaCO ₃ /l)	0.004 ***	-63.02	0.002 ***	-69.80
Chloride	(mg/l)	0.000 ***	-40.334	0.000 ***	-33.24
Fluoride	(mg/l)	0.284	0.36	0.000 ***	1.17
Nitrate	(mg/l)	0.001 ***	-9.42	0.000 ***	-10.50
Sulphates	(mg/l)	0.000 ***	-14.47	0.000 ***	3.89

Iron (mg/l)	0.150	-0.169	0.000***	-16.98
Manganese (mg/l)	0.018***	0.17	0.001***	-54

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

The mean manganese values for the borehole and shallow wells are 0.50 mg/l and 0.09 mg/l for the dry season and 0.05mg/l and 0.08mg/l for the wet season (Table 4 and 5). Boreholes exhibit relatively higher concentration than shallow wells .On seasonal variability, dry season show higher values. There is significance difference ($p \leq 0.01$) between the mean values of boreholes and shallow wells in the dry and wet season (Table 6). The boreholes exhibited higher values during the dry season and thus exceeded the permissible value of 0.1mg/l for WHO but was within the 0.5mg/l of KEBS. Manganese is a naturally occurring element in rocks and is released into the soil through weathering of the rocks. It can therefore be deduced that the high levels of manganese contamination is as a result of the underlying geological formation (rocks). Manganese like other trace metals is essential to the sustenance of life. Manganese, molybdenum, selenium and zinc are needed at low levels as catalyst for enzyme activities. However, drinking water containing high levels of these essential metals or elements may be hazardous to human health (41). Excess manganese in a person’s diet may inhibit the use of iron in the regeneration of blood hemoglobin.

iii. Variations in the microbiological characteristics-Coliform and E.coli

Coliform populations are indicators for pathogenic organisms. They should not be found in drinking water but are usually present in surface water, soil and feces of humans and animals. Human waste contaminant in water causes water-borne diseases such as diarrhea, typhoid and hepatitis (14). High coliform populations in all the water samples are an indication of poor sanitary conditions in the community. Inadequate and unhygienic handling of solid-wastes in the rural area could have generated high concentration of microbial organisms. Faecal coliforms (FC) of which *E.coli* is one of them, are the most commonly used bacterial indicator of faecal pollution (42). They are found in water that is contaminated with faecal wastes of human and animal origin. Total coliforms (TC) comprise bacterial species of faecal origin as well as other bacterial groups (e.g. bacteria commonly occurring in soil). The coliforms are indicative of the general hygienic quality of the water and potential risk of infectious diseases from water. High levels of total coliforms and *E.coli* counts in water are usually manifested in the form of diarrhoea and sometimes by fever. {Insert Table 7 and 8 below}.

Table 7: Microbiological characteristics of boreholes and shallow wells in dry season and their comparisons with WHO and KEBS standards

Water Quality Parameter	Units	Borehole		Shallow well	
		Mean± Std. Error	Mean± Std. Error	WHO (2009)	KEBS (2006)
Total coliforms	MPN/100ml	0.05 ±0.02	1804.22±108.69	0	10
<i>E.coli</i>	MPN/100ml	37.06 ±21.28	277.31±74.76	0	0

Table 8: Microbiological characteristics of boreholes and shallow wells in wet season and their comparisons with WHO and KEBS standards

Water Quality Parameter	Units	Borehole		Shallow well	
		Mean ± Std. Error	Mean ± Std. Error	WHO (2009)	KEBS (2006)
Total coliform	MPN/100ml	319.49±97.36	2097.4±80.26	0	10
<i>E.coli</i>	MPN/100ml	419.04±114.39	1524.33±131.16	0	0

Note: Number of samples =109, WHO-World Health Organization; KEBS-Kenya Bureau of Standards.

The result obtained for the microbial analysis indicated that all the water samples were contaminated with faecal coliforms (faecal contamination). The mean total coliform values for the sampled boreholes are 0.05 MPN/100ml (dry season) and 319.49MPN/100ml (wet season) while those for *E.coli* are 37.06 MPN/100ml and 419.04 MPN/100ml in the dry and wet season respectively (Table 7 and 8). From the mean differences, shallow wells are more contaminated as compared to the boreholes (Table 9). High coliform counts appear to be characteristic of all the shallow wells in the study area, consistent with the findings by (43)who determined the microbiological pollution status of groundwater sources in Mombasa. Season wise, groundwater

contamination was more during the wet season. The contamination can be attributed to increased infiltration during the wet season. The high amount of these coliform during the wet season could be due to the fact that water availability favors the movement and reproduction of the organisms especially from surface run off, sewage and waste material. However, there is a significance difference ($p \leq 0.01$) in the mean counts of total coliforms between boreholes and shallow wells in the dry and wet season. The mean *E.coli* concentrations are significant ($p \leq 0.01$) between boreholes and shallow wells in both seasons (Table 9).

Table 9: Independent Samples t-test of means of the microbiological characteristics of Boreholes versus shallow wells in the Dry and Wet Season

Microbiological parameters				
Water quality parameter	Borehole versus Shallow well in the Dry season		Borehole versus Shallow well in the Wet season	
	p-value	Mean Difference	p-value	Mean Difference
Total coliforms (MPN/100 ml)	0.000***	-1484.73	0.001***	-1678.357
<i>E.coli</i> (MPN/100 ml)	0.003***	-240.25	0.000***	-1962.80

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

V. CONCLUSION

The boreholes and shallow wells in the area are bacteriologically contaminated and therefore not suitable for domestic purposes unless treated. The mean fluoride levels in boreholes are high in both seasons even in the wet season when it is expected to reduce due to dilution effect. The high levels of fluoride might pose a health risk on children below eight years of age. The contamination of groundwater is more pronounced during the wet season. Our findings, therefore suggest that the physical chemical quality of water from boreholes and shallow wells is within the WHO standards for majority of the parameters with exceptions of fluorides, nitrate and turbidity. The boreholes have comparatively lower levels of contaminations bacteriologically as compared to shallow wells. In this case the levels of microbiological contamination represent the strongest concern, as high levels of *E.coli* were present in all sampled shallow wells. It is therefore needful that urgent steps be taken to ensure effective water resources management.

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