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Analysis of Constituent Chemicals and their Effects on the Physico-Chemical Properties of Spring Water in Ngariama location Gichugu Division Kirinyaga County of Kenya

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Abstract

Gichugu division has numerous springs, which are a manifestation of potentially high volumes of groundwater. This water is characteristically different from river water in terms of physical parameters like fizzling, characteristic taste and clarity. Its chemistry was studied to explain the above differences. The study established that groundwater in Gichugu area is slightly acidic (pH 6.49), moderately hard (123.99 mg/l $CaCO_3$) and $NaHCO_3$/NaCl type (362.94 mg/l Na, 147.24 mg/l HCO_3^-, 6.58 mg/l Cl^-). These salts and the pH explained the taste of the water. Also, NaCl and other ionic compounds accounted for the relatively higher conductivity (4.700 Ec μS/cm) while such ions as Ca^{2+} and Mg^{2+} explained the moderate hardness of this ground water. The percolation of this water through the surface soils of recharge areas generally results in significant purification hence the clarity. Fizzling was as a result of dissolved gases such as carbon dioxide and oxygen as they escaped. It was also established that a common groundwater aquifer underlies the area. Iron (0.426 mg/1) and manganese (0.322 mg/1) were found in excess of WHO recommended limits (0.3 mg/1 and 0.1 mg/1 respectively) for potable water quality while fluoride was in relatively low amounts (0.642 mg/1). However, their levels in this water do not make this water unsuitable for drinking since they are still within the acceptable tolerance levels.

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Introduction

Water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking-water can result in tangible benefits to health. Every effort should be made to achieve drinking-water that is as safe as practicable (WHO, 2011). Increased public awareness of environmental issues has caused consumers to be conscious about the quality of drinking water. This is reflected by the large increase of the sales of bottled water and home treatment systems (Ogenge, et al., 2002). Natural water quality varies from place to place, with the seasons, climate and the types of soils and rocks through which water moves (Gail, et al., 2001). Though spring water has been considered to be pure because of its filtration through layers of soil, it has its own health and acceptability problems based on concentration level of certain chemical parameters. It is therefore important to understand the level of toxicity of the chemical elements and compounds in water used for domestic purposes. It is also important to know the quality of water in any community and the 'quality requirements' for various water users (Ogenge, et al., 2002). While most chemical elements in groundwater such as Zinc, Copper, Manganese and Lead are potentially toxic; other essential elements like fluoride and Iron (at required levels) may give rise to health problems due to their deficiency in water. The toxicological and deficiency problems of the chemical constituents in water continue to become more apparent as people progressively switch from traditional supplies of surface water to biologically safer groundwater. It is consequently important to understand groundwater characteristics in terms of its chemical constituents (Ogenge, et al., 2002). The basic requirements for drinking water are that it should be free from pathogenic organisms, containing no compounds that have an adverse effect in the short or long term on human health, fairly clear i.e. low turbidity, little colour, not saline. It should contain no compounds that cause an offensive taste or smell and not causing corrosion or encrustation of the water supply system or staining of clothes washed in it.

Gichugu division of Kirinyaga district has numerous streams/rivers and protected springs, which serve as the sources of water for domestic use to the surrounding communities. The springs such as Kindiri, Kongu, Ngungu, Kabuga, Kainamui among others and streams such as River Kiringa, Kabuyu, Nyamindi, Kathogondo among others are a manifestation of the potentially high volume of ground and surface water in the area. These springs are either from within the stream or near a river/stream. The strangest aspect of spring water is that it is very different from the water in the river/ stream in terms of taste, clarity and also

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the way it fizzles like carbonated water. People of Gichugu call it Munyu (salt), which suggests that the water is salty. This taste makes Gichugu people to drink this water and not the stream water, which they use for any other domestic use like washing and cooking. Their animals drink from the springs also. The altered physical characteristics are thought to be due to some chemical constituents and should be of interest therefore to find out the chemical constituents of this water which was the core objective of our study. The knowledge of the chemical compositions therefore, goes a long way in trying to understand the relationship between chemical composition and these physico–chemical properties of the water. It is also useful to all those concerned with issues relating to water quality and health, including environmental and public health scientists, water scientists, policy-makers and those responsible for developing standards and regulations.

Methodology

Sample Collection

Using clearly labelled 1-litre polythene bottles, water samples were collected in replicate from three springs and three streams (Figure 1-3) of Ngariama location of Gichugu division. They were refrigerated pending laboratory analysis. The refrigeration was to avoid any chemical reactions likely to occur before laboratory analysis. Certain properties of water, especially its pH, temperature, conductance and dissolved oxygen are so closely related to the environment of the water, that they are likely to be altered by sampling and storage, and a meaningful value can be obtained only in the field. They were therefore measured at the collection site by use of Jenway model 3405-electrochemical analyser.

Determination of Cations

Cations analysed included Fe^{2+}, Fe^{3+}, Zn^{2+}, Cd^{2+}, Cu^{2+}, Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Co^{2+}, Mn^{2+} and Pb^{2+} whereas anions included NO_3^-, NO_2^-, Cl^-, HCO_3^- and F^-. Cationic determination was done using ChemTech Analytical CTA-2000 AAS and Corning M410, Ciba Corning Diagnostic Scientific frame photometer. Standard addition method was used since it helps to avoid effect of interference where sample matrix is unknown. The samples were pre-treated with nitric acid to release more of the metals held in suspended particles. For Mg^{2+} and Ca^{2+}, 1 ml lanthanide chloride was added. Frame photometer was used for Na and K because it provides rapid, accurate results and can be applied to trace levels of these ions.

Non-Metal Determination

Manual phenate method with sensitivity of 10μg NH_3/l was used for NH_3 because of the concentration suspected to be present in the water samples. SP6-500 UV-Vis spectrophometer Pye Unicum model was used for NO_3^-, NO_2^- and Cl^-. Ion selective electrode model 96-09 was used for F^-. It makes it possible to measure total amount of free and complex-bound fluoride dissolved in water. Total hardness and bicarbonates were determined using titrimetric method.

Results and Discussion

Chemical analyses carried out in this study area were on groundwater and surface water from 6 sources; 3 springs and 3 streams that were used as representatives of domestic water sources of Ngariama location Gichugu Division. In every site visited, a spring and a stream were sampled. Tables 1 and 2 show concentration of each investigated physical and chemical parameters.

From the tables one can tell the physico-chemical parameters contributing to quality of each particular source (spring or stream) e.g. of all the investigated chemical parameters in munyu wa Matiru and Nyamindi river sodium is the most abundant (360.24 mg/l, 4.104mg/l) among the cations and bicarbonate (166.7 mg/l, 86.00 mg/l) among the anions respectively. The spring water is slightly acidic with a pH of 6.49 and also slightly hard (127.0 mg/l of $CaCO_3$) while the stream water is almost neutral with a pH of 7.68 and is soft with total hardness of (1.60 mg/l).

This study however looks at the general contribution of each parameter to the quality of groundwater and surface water of Gichugu area hence the mean values. Tables 3, 4 and 5 give the mean values of each parameter in the springs (Source 1) and in the streams (source 2). They also show the extent of variation (whether significant or insignificant at α=0.05) for each parameter.

The most abundant constituents in groundwater are two alkali metals sodium (with a mean of 362.68 mg/1) and potassium (with a mean of 38.587 mg/1) and two alkaline earth metals calcium (with a mean of 83.267 mg/1) and magnesium (with a mean of 123.6 mg/1). For the anions, bicarbonate (with a mean of 147.24 mg/1) is the most abundant while nitrate (0.084 mg/1), chloride (6.580 mg/1), fluoride (0.642 mg/1), ammonia (0.177 mg/1) and nitrite (0.035 mg/1) all occur in small but rather appreciable amounts.

Electrical conductivity levels range from 0.05 μS/cm to 5.73 μS/cm with a mean value of 4.7 μS/cm and 0.043 μS/cm in the groundwater and surface water respectively. The pH values were 6.41 in the groundwater and 7.56 in the surface water. Dissolved oxygen had a mean value of 0.6 mg/1 in the groundwater and 1.967 mg/1 in the surface water. Total hardness measured in the groundwater ranged between 121 - 127 mg/1 in the groundwater and 1.6 -3.2 mg/1 in the surface water. Similarly, calcium, magnesium, potassium and sodium are still the most abundant cationic constituents in surface water although their mean values are much less compared to those of the groundwater. For anions, bicarbonate is the most abundant followed by chloride.

Correlation analysis carried out on the data from the 3 different sites and two different sources (springs and streams) of the study area yielded significant variations between the sources but showed no significant differences between the sites. This insignificant variation between the sites suggests that one groundwater aquifer generally underlies Gichugu

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area. Between the sources however, most elements and physical parameters had higher concentrations in groundwater than in surface water but the trend is similar (figure. 4, 5 and 6).

Ordinarily, higher concentrations of dissolved constituents are found in groundwater than in surface water. This is because of the greater exposure to soluble materials in geologic strata. Soluble salts in groundwater are thought to have originated primarily from solution of rock materials. As groundwater moves through the aquifer, contact with soluble rocks may result in dramatic increase in dissolved minerals, particularly calcium bicarbonate $Ca(HCO_3)_2$; Magnesium bicarbonate $Mg(HCO_3)_2$ etc. (Douglas and Considine, 1984). This difference in chemical composition is the likely cause of differences in physical properties.

Sodium and bicarbonate ions are the most abundant in the ground waters of this area and hence $NaHC0_3$ salt is formed. Chloride is also known to occur as sodium chloride in groundwater (Garg, 1987). It can therefore be inferred that groundwater of this area is $NaHCO_3$/ NaCI type. Sodium ion in these salts exceeds the required amounts on taste basis hence it is thought to be responsible for the characteristic taste. One of the possibly sources of Sodium in the waters of this area is agricultural runoff as fertilizers are quite extensively used for maize, tea, coffee, beans and horticultural crops production. Bicarbonate, usually the primary anion in groundwater is derived from carbon dioxide released by organic decomposition in the soil (Todd, 1980).

Magnesium and calcium are some of the alkaline earth metals that are widely distributed in the earth's crust and are present in almost all waters as is the case in the waters of this area. Calcium occurs as $CaCO_3$ and $Ca(HCO_3)_2$ although in waters of high salinity, calcium chloride and nitrates can also be found. This is based on the fact that in the presence of carbon dioxide, calcium bicarbonate can normally be dissolved up to 20 g/l (as Ca) at atmospheric pressure and up to 100 g/l at higher pressures, though the concentration may be much higher in water coming from limestone areas (equation 1).

$$CaCO_{3(s)} + H_2O_{(l)} \rightarrow Ca(HCO_3)_{2(aq)} \ldots\ldots \text{(Equation 1)}$$

Also, the presence of sodium and potassium salts increases the solubility of calcium carbonate. This behaviour of magnesium resembles that of calcium although its solubility is about ten times that of calcium (Garg, 1987). The relatively high levels of these elements in the groundwater of Gichugu division confirm the water hardness. Calcium hydrogen carbonate forms temporary hardness that can be removed by boiling the water so that the carbon dioxide is driven out and the carbonates get precipitated. Magnesium also forms highly soluble salts which contribute to both carbonate and non-carbonate hardness but to a lesser extent than the calcium component. There is no health objection to high calcium and magnesium content in water; on the contrary both minerals are essential to humans; the main limitations being on basis of excessive scaling, hardness, taste and alkalinity (CDN, 2000). The chloride salts of magnesium and calcium i.e. CaCl and $MgCl_2$ are not usually detected by taste until levels of 1000 mg/l The UK regulations set an average maximum of 250 mg/1 for calcium and 50 mg/1 for magnesium but no maximums are set under WHO, EC or EPA standards (Twort et al., 1994).

Groundwater of this area is moderately hard while surface water is soft. Water with hardness above 200 mg $CaCO_3$/l tends to cause scale deposition in distribution systems. However, the level of corrosion or deposition is dependent on pH, alkalinity, dissolved oxygen and temperature in the water (CDN, 2000).

High iron and manganese levels are objectionable in water supplies used for domestic purposes. They cause unpleasant tastes, stain laundry and plumbing fixtures. In groundwater, the occurrence of iron at concentration of 1.0-10 mg/1 is common. In the waters of Gichugu division, the mean values of iron are 0.426 mg/1 in groundwaters and 0.076 mg/1 in the surface waters. However, higher concentrations (above 50 mg/1) are possible in low bicarbonated and low oxygen water. It may be present in varying quantities depending upon the geological area and other chemical components of the waterway. Iron in the groundwater of this area is slightly above the WHO recommended value. However, it appears to be more of a nuisance than a potential health hazard. According to CDN report (2000), consumers can find iron levels between 0.3 mg/l and 3 mg/1 acceptable. Taste thresholds of iron in water are 0.1 mg/1 for ferrous iron and 0.2 mg/1 ferric iron, giving a bitter or an astringent taste. The iron standard given for domestic and drinking water (0.3 mg/l) is meant to prevent objectionable tastes or laundry staining and is therefore of aesthetic rather than toxicological significance although iron at high concentrations is toxic to livestock by interfering with the metabolism of phosphorus (WHO, 2011).

Concentrations of manganese rarely exceed 1.0 mg/1 in well-aerated surface water, but much higher concentration can occur in the groundwaters subject to reducing conditions. It occurs in groundwater much less frequently and with smaller concentration than iron, which it resembles in behaviour. It occurs as soluble manganese bicarbonate (Garg, 1987). The WHO has given a provisional value (0.5 mg/1) based on toxicity and for lower level required to avoid deposition problems (Twort et al., 1994). At concentrations exceeding 0.1 mg/l, the manganese ion imparts an undesirable taste to beverages and stains plumbing fixtures and laundry When manganese (II) compounds in solution undergo oxidation, manganese is precipitated as manganese (IV) e.g. MnO_2, resulting in encrustation problems (WHO, 2011).

The mean value of manganese in the groundwater of Gichugu; (0.322 mg/1) is above WHO guideline value (0.1 mg/1) given on health basis and also to avoid staining of laundry. This makes the groundwater unsuitable for washing. Manganese intake from drinking water is normally substantially lower than intake from food. At typical drinking-water levels of 4-30 jug/l, the intake of manganese would range from 8 to 60 μg/day for an adult. Other sources indicate that manganese intake from water can be an order of magnitude higher (Environmental Criteria and Assessment

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Office, 1984). Drinking this water regularly can add significantly to manganese intake (Dieter et al., 2006). Mean value for surface water (0.04 mg/l) is within WHO guideline value.

Copper, Cadmium and Cobalt, were found in trace amounts in the two sources; streams and springs. In fact, they were insignificantly different. Table 4 shows that they are also within WHO recommended values. Zinc was found only in trace amounts i.e. 0.017 mg/1 in groundwater and 0.002 mg/1 in surface water. These concentrations are unlikely to be detrimental to health. WHO recommends 3 mg/1 maximum. Lead is rarely detectable below 0.02 mg/1 in most waters. The mean values of Lead in this water are 0.073 mg/1 in groundwater and 0.013 mg/1 in surface water. The WHO 1993 revised guideline value is 0.01 mg/1 (formerly 0.05 mg/1) but it recognises that not all waters will meet the guideline immediately (Twort et al., 1994).

Chloride and fluoride in water are not usually harmful to people at recommended values. Fluorides may occur naturally in water and unlike chlorides, they have low solubility. The groundwater of Gichugu area has a mean value of 0.642 mg/1 while surface water has 0.14 mg/1. These are obtained from dissolution of fluorite (calcium fluoride). Levels not more than 1 mg/1 of fluoride are safe and effective in reducing dental caries. Ordinarily, concentration of fluoride (F) in groundwater does not exceed 10 g/l. The maximum concentration has to be related to climate, local circumstances and amount of water consumed (Garg, 1987). On the other hand, chloride in groundwater does not exceed 5 g/l, and water high in chloride is also high in sodium. As mentioned earlier, chloride in groundwater is generally present as sodium chloride and to a lesser extent as calcium and magnesium chlorides. The sodium chloride salt in the groundwater explains the high conductivity compared to the surface water. The salt acts as an electrolyte. It dissociates to Na^+ and Cl^- ions.

Chlorides are not usually harmful to people; however, the sodium part of table salt has been linked to heart and kidney disease. Public drinking water standards require chloride levels not to exceed 250 mg/1 (Garg, 1987 & Twort et al., 1994). They may get into water from several sources including; rocks containing chlorides, agricultural runoff, wastewater from industries, oil well wastes, and effluent wastewater from wastewater treatment plants.

The quantity of dissolved oxygen in groundwater is generally very low. This is because most of the oxygen dissolved from the atmosphere is used up in oxidising organic matter during the downward passage of water. Up to 29 g/l of air can be dissolved in water at atmospheric pressure and at 0°C out of which oxygen is 10 g/l. Adequate dissolved oxygen is necessary for good water quality. Oxygen is a necessary element to all forms of life. Natural stream purification processes require adequate oxygen levels in order to provide for aerobic life forms. As dissolved oxygen levels in water drop below 5.0 mg/1, aquatic life is put under stress. Oxygen is however known to hasten the corrosive action of water on steel, iron and brass. No health-based guideline value is recommended (Garg, 1987).

In most natural waters, pH is controlled by the carbon dioxide–bicarbonate–carbonate equilibrium system. An increased carbon dioxide concentration therefore lowers pH, whereas a decrease will cause it to rise. Temperature will also affect the equilibria and the pH. In pure water, a decrease in pH of about 0.45 occurs as the temperature is raised by 25 °C. The pH of most natural water lies within the range of 6.5 -8.5. pH outside the range can have adverse effects on the taste, colour and appearance of water. Groundwater from sampled springs was slightly acidic while the surface water was neutral. This is due to the inter-relationship between free carbon dioxide and the amounts of carbonate and bicarbonates present. The free CO_2 combines with water partly to form carbonic acid ($H2CO_3$) which is further dissociated into hydrogen (H^+) and bicarbonate (HCO_3^-) ions. The bicarbonate ions thus formed get further dissociated into H^+ and carbonate (CO_3^{2-}) ions (equation 2).

$$CO_2 + H_2O \rightarrow H_2CO_3$$
$$H_2CO_3 \rightarrow HCO_3^- + H^+ \ldots\ldots\ldots\ldots\ldots\ldots\text{(equation 2)}$$
$$HCO_3^- \rightarrow CO_3^{2-} + H^+$$

The hydrogen ion contributes to the weak acidity of water. The carbonate and the bicarbonate ions in water further yield hydroxyl (OH^-) ions, which lead to the rise in pH (equation 3).

$$CO_3^{2-} + 2H_2O \rightarrow H_2CO_3 + 2OH^-$$
$$HCO_3^- + H_2O \rightarrow H_2CO_3 + OH^- \ldots\ldots\text{(equation 3)}$$

This interrelationship yields H_2CO_3 (lowers the pH), H^+ (lowers pH), and OH^- (raises pH) ions, hence the above range. No health-based guideline value is proposed for pH (CDN, 2000). Dissolved gases such as carbon dioxide in the water give the fizzling property. Spring water is clearer compared to surface water in this area. This could be due to filtration of groundwater through soil and its long residence time underground (Colin 1995). It comes from aquifers whose waters have been in contact with the atmosphere as recently as a few hours ago or as long ago as few centuries. Its quality characteristics are therefore affected by the downward movement in recharge areas (percolation) and the lateral movement through aquifers (underflow). The percolation of this water through the surface soils of recharge areas generally results in significant purification (Linsley, 1982).

Ammonia, nitrate and nitrite are usually expressed in terms of nitrogen i.e mg/1 -N. their mean concentrations in groundwater of Gichugu are very low. Ordinarily, nitrate concentration in surface water is normally low (0-18 mg $N0_3^-$ /l), but can reach high levels as a result of agricultural runoff, agricultural activities and contamination by human and animal wastes. In groundwater, it is normally below 5-10 mg/1 however, increasing use of artificial fertilizers, the disposal of animal wastes and changes in land use can cause an increase to several hundred mg/1.

The general level of nitrite is not so well documented but is expected to be much less than the concentration of nitrate, as nitrite is reduced to nitrate, which is the most stable form of nitrogen in most natural environments. The effects of nitrates

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and nitrites on humans are very complex and not well established; however there seems to be enough evidence for toxicity to recommend a health-based guideline for both nitrate and nitrite. The WHO recommends a health-based guideline (max) of 50 mg NO_3^-/l and 3 mg $N0_2^-$. As nitrate and nitrite interact, a combined guideline is recommended. Ammonia is of no direct importance to health in the concentrations that can normally be expected in drinking water. Natural levels in groundwater are usually below 0.2 mg/1 while surface water may contain up to 12 mg/1. The taste threshold is 33 mg/1. In the groundwater of Gichugu it is barely 0.176 mg/1 and 1.637 mg/1 in the surface water. The presence of ammonia can be an indicator of faecal pollution. The WHO recommendation is 1.5 mg/1 based on odour (CDN, 2000).

Conclusion

Water should be palatable rather than free from taste and odour, but with people having very different abilities to detect tastes and odour at low concentrations, this is often very difficult to achieve. Users may become accustomed to waters containing high concentrations of major ions, however, and prefer the taste of such water to the "tastelessness" of more dilute solutions. This is so with the people in Gichugu area who prefer the spring water to stream water for drinking. The dissolved cations that constitute a major part of the dissolved-solids content in groundwater of this area are Sodium, Potassium, Calcium and magnesium; the major anions being chloride and bicarbonate. However, their concentrations in the surface water are relatively low. Sodium being the most dominant cation, groundwater of this area can be said to be $NaHCO_3$/NaCI type. These salts give the water a salty taste because the sodium concentration has exceeded the taste threshold (200mg/l) as given by the WHO. In surface water sodium concentration is less by far than the above taste threshold value. These salts explain the high conductivity and hardness of the groundwater compared to surface water. Dissolved gases under pressure explain fizzling in this water as it occurs in Coca-Cola. It causes fizzling in the groundwater as it tries to escape. It also explains the slight acidity of this water whose pH values are below 7.5 but above 6.0. pH is controlled by carbon dioxide–bicarbonate–carbonate equilibrium system and temperature. The slight acidity shows presence of CO_2 forming H_2C0_3 which dissociates to hydrogen ions. The clarity of the groundwater compared to surface water in this area is due to filtration of groundwater through soil and its long residence time underground. This is through underflow and percolation of this water through the surface soils of recharge areas generally resulting in significant purification. The sampled springs recorded iron and manganese concentration levels above 0.3 mg/1 and 0.1 mg/1 respectively thus exceeding the recommended limit for drinking. They also recorded fluoride concentration below the required levels (1.5 mg/1) for drinking water quality by WHO.

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Figure 1: Matiru spring & Nyamindi River

Figure 2: Wanjiku spring & Kathogondo stream

Figure 3: Kainamui spring & Nyamindi River

Table 1: Cations contributing to the groundwater and surface water quality in the study area

	Cation Concentration (mg/l)										
Source	K	Na	Fe	Pb	Cu	Zn	Ca	Mg	Cd	Mn	Co
MwM1	40.59	360.24	0.232	0.055	0.014	0.022	88	128.2	0.001	0.134	0.01
NR1	1.053	4.104	0.074	0.023	0.001	0.002	9	1	0.001	0.024	0.01
MwK2	41.59	359.66	0.777	0.106	0.014	0.011	79	82.4	0.001	0.596	0.01
NR2	0.652	2.158	0.075	0.002	0.004	0.004	4	0.2	0.001	0.054	0.01
MwK3	33.58	368.14	0.27	0.058	0.008	0.017	82.8	50.2	0.001	0.237	0.02
KS3	0.351	1.866	0.08	0.013	0.007	0.001	7	0.4	0.001	0.041	0.01

1,2 and 3 are the numbers of sites in order of sampling

MwM1 –Munyu wa Matiru — NR1 –Nyamindi River

MwK2 –Munyu wa Kainamui — NR2 –Nyamindi River

MwK3 –Munyu wa Wanjiku — KS3 –Wanjiku stream

	Anions and physical Parameters									
Source	NO_3^- mg/l	NO_2^- mg/l	Cl^- mg/l	NH_3 mg/l	F^- mg/l	TH mg/l	pH	DO mg/l	Ec µS/cm	HCO_3^- mg/l	T °C
MwM1	0.085	0.033	7.86	0.35	0.875	127	6.49	0.7	5.73	166.37	25
NR1	0.093	0.022	3.85	2	0.133	1.6	7.68	1.7	0.04	86	25
MwK2	0.08	0.033	5.61	0.11	0.391	123.37	6.4	0.4	4.34	162.62	25
NR2	0.1	0.022	3.44	0.68	0.155	1.6	7.57	2.1	0.05	91	25
MwK3	0.088	0.039	6.27	0.07	0.659	121.6	6.34	0.7	4.03	170.54	25
KS3	0.109	0.024	5.52	2.23	0.133	3.21	7.43	2.1	0.04	95	25

TH –Total hardness , Ec –Electrical conductivity, DO –Dissolved oxygen

Table 2: Mean values of cationic constituents of the groundwater and surface water of Gichugu area

	K	Na	Fe	Pb	Cu	Zn	Ca	Mg	Cd	Mn	Co
Source 1 Mean (mg/l)	38.587	362.680	0.426	0.073	0.012	0.017	83.267	123.600	0.001	0.322	0.013
Std	4.365	4.737	0.304	0.029	0.003	0.006	4.518	4.133	0.000	0.243	0.006
Source 2 Mean (mg/l)	0.685	2.709	0.076	0.013	0.004	0.002	6.667	0.533	0.001	0.040	0.010
Std	0.352	1.217	0.003	0.011	0.003	0.002	2.517	0.416	0.000	0.015	0.000

Std – represents standard deviation

* Mean concentrations for these elements are not significantly different between the two sources (at α=0.05)

Table 3: Mean values of anionic constituents in the groundwater and surface water of Gichugu area

	NO_3^-	NO_2^-	HCO_3^-	Cl^-	F^-	NH_3
Source 1 mean (mg/l)	0.084	0.035	147.240	6.580	0.642	0.177
Std	0.004	0.003	32.493	1.157	0.242	0.151
Source 2 mean (mg/l)	0.101	0.023	88.000	4.27	0.140	1.637
Std	0.008	0.001	2.646	1.102	0.013	0.836

Table 4: Mean values of physical parameters in groundwater and surface water of Gichugu area

	TH mg/l	pH	DO mg/l	Ec µS/cm
Source 1 mean	123.99	6.41	0.600	4.700
Std	2.753	0.075	0.173	0.905
Source 2 mean	2.137	7.560	1.967	0.043
Std	0.930	0.125	0.231	0.006

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Fig 4: Mean values of cationic constituents

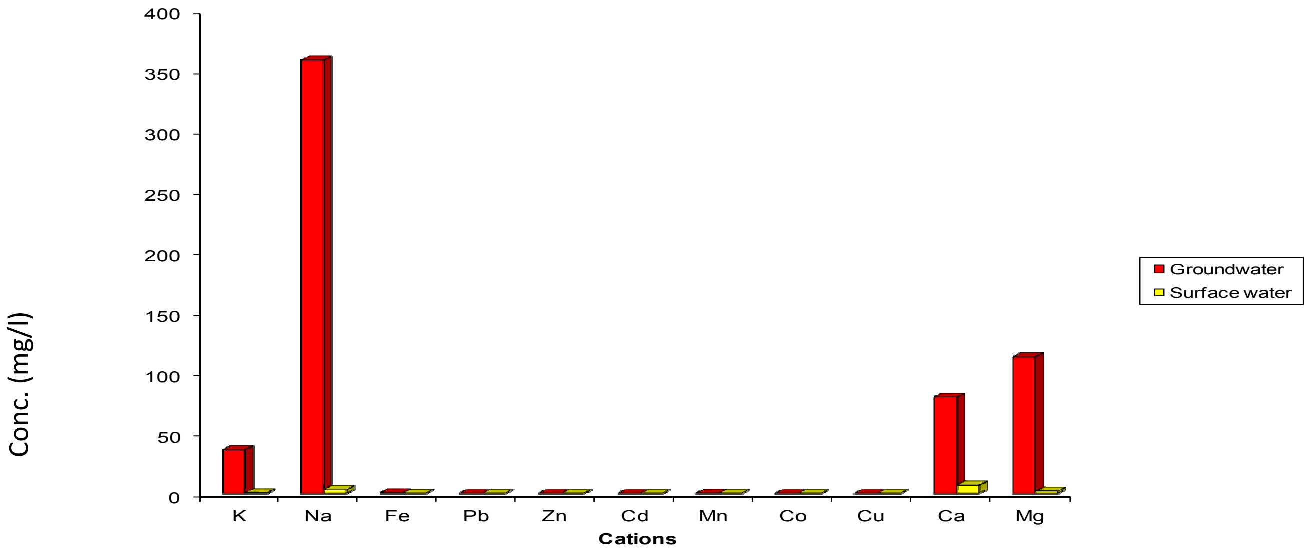


Fig 5: Mean values of anionic constituents

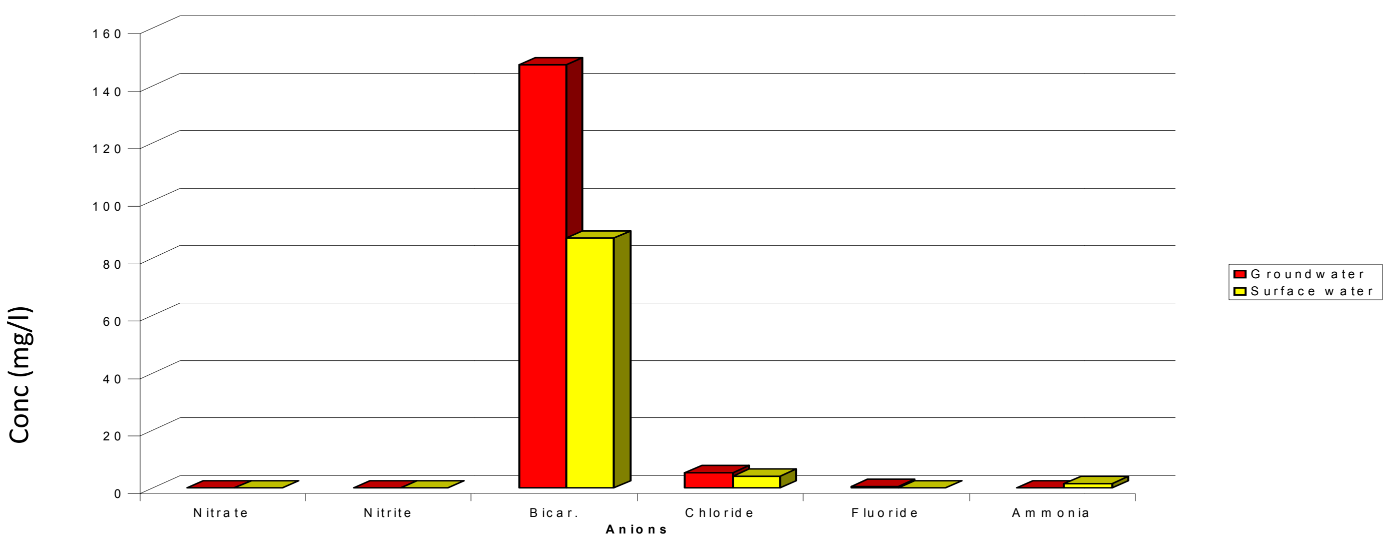
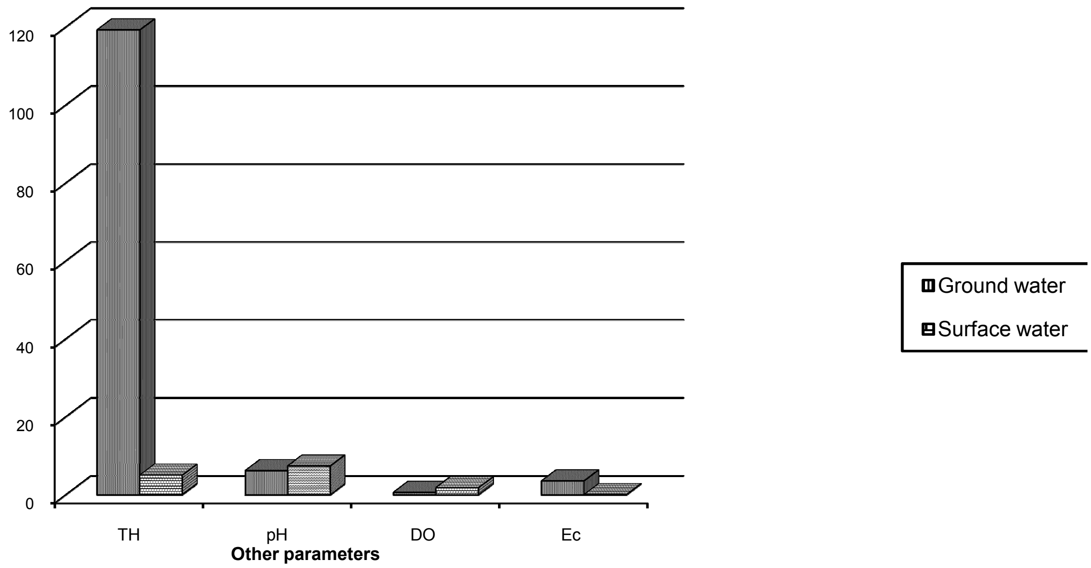


Fig 6: Mean values of other physical parameters



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