Hydrogeochemistry of Ground Water in Mbeere South Sub-County, Kenya

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Abstract

This paper presents the experimental and simulated results of ground water in Mbeere South Sub -County, Kenya. A total of 30 samples from 10 boreholes were collected and used to investigate the chemical characteristics of groundwater. The samples were analyzed for physicochemical characteristics such as pH, temperature and Total Dissolved Solids along with major cations and anions using standard analytical procedures. The laboratory data obtained was run into a hydrogeochemical computer model, PHREEQC for aqueous speciation modelling. Origin pro and AqQA computer software were also used to reveal more hydrogeochemistry of the groundwater in the area. The results showed that the $Na^+ > Ca^{2+} > Mg^{2+} > K^+ > Fe^{3+}$ were the dominant cations while $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > F^-$ were the dominant anions. The hydrogeochemical facies indicated that 40% of the samples belong to the Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-} type, 40% belong to the Ca^{2+}-Mg^{2+}-HCO_3^-, 20 % are of the type Na^+-K^+-HCO_3^- with no Na^+-K^+-Cl^--SO_4^{2-} water type. The facies also illustrated atmospheric precipitation, dissolution of salt deposits within the vadose zones and weathering of halite, anhydrite, gypsum, huntite, hydromagnesite, artinite, dolomite and magnesite as the major contributors to the variation in Mbeere South groundwater chemistry. The Saturation Indices (SI) showed that the specimens were slightly saturated with aragonite, calcite, and dolomite; slightly under-saturated with anhydrite and gypsum; moderately under saturated with halite and under-saturated with hydromagnesite, trona and portlandite.

Keywords: facies, Groundwater modelling, Hydrogeochemical processes, Saturation index, Water-rock interaction

1. Introduction

Water is an important natural resource that is essential for all forms of life (Zhang *et al.,* 2017). Water as a resource is important for economic development due to its support for agricultural development, energy generation, municipal and commercial uses livestock development, industrial growth, wildlife and recreational activities among others (Kinuthia *et al*., 2009). In arid and semi arid areas, groundwater is the main source of water for agricultural, industrial and domestic uses (Kinuthia *et al*., 2009). In order to manage this limited resource effectively, hydrogeochemistry of groundwater is essential to establish the hydrogeochemical processes affecting it (Zhang *et al.,* 2017). Groundwater contains a wide range of dissolved inorganic constituents due to the hydrogeochemical processes .Some of these processes are mineral dissolution, rock weathering, precipitation and ion-exchange. The concentration and type of these inorganic constituents depends on a number of factors such as the, geological structure, composition of the precipitation and mineralogy of the watershed and aquifers,

Groundwater hydrochemistry provides researchers with all the information needed to understand the physical processes and chemical reactions through which the groundwater undergoes, starting from rainfall, runoff, and infiltration to the roots which it passes through to reach the vadose zone and finally recharge the aquifer (Kura *et al.*, 2017). Hydrogeochemistry uses the water's chemistry as a forensic tool to find out where groundwater has been and what has happened to it along its journey (Bundschuh and Zilberbrand, 2012). This information gives a wide, more regionally understanding of ground water systems (Zhang *et al.,* 2017). Furthermore, this improved knowledge can be used to create more inclusive management, conservation plans and more equitable groundwater/surface water regulations. The hydrogeochemistry of groundwater would therefore be an informative basis that can be used in its management and conservation for effective domestic, industrial and agricultural purposes. Hydro-geochemical information is useful in predicting changes associated with groundwater quality (Zhang *et al.,* 2017). The information can be used further in

developing step-gap measures to address the changes in water quality and therefore management of this scarce commodity especially in arid and semi-arid areas.

Mbeere South is a Sub-County in Kenya that heavily relies on agricultural production, therefore water is an essential component in the economic development of the area (Kura *et al.*, 2017). However, due to an increased human population and expansion of agricultural activities, the demand for water is constantly rising. This has put enormous pressure on the existing water sources in the region. This poses the challenge of managing the available water resources in a sustainable and integrated manner. In the last two decades, extensive development in the field of agriculture in Mbeere South has caused large uncertainties about the groundwater quality for drinking and agricultural purposes (Kinuthia *et al.*, 2009). Currently, there is limited research work that has been conducted to provide more information on the quality of water and change of groundwater chemistry of the boreholes in this region.This Study aimed to identify Hydrogeochemical characteristics, Processes and Saturation Indices controlling groundwater chemistry, Groundwater drinking suitability, and the quality of groundwater for irrigation purposes in Mbeere South.

2. Materials and Methods

2.1 Materials

2.1.1 Study Area

The study area is Mbeere South Sub-County and its adjoining regions, which is located in Embu County, Kenya. The area lies between latitudes-0.62, -0.68 (0^0 37' 14" S, $0^0$40' 50" S) and longitudes 37.53, 37.79 (37^0 30'4" E, 37^0 47' 56" E). The study area map is given in Figure 2.10. It has 11 administrative locations and covers a total area of about 1321.4 km^2. The area mainly has agricultural activities as the main economic activity utilizing borehole water as the main source of water (Agricultural Sector Development Support Programme, 2016).
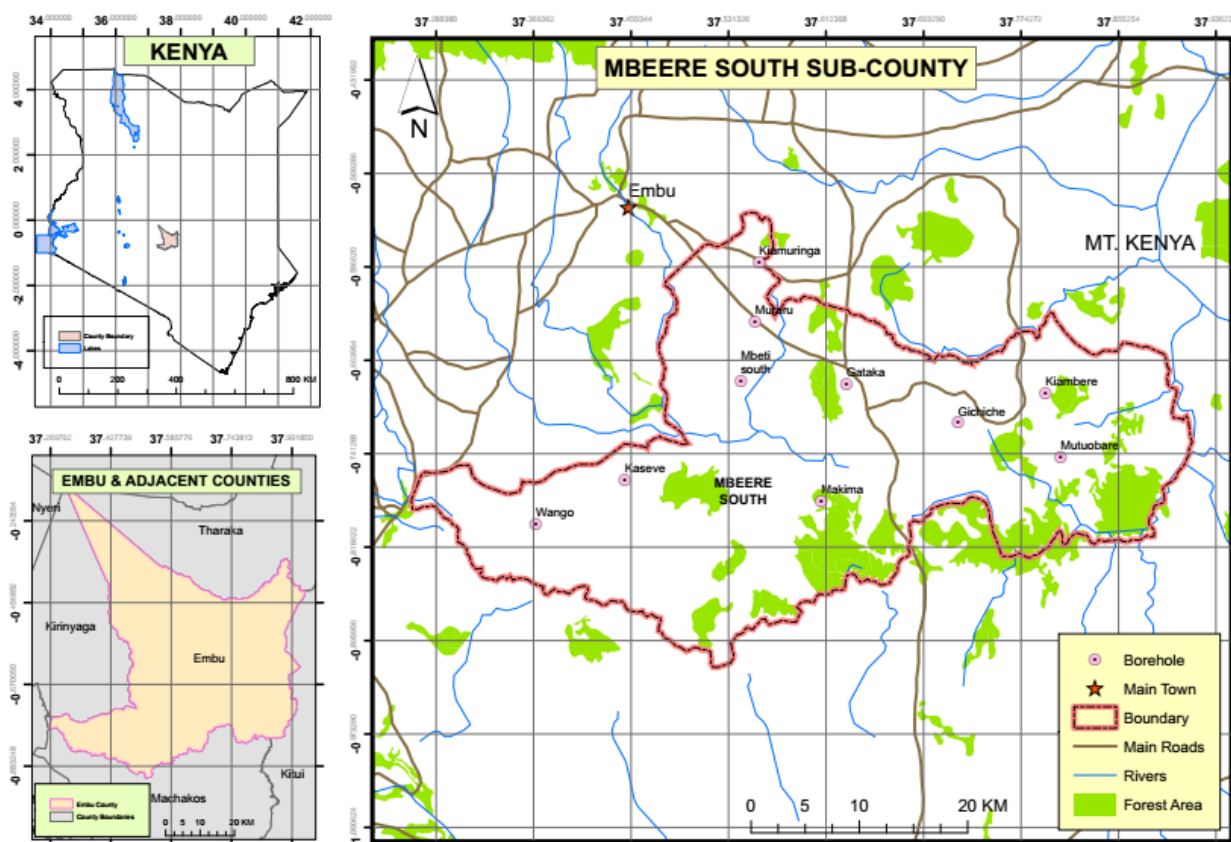

Figure 2.1. Maps of Mbeere South, Embu County and Kenya

2.1.2 Regional Geology/Hydrogeology of Study Area

The landscape of Mbeere South is typically of undulant upland that slopes from the Northwest to Southwest direction (Kinuthia *et al.*, 2009). Altitude ranges between 500 and 1,200 meters above sea level on the Tana River basin. The slope is however broken by the existence of a few hills such as Kiang'ombe, Kiambere, and Kianjiru which rises above the general height. Mwea plains cover the southern parts of the Sub County Five permanent rivers serve the sub-county,

namely: Rupingazi, Tana, Thiba Thuci, and Ena all flowing in a South-East direction draining the region (Kinuthia *et al.*, 2009). These rivers draw their waters from Mt. Kenya.

The rocks of the area fall into three groups namely; Post-Basement System rock, Basement System rocks, and Tertiary Volcanics. The Basement System includes pelitic calcareous, psephitic, and psammitic types with subordinate gabbroic intrusives. The Embu Series, considered to be of post-Basement System in age, is a group of ungranitized rocks of low-grade metamorphic state consisting of essentially banded gneisses, knotenschiefer, and hornfelses, with subordinate conglomerates and limestones. Lastly, the Tertiary volcanics of the Mt. Kenya suite are represented by agglomerates, kenytes, phonolites tuffs, and olivine basalts (Bear, 1952).

Rainfall in the area is bimodal with annual averages between 640 – 1110 mm (Republic of Kenya. (2001). The rains are however not very reliable with the long rains witnessed between April and June, while the short rains are experienced from October through December. The average rainfall figures are comparatively high but the rainfall is irregular in nature making it to be highly unreliable. Furthermore, the erratic nature of the rainfall tends to increase surface runoff which together with poor farming practices accelerates formation of gullies and soil erosion. Droughts are very common in the area and the temperatures range between 20 and 32 ^{0}C. August month is normally the coldest with temperatures falling as low as 15 ^{0}C. The hottest month is March with temperatures rising to as high as above 30 ^{0}C. As a result of the high temperatures, the region experiences high evapo-transpiration all through the year. This has resulted to low humidity in most parts of the region except where large water masses exist, for example in the areas around Kindaruma, Kiambere, Kamburu and Masinga dams (Kinuthia *et al.*, 2009).

2.1.3 Sampling

Water samples were collected from selected bore holes in Mbeere South with depths ranging between 23 to 120 meters during the month of February 2017.The selection of the borehole to be sampled was based on administrative locations and ease of access from the road. After sampling, field analysis of pH, total dissolved solids and temperature was done followed by sample pre-treatment then samples were kept in a cold box and transported to the laboratory for analysis of chemical parameters.

Prior to sampling, the GPS of the borehole location was taken using a GPS device and recorded. All the sampling containers which had previously been washed with nitric acid and rinsed with distilled water were again washed and rinsed thoroughly with the borehole water to be collected. Before collection of the samples, each borehole was flushed for about 3 minutes to avoid collecting the water that was initially in the pipe. Three 500 ml water samples were collected from each borehole per location to make a total of 30 samples using pre-cleaned polyethylene plastic bottles. Sampling followed standard sampling procedures (Agricultural Sector Development Support Programme, 2016).Accessibility to the water sources, geographical location, presence of human activities and current well exploitation were some of the factors that were considered when selecting a borehole. The following parameters were then analyzed in the field; pH and temperature were done using a pHEP by Hanna (HI98127) pH meter, while total dissolved solids (TDS) using EC-TDS Scan (Zaharin, *et al.,* 2007). The samples were then taken for analysis at the chemistry laboratories of both Kenyatta and Embu universities. During sample collection, handling, and preservation, standard procedures (APHA, 1995) were followed to ensure data quality and consistency.

2.1.4 Sample Pre-Treatment

All samples were filtered using 0.45um filter papers, those for cation analysis acidified with analytical grade nitric (v) acid while the ones for anion analysis were not acidified. Immediately, all the samples were transported to the laboratory in a cold box where they were stored at 4^0C in a refrigerator for subsequent analyses of both cations and anions (Hach, 2004).

2.2 Methods

2.2.1 Experimental Analysis

Cl$^-$ ions were determined using argentometric titration, F$^-$ ions using HACH 850, SPADNS colorimetric method, SO_4^{2-} and NO_3^- ions using UV-Vis (SO_4^{2-}-Spectro-VIIID; NO_3^-UV-mini), and HCO_3^- was determined via titrimetric analysis using 0.02N H_2SO_4. The alkaline earth metal (Ca^{2+} and Mg^{2+}) cation concentrations were determined using EDTA titration and Fe was determined using an AA320N Biobase Meihua flame atomic absorption spectrometer while the alkali metals (Na^+ and K^+ ion) concentrations were determined using Sherwood M410 flame photometer. Overall procedures were as per the standard methods of analysis of water and waste water (APHA, 2012).

2.2.2 Hydrogeochemical Modelling

The experimental results obtained for pH, temperature, Na^+ , K^+, Mg^{2+}, Ca^{2+} , HCO_3^{2+} and Cl$^-$ were used to generate modelled data using; PHREEQC 3.3, Origin Prob9.4, and AqQAvl.50, programs. In order to determine the chemical

equilibrium between minerals and water, saturation indices of gypsum, anhydrite and halite (Evaporites) and aragonite, calcite, and dolomite (Carbonates) were calculated using PHREEQC 3.3 computer software (Deutsch, 1997; Parkhurst *et al.,*2005) using Equation 2.1;

$$SI = Log\left(\frac{IAP}{K_{sp}}\right)$$
2.1

Where SI is the saturation index, IAP is the ion activity product of particular solid phase and K_{sp} is the solubility product of that phase.

Ion activity and Debye–Huckel expression is used by PHREEQC software to compute the coefficient activity. The aqueous model is suitable for low ionic strength (lower than sea water) which is acceptable for groundwater in the study area (Zaharin *et al.,* 2007). The saturation index describes the deviation of water from equilibrium with respect to dissolved minerals quantitatively. If the saturation index is less than zero, the mineral is under-saturated with respect to the solution and the mineral might dissolve. This reflects the character of water from a formation with insufficient amount of mineral for solution or short residence time. Conversely, positive values of SI indicate that the water is supersaturated with regard to that particular mineral phase. This implies that this water is incapable of dissolving more mineral under the same physico-chemical conditions. It can only precipitate that mineral. An SI = 0 implies that the water is in equilibrium state with the particular mineral phase and can neither dissolve nor precipitate that mineral.

In order to understand chemical character of the groundwater and relationships between the dissolved ionic constituents, the hydrochemical data were plotted on Piper and Durov diagrams using Origin Pro b9.4 and AqQAv1.50 softwares respectively. For determination of irrigation water quality; Salinity Hazard, Sodium Absorption Ratio (SAR), Exchangeable Sodium Ratio (ESR), and Magnesium Hazard (MH) were generated from AqQAv1.50 software.

3. Results and Discussion

The experimental and modelled results for underground water are presented in Table 3.1.

Table 3.1. Water Quality Analysis Results

Location	Temp °C	pH	TDS** mg/L	Ca²⁺ mg/L	Mg²⁺ mg/L	K⁺ mg/L	Na⁺ mg/L	Fe³⁺ mg/L	F⁻ mg/L	Cl⁻ mg/L	HCO₃⁻ mg/L	SO₄²⁻ mg/L	NO₃- mg/L	Modeled data Water types
Kiambere H. C.	28.7	6.8	681.0	430.0	251.0	6.0	431.7	0.0	2.1	843.7	395.0	66.7	8.8	Ca-Cl
Muraru	27.7	8.9	12.0	80.0	40.0	5.0	134.7	0.0	0.8	10.0	156.0	120.0	4.3	Na-HCO₃
Kanyonga	28.7	7.1	510.0	180.0	330.0	6.0	75.3	0.0	0.5	170.0	349.0	2.5	24.2	Mg-HCO₃
Gataka	26.7	6.8	178.0	120.0	58.0	4.0	124.2	0.0	0.6	130.0	182.0	110.8	19.7	Ca-Cl
Wango	28.4	7.0	266.0	150.0	116.0	7.0	263.4	0.0	1.1	16.0	309.0	81.7	38.3	Na-HCO₃
Kinyaga	27.8	6.7	326.0	206.0	120.0	12.0	253.5	0.0	1.4	393.9	379.0	22.5	36.7	Na-Cl
Kanyariri P. S.	26.4	6.6	500.0	220.0	280.0	9.0	55.5	0.0	0.6	70.0	205.0	84.2	6.7	Mg-HCO₃
Kabingori SDA	27.9	7.2	268.0	210.0	3.0	11.0	174.3	1.0	1.7	152.0	241.0	37.5	30.5	Ca-Cl
Kaseve	28.7	7.2	213.0	130.0	138.0	3.0	194.1	0.0	1.2	187.9	317.0	351.7	48.8	Mg-SO₄
Kangami	26.7	6.8	148.0	120.0	28.0	9.0	114.9	0.0	0.6	34.0	220.0	5.8	26.2	Ca-HCO₃
Maximum	28.7	8.9	681.0	430.0	330.0	12.0	431.7	1.0	2.1	843.7	395.0	351.7	48.8	
Minimum	26.4	6.6	12.0	80.0	3.0	3.0	55.5	0.0	0.5	10.0	156.0	2.5	4.3	
Mean	27.8	7.1	310.2	184.6	136.4	7.2	182.2	0.1	1.1	200.8	275.3	88.3	28.4	
Standard Deviation	0.9	0.7	199.9	97.8	114.0	3.0	111.4	0.3	0.5	252.7	85.3	101.4	14.8	
WHO (2011)	-	6.5-8.5	500.0	75.0	50.0	10.0	200.0	0.3	1.5	250.0	-	250.0	50.0	
EAS 459-1:2007	-	6.5-8.5	1500.0	250.0	100.0		200.0	0.3	1.5	250.0	500.0	400.0	10.0	

***TDS-Total Dissolved Solids*

Based on Table 3.1, the pH value for ground water samples varied from 6.6 to 8.9. This shows a slight variation from acid to alkaline nature which is preferred for drinking. The pH is affected not only by the reaction of Carbon Dioxide but also by organic and inorganic solutes present in water. The rocks and minerals in an area (geology) also strongly influences the natural pH of water (Ombaka *et al.,* 2013). The high PH of Muraru borehole water could be as a result of the oversaturation of calcite and aragonite which is revealed by their positive saturation indices (Table 310).

The total dissolved solids were in the range of 12.0 to 681.0 mg/L. High total dissolved solids may affect the aesthetic quality of the water, interfere with washing clothes and corroding plumbing fixtures. For aesthetic reasons, a limit of 500 mg/l (milligrams per litre) has been established as part of the Secondary Drinking Water Standards (Oram, 2018). The differences in TDS levels witnessed in the boreholes can be attributed to the underlying rocks in the study sites (Mwamati *et al.,* 2017). The high TDS values in Kiambere, Kanyonga and Kanyariri p.s boreholes therefore shows that these areas are highly mineralized.

The results showed that the $Na^+ > Ca^{2+} > Mg^{2+} > K^+ > Fe$ were the dominant cations while $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > F^-$ were the dominant anions. The observed order of cations can be attributed to the dissolution of halites, deposition of rock salts, weathering of rocks containing sodium and its displacement from absorbed complex of rocks and soils by carbon and magnesium(Hussien *et al.,* 2016).

The chloride concentration in the groundwater varies between 10.0 and 843.7 mg/L. The dissolution of salt deposits within the vadose zones, atmospheric precipitation, and weathering of halite are considered as the main contributors to chloride in the groundwater. As a result of deep groundwater occurrences in this semi-arid region, the anthropogenic sources of chloride are very minimal (Hussien *et al.,* 2016). High chloride content in Kiambere borehole water could be due to weathering of chloride bearing minerals such as halites together with anthropogenic activities e.g. Domestic effluents, use of fertilizers, and septic tanks leakages.

Sulphate ion concentration in the groundwater samples varies from 2.5 to 351.7 mg/L within the study region. The recommended WHO value is 250 mg/L. The concentration of SO_4 is attributed to the weathering of rocks forming minerals such as anhydrite and gypsum (Hussien *et al.,* 2016). Saturated indices of gypsum and anhydrite show negative values in Table 3 therefore the groundwater is still active to leach sulphate ions from anhydrite and gypsum minerals phase. This explains why sulphate concentrations are relatively lower than bicarbonates in all the sampling sites. Sulphate in drinking water may cause significant taste at concentrations above 250mg/L and may contribute to the corrosion of distribution systems, nevertheless, sulphate related impacts such as gastrointestinal impacts occur in concentration above 500mg/L (Hussien *et al.,* 2016).

The nitrate concentration in the study area ranges between 4.3 and 48.8mg/L with a mean of 28.4 mg/L. Nitrates concentration in ground water can be derived from faulty septic tanks, sewage discharge, oxidation of organic materials, farming and agricultural processes. Nitrate concentrations greater than 45 mg/L are undesirable in domestic water supplies due to its potential toxic effect on young babies. A high level of nitrates in drinking water causes methaemoglobinemia. This is a disease caused by nitrates, which convert to nitrites in the intestines, resulting in an over abundance of Methaemoglobin molecules. Cattles are also tremendously vulnerable to this disease. Loss of milk production and aborted calves are two signs of nitrate poisoning in cattle. The safe nitrate limit for domestic water is set at 50 mg/1 by the WHO (2011)

The concentration of HCO_3 varies from 156.0 to 395.0 mg/L. The higher proportions of bicarbonate dominated by alkaline earths Ca and Mg in relation to other anions may indicate weathering of huntite, hydromagnesite, artinite, dolomite and magnesite. Carbonates and alumino-silicate rocks weathering with a minor contribution of CO_2 gas dissolution are the main source of HCO_3^- in the borehole water.

The fluoride concentration ranges from 0.1 to 2.1 mg/L with an average of 1.1 mg/L. The WHO standard for concentration of fluoride in portable water is 1.5 mg/L From the study, its only Kabingori SDA and Kiambere H. C. boreholes which had fluoride values exceeding this limit. Low levels of fluoride in the study area can be attributed to the fact that the only principal independent fluoride mineral of igneous rocks is fluorite (calcium fluoride).Fluorite is a source of fluoride in groundwater but its solubility is very low. Fluorides are important in drinking water when their concentration is below 1 mg/L. This is because they prevent the teeth against dental carries. However, when their concentration goes beyond 1.5 mg/L, they cause mottled teeth enamel, also known as fluorosis

Sodium and potassium ions concentration in the sampled groundwater varies between 55.5 and 431.7 mg/L and from 3.0 to 12.0 mg/L respectively Saturation index of halite shows negative values in Table 3 indicating a possibility of leach process of the still active halite. High levels of sodium can be attributed to the dissolution of halites, deposition of rock salts, weathering of rocks containing sodium and its displacement from absorbed complex of rocks and soils by calcium and magnesium (Subramani *et al*., 2005). Kiambere, Wango and Mutuobare boreholes had sodium concentration values above the standards hence not portable with respect to this parameter. Potassium concentration in most of the ground water samples in the study area is below the WHO (2011) allowable limits (10.0 mg/L). Lower levels of potassium in the region are mainly due to lack of potassium bearing rocks in the lithological units and substitution in the crystal structure of some clay materials. The greater resistance of potassium-containing minerals to weathering could also have contributed to its low levels in groundwater.

Calcium and magnesium concentration in the study area ranges from 80.0 to 430.0 and 3.0 to 330.0 mg/L respectively. The taste threshold for calcium and magnesium is in the range of 100 to 300 and 50 to 150 mg/L respectively depending on the associated ion (Hussien *et al.,* 2016). Processes controlling groundwater chemistry such as exchange of ions could be responsible for low concentration of calcium and magnesium in some areas. High levels of calcium in Kiambere H.C borehole could be attributed to weathering of limestone, sedimentary rocks and calcium bearing minerals which are evidenced in the study area. High magnesium levels are attributed to the fact that Magnesium is a common element and is found in all natural waters. Magnesium ion in waters from igneous and metamorphic rocks is derived

mainly from ferromagnesian minerals and their alteration products. The SI of dolomite, gypsum, hydromagnesite (Table 3) shows that both Ca and Mg can still go into underground water because of their undersaturation.

The concentration of Iron in the study area ranges from 0.0 to 1.0 with a mean of 0.1. The WHO (2011) and EAS 459-1:2007 have permissible limits for iron in portable drinking water as 0.3 mg/L. Its only one sample (Kabingori SDA) which showed some detectable iron concentration of 1.0 from the study area Exposure of water sample to air could cause (Fe^{2+}) ferrous to oxidize to ferric (Fe^{3+}) ion which would precipitate as ferric hydroxide hence removed during filtration. Ferric hydroxide if not removed from water stains laundry, plumbing fixtures and cooking utensils.

3.1 Hydrogeochemical Facies

The hydrochemical facies were separately represented in the Piper diagram and Durov Plots.

3.1.1 Piper Diagram
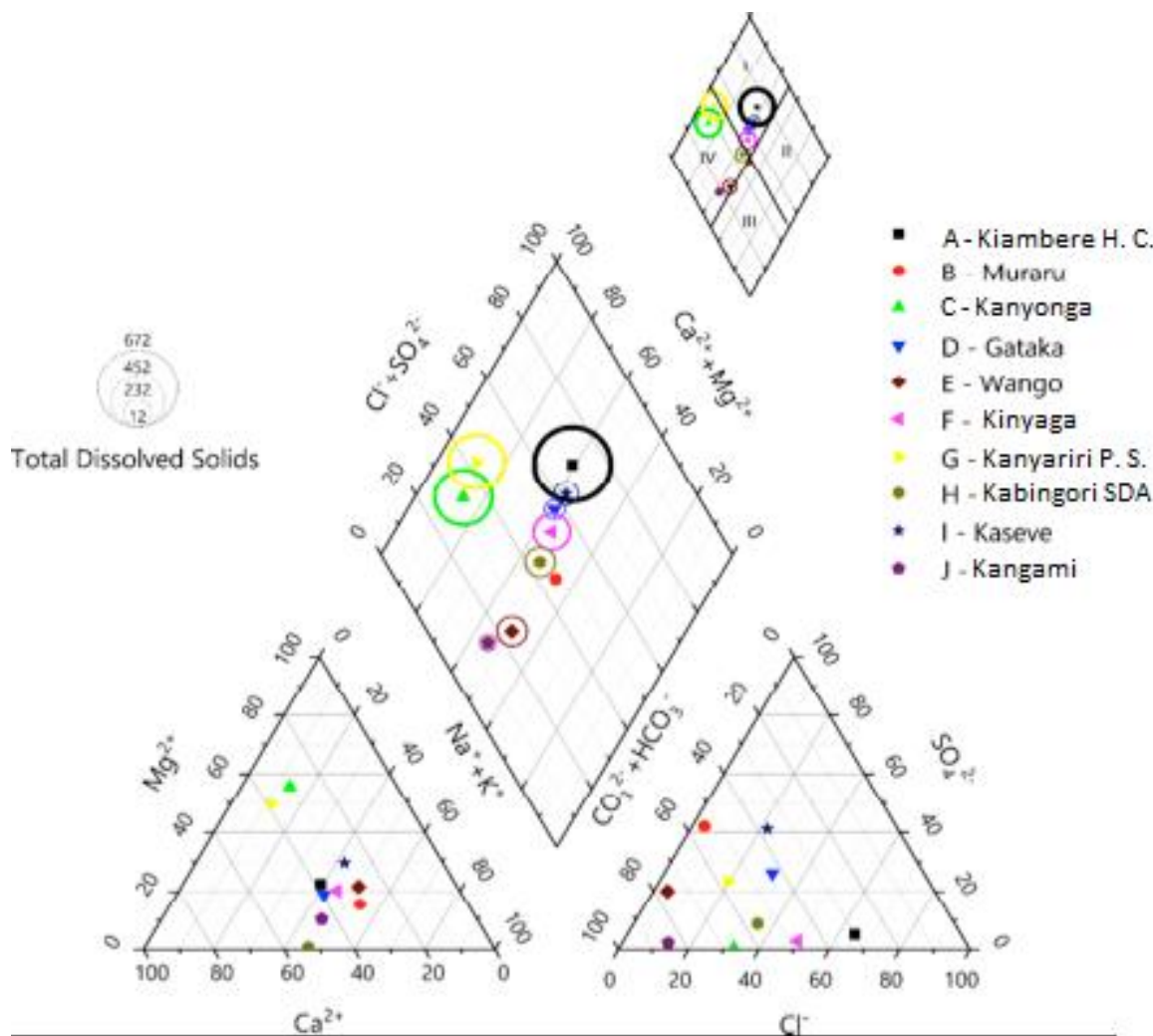
The Piper diagram obtained is presented in Figure 3.1;

Figure 3.1. A Piper Plot for the Groundwater

From the piper trilinear diagram, it is apparent that 40% of the samples belong to Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-} (field I; fields are named on the top right diamond). This is due to the dominance of alkaline earths over alkalis (Ca^{2+}+Mg^{2+}> Na^++K^+) and strong acidic anions over weak acidic anions (Cl^-+SO_4^{2-}> HCO_3^-). It was observed that 40% of the samples plotted under field IV belong to Na^+-K^+-Cl^--SO_4^{2-}. This could be attributed to the dominance of alkalis over alkaline earths and strong acidic anions over weak acidic anions. It was further observed that 20% of the samples under field III belong to Na^+-K^+-HCO_3^- .This was caused by mixing of waters or water-rock interactions. It also shows the shifting of waters from Ca - HCO_3 to Na - HCO_3. No samples observed to be represented in Ca^{2+}-Mg^{2+}-HCO_3^- region implying that there was no recharge or fresh waters in the study area.

3.1.2 Durov Diagram

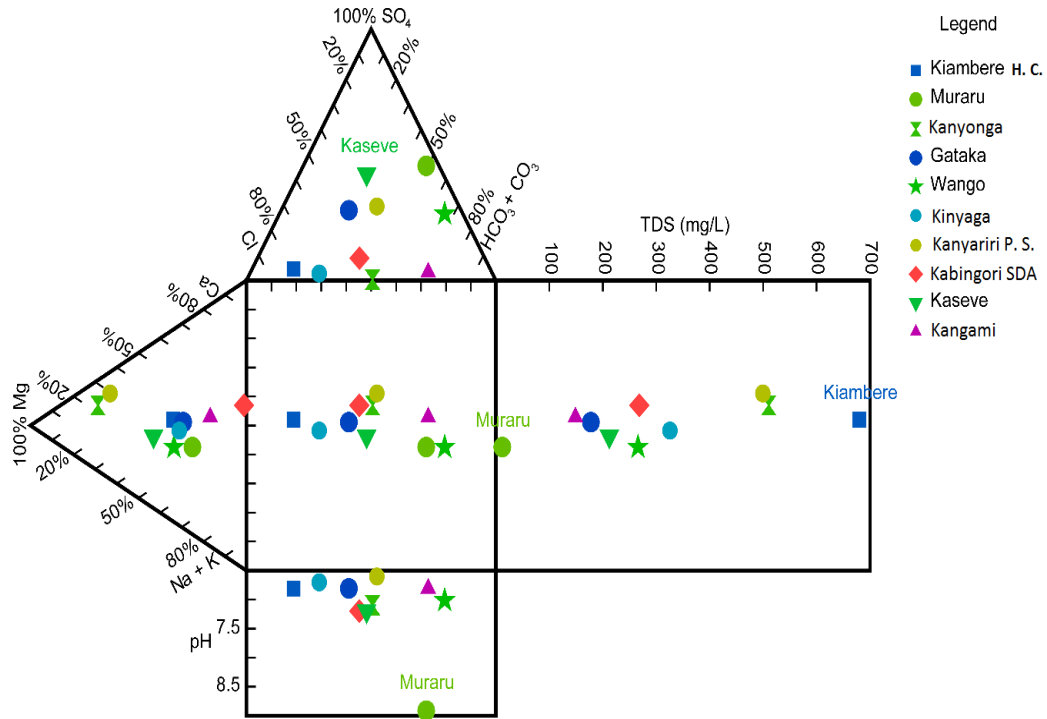The Durov diagram obtained is presented in Figure 3.1;

Figure 2.1. Durov Diagram for Sampled Boreholes

The Durov diagram shows that 50.0 % of the samples in the graph are along the mixing line. This trend was attributed to the fresh recent recharge water exhibiting simple dissolution or mixing with no dominant major anion. In addition, 30 % of the samples show SO_4 dominant or anion discriminate and Na^+ dominant which is a water type that is not frequently encountered and indicates probable mixing or uncommon dissolution influences. Of the 20% remaining samples, Ca and SO_4 dominates which indicates recharge water in lava and gypsiferous deposits, otherwise mixed water or water exhibiting simple dissolution may be implied. The Durov plot also shows that the samples from Muraru had the highest pH and with the lowest Total Dissolved Solids (TDS) while Kiambere H. C. had the highests TDS whereas the rest of the samples were within TDS, WHO standards. These observations were also supported by the series plots in Figures 3.2 and 3.3.
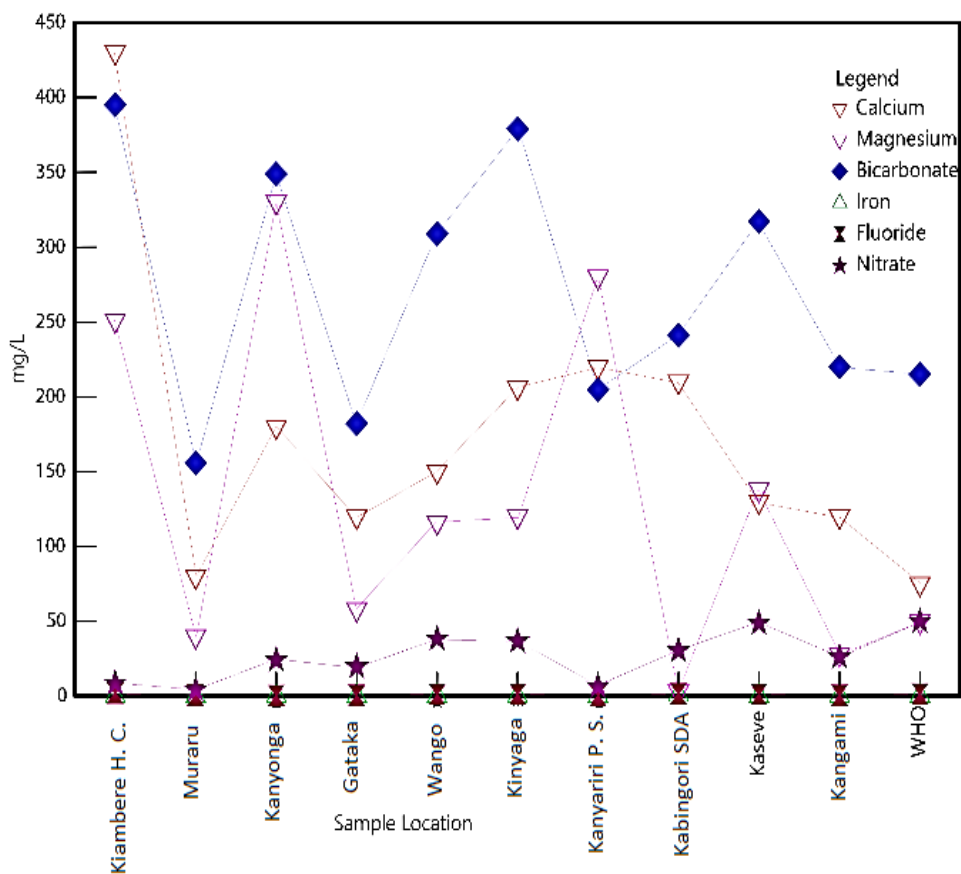
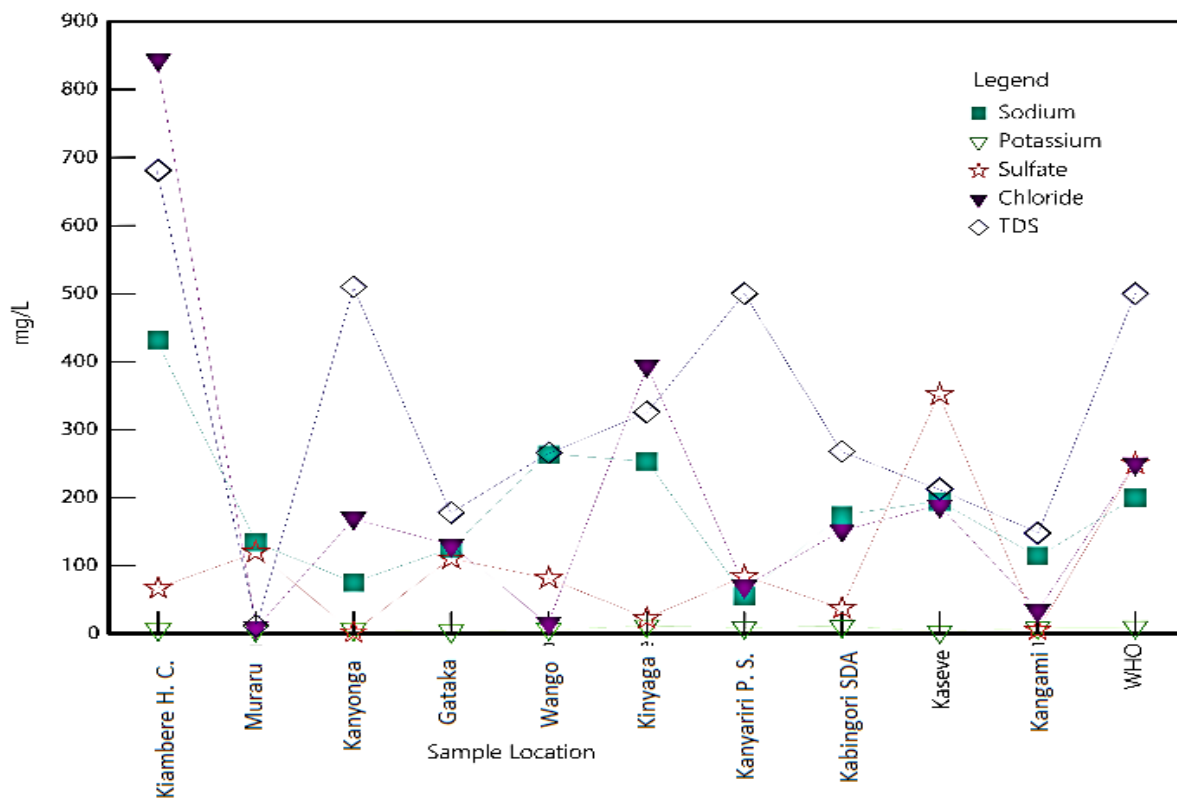Figure 3.2. Series Plots for the Borehole Water Minerals

Figure 3.3. Series Plots for the Borehole Water Minerals– Continued.

3.2 Irrigation Water Quality

The irrigation water quality resulsts obtained from AqQA software are presented in Table 3.2;

Table 3.2. Results for the Quality of Water for Irrigation Purposes

Site	Water Sample	Salinity Hazard	Sodium Adsorption Ratio (SAR)	Magnesium Hazard (MH)
A	Kiambere H. C.	High	4.090	49
B	Muraru	Low	3.070	45.2
C	Kanyonga	High	0.7710	75.1
D	Gataka	Low	2.330	44.4
E	Wango	Medium	3.930	56
F	Kinyaga	Medium	3.470	49
G	Kanyariri P. S.	Medium	0.5850	67.7
H	Kabingori SDA	Medium	3.270	2.3
I	Kaseve	Medium	2.830	63.6
J	Kangami	Low	2.450	27.8

Kiambere H. C. and Kanyonga waters possess high salinities (500-1500mg/L). .High salinity in ground water can be attributed to increased groundwater recharge, due to irrigation which mobilizes naturally accumulated salts in the soil. High salinity (500-1500mg/L) causes adverse effects on many crops, since it reduces the osmotic activity of plants (Zheming *et al.,* 2017). Low salinity (< 200mg/L) waters were exhibited in sites B, D and J. This can be attributed to the low levels of sodium and chloride ions in these boreholes as observed in Table 4.1. Low salinity has no detrimental effects on crops hence these waters can be used for irrigation purposes with respect to this parameter.

Sites E, F, G, H, and I had Medium salinity (200-500mg/L).This could be as a result of medium levels of sodium and chloride in these boreholes with the exception of site G (Table 4.1). Medium salinity hazard has detrimental effects to sensitive crops hence these waters should be used with caution.

From the data, sites A, C and E had the highest SAR, above 3. This could be attributed to halite dissolution, agricultural activities, and pollution from domestic sewerages or cation exchange processes in these areas. High sodium ions in water affect the permeability of soil and causes infiltration problems. The higher the SAR, the less suitable the water is for irrigation and when SAR is less than 3, there is usually no problem (Zheming *et al.,* 2017).

3.3 Saturation Index, SI

The saturation indices for the varied phases simulated using PREEQC are presented in Table 3.3;

Table 3.3. Saturation Indices for the Varied Phases Simulated

Phase	Saturation Indices, SI										Chemical Formula
	Kiambere H. C.	Muraru	Kanyonga	Gataka	Wango	Kinyaga	Kanyariri P. S.	Kabingori SDA	Kaseve	Kangami	
Anhydrite	-1.78	-1.8	-3.5	-1.72	-1.87	-2.35	-1.86	-1.94	-1.35	-2.92	$CaSO_4$
Aragonite	0.18	1.22	0.12	-0.54	-0.04	-0.15	-0.54	0.24	0.05	-0.41	$CaCO_3$
Calcite	0.32	1.36	0.26	-0.4	0.1	-0.01	-0.39	0.38	0.2	-0.27	$CaCO_3$
Dolomite	0.82	2.8	1.19	-0.75	0.48	0.13	-0.31	-0.7	0.8	-0.79	$CaMg(CO_3)_2$
Gypsum	-1.58	-1.59	-3.3	-1.51	-1.67	-2.14	-1.64	-1.73	-1.14	-2.7	$CaSO_4{:}2H_2O$
Halite	-5.13	-7.47	-6.56	-6.41	-7.01	-5.65	-7.06	-6.2	-6.09	-7.01	NaCl
Hydromagnesite	-12.25	-4.99	-9.74	-16.26	-12.58	-14.16	-14.31	-19.6	-11.24	-17.23	$Mg_5(CO_3)_4(OH)_2{:}4H_2O$
Portlandite	-11.27	-7.76	-10.99	-11.85	-11.26	-11.78	-12.07	-10.71	-10.95	-11.81	$Ca(OH)_2$
Trona	-12.66	-12.89	-14.68	-14.82	-13.16	-13.4	-16.12	-13.69	-13.34	-14.72	$NaHCO_3{:}Na_2CO_3{:}2H_2O$

SI<0 Undersaturated, SI>0 Supersaturated, SI=0 Equilibrium phase with underground water

The calculated saturation index values of calcite, aragonite, dolomite, gypsum, anhydrite, halite, hydromagnesite, portlandite, and trona, demonstrated that nearly all groundwater samples of Mbeere South aquifer are slightly saturated with regards to aragonite, calcite and dolomite. This could be attributed to an input in excess of Mg^{2+} and Ca^{2+} ions from aragonite, calcite and dolomite weathering processes. The saturation of carbonate phases usually influences the groundwater composition and leads to the precipitation of calcium as Ca or Ca-Mg carbonate under suitable physico-chemical conditions. The decline in alkalinity, pH and saturation index connected with precipitation of calcium carbonate can be explained by the following Equations 3.1 and 3.2 (Shodhganga, 2012).

$$Ca^{2+} + HCO_3^- \rightarrow CaCO_3\,(s) + H^+ \qquad 3.1$$

$$H^+ + HCO_3^- \rightarrow CO_2\,(g) + H_2O(l) \qquad 3.2$$
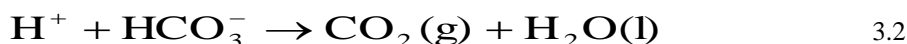
Similar results were reported by Zheming *et al.* (2017), where they attributed oversaturation of calcite and dolomite to their dissolution.

All the samples were slightly undersaturated with respect to anhydrite, gypsum, and halite and undersaturated with respect to hydromagnesite, portlandite and Trona. This is perhaps due to the fact that the soluble components in halite, hydromagnesite, portlandite trona and gypsum were limited by the mineral equilibrium. This implies that the dissolution of these minerals may occur in the respective boreholes.

4. Conclusions

1. With the exception of Muraru, all the other boreholes had some elevated levels of cations and anions: Kiambere-Ca^{2+}, Mg^{2+}, Na^+, F^-, Cl^-; Kinyaga-Mg^{2+}, K^+, Na^+, Cl^-, NO_3^-; Kabingori SDA-K^+, Fe^{2+}, F^-, NO_{3-}; Wango-Mg^{2+}, Na^+, NO_3; Kanyonga& Kaseve-Mg^{2+}, NO_3^-; Gataka &Kangami-NO_3^-; Kanyariri P. S.-Mg^{2+} .The pH of muraru(8.9) was higher than the WHO permissible limit.

2. Gataka, Kanyariri P. S. and Kangami SI<0 in all the rock salts; the other boreholes, SI>0 in Aragonite, Calcite and Dolomite with undersaturation in Anhydrite, Gypsum, Halite, Hydromagnesite, Trona and Portlandite. The hydrochemical processes controlling groundwater chemistry are; atmospheric precipitation, dissolution of salt deposits within the vadose zones and weathering of halite, anhydrite, gypsum, huntite, hydromagnesite, artinite, dolomite and magnesite.

3. Kiambere H. C., Kinyaga, and Kaseve groundwater samples did not meet the permissible limit for domestic use purposes based on their concentration of Mg, Ca, K, Na, F, Cl, and total dissolved solids . their respective concentrations were above WHO and EAS 12:2014standards. For Instance, Kiambere H. C. well had higher concetrations of Ca^{2+}, Mg^{2+}, K^+, F^-, and Cl^- above the WHO and KEBS standards. Generally, the levels of Ca^{2+} and Mg^{2+} were higher than allowed standards for all the sampled boreholes.

4. Kiambere H. C, Kinyaga and Wango borehole waters are not suitable for irrigation purposes with respect to SAR while Kiambere H. C. and Kanyonga borehole waters not suitable for irrigation purposes with respect to Salinity Hazards.

5. Recommendations

This study recommends that regular and improved monitoring of groundwater quality be carried out in order to establish which parameters certainty affects the trends of groundwater quality. It is also recommended that determination of seasonal variations of various components of groundwater be carried out. An exhaustive geologic exploration should also be conducted for the groundwater in the region in order to establish the causes of variations of borehole water quality parameters.

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