Geochemistry of Groundwater in the Volcanic Rocks of Nairobi City

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Abstract - Nairobi City the Capital of Kenya lies on the eastern flank of the Kenya Rift Valley. The geological succession includes metamorphic and igneous rocks as well as interbedded lacustrine and alluvial sediments. Groundwater has been encountered in aquifers within the thirteen different geologic units in the succession. The objective of this study was to analyse the geochemistry of groundwater for major and minor elements, heavy metals as well as the presence of pollutants. The 30 samples were collected and analysed using international standards. Membrane Filter Technique, Ion chromatography, Atomic Absorption Spectrometry and Inductively Coupled Plasma were some of the methods of analysis used. The results show that the physical parameters of the groundwater across the study area range from those within the recommended World Health Organisation limits to those that raise concern such as the high turbidity, pH and electrical conductivity values in boreholes in Embakasi, Industrial area, and Karen. Since these parameters signify potential for microbial contamination, a research should be carried out to analyse their variation and the relationship with lithology and structural geology of the area. Results of this study as well as those of past chemical analyses indicate that major anions and cations concentrations are within the limits recommended by WHO. High nitrate concentrations are detected in the shallow wells. Fluoride content is above internationally recommended limits in majority of the boreholes.

Keywords : groundwater, geochemistry, volcanic rocks, international standards, domestic use, nairobi city.

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GEOCHEMISTRY OF GROUNDWATER IN THE VOLCANIC ROCKS OF NAIROBI CITY

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Caroline Onyancha [α] & Zachary Getenga [σ]

Abstract - Nairobi City the Capital of Kenya lies on the eastern flank of the Kenya Rift Valley. The geological succession includes metamorphic and igneous rocks as well as interbedded lacustrine and alluvial sediments. Groundwater has been encountered in aquifers within the thirteen different geologic units in the succession. The objective of this study was to analyse the geochemistry of groundwater for major and minor elements, heavy metals as well as the presence of pollutants. The 30 samples were collected and analysed using international standards. Membrane Filter Technique, Ion chromatography, Atomic Absorption Spectrometry and Inductively Coupled Plasma were some of the methods of analysis used. The results show that the physical parameters of the groundwater across the study area range from those within the recommended World Health Organisation limits to those that raise concern such as the high turbidity, pH and electrical conductivity values in boreholes in Embakasi, Industrial area, and Karen. Since these parameters signify potential for microbial contamination, a research should be carried out to analyse their variation and the relationship with lithology and structural geology of the area. Results of this study as well as those of past chemical analyses indicate that major anions and cations concentrations are within the limits recommended by WHO. High nitrate concentrations are detected in the shallow wells. Fluoride content is above internationally recommended limits in majority of the boreholes. Past records indicate fluoride contents in the range of 0.5-13.7 ppm. Four elements that are known to endanger life if they occur in drinking water above certain limits (selenium 0.05 ppm, arsenic 0.2 ppm, chromium 0.05 ppm and cyanide 0.01 ppm) have not been investigated. It is recommended that these elements be analysed in future studies. The presence of general coli and E.coli in eight out of ten tested samples underlines the importance of disinfecting the water for domestic use. Shallow wells within the city should be discouraged since the water sampled at Kanungaga and Kabiria was found to be unfit for domestic use due to chemical and bacteriological contamination.

Keywords : *groundwater, geochemistry, volcanic rocks, international standards, domestic use, nairobi city.*

I. Introduction

Nairobi City the Capital of Kenya lies on the eastern flank of the Kenya Rift Valley. The geological succession includes metamorphic and igneous rocks as well as interbedded sediments.

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The metamorphic rocks originate from folding and high temperature and pressure metamorphism of ancient sediments in the period between late Precambrian and Lower Palaeozoic. Following the metamorphism and folding, the area was subjected to erosion that lasted for more than 400 million years, leaving an erosion surface dated to end Cretaceous Age.

In the Upper Miocene times, volcanic lava started flowing across the eroded surface from the edge of the newly-formed Rift Valley. This led to the formation of welded and vesicular phonolitic and trachytic tuffs. At some stage during the formation of the volcanic rocks, the area being at the edge of the rift valley was covered with water. Lacustrine sediments were formed in between the volcanic flows that were cooled under subaqueous conditions. Some of these sediments have been found to contain ostracod shells and are rich in obsidian. At the later stages of the volcanism, the lake(s) dried up and some pyroclastic volcanic flows were deposited under aerial and dry conditions. The pyroclasts covered most of the existing rivers whose alluvial sediments have been encountered in boreholes across the study area. The north- South trending rift valley faults affecting the volcanic rocks have been concealed by the Pleistocene formations or by landscape modification within the city.

Borehole profiles indicate that the interval between the ground surface and the top of the metamorphic rocks comprises alternate layers of volcanic rocks and lake sediments. The volcanism took place over a long period of time with intermediate periods of no activity such that old land surfaces can be recognized (Saggerson, 1991). The thickness of the volcanic rocks and lake sediments was established from a 472 m deep borehole at the Railway Station (BH C-756) within the Nairobi City Centre. Here, metamorphic rocks that are predominantly biotite gneisses, frequently migmatitic and rich in hornblende were encountered (Gevaerts, 1964).

Groundwater abstracted within Nairobi City is encountered within the fractured/weathered volcanic rocks and in the intervening sediments. Figure 1 is a digitized geological map showing thirteen different geologic materials exposed at the surface or encountered in boreholes as well as the sampling sites for this study. The youngest rocks are exposed to the west and the oldest rocks are concealed by Pleistocene and Quaternary deposits to the east.
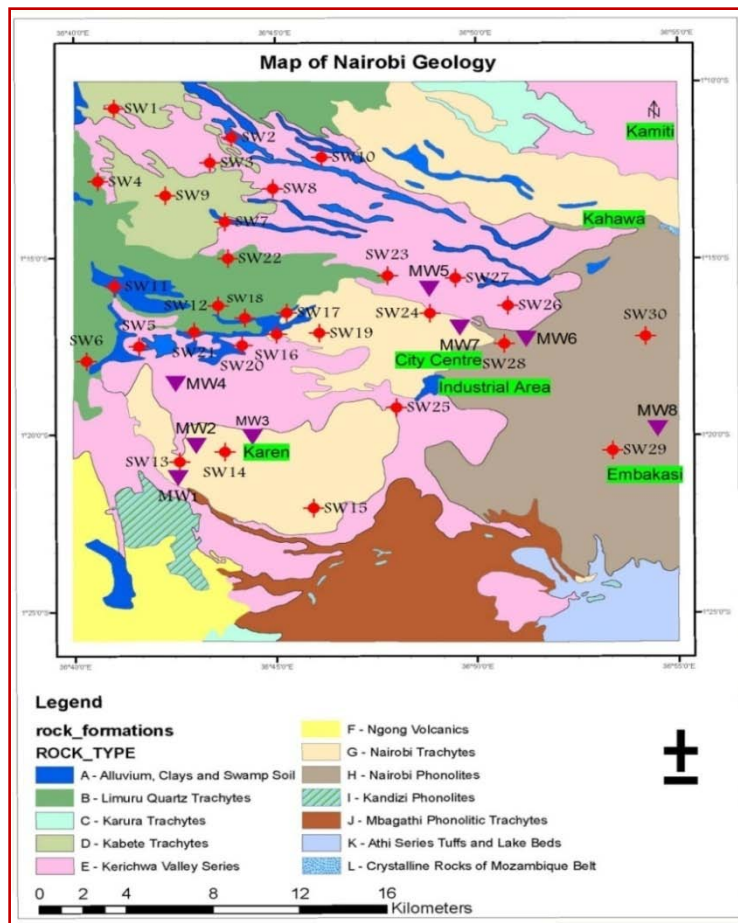
Figure 1 : Digitized geological map of Nairobi City (After Saggerson, 1991) showing study wells (SW) and monitoring wells (MW)

Table 1 presents a geologic profile and summary of thickness ranges of the geological units. The depth of encounter of the geological units varies depending on the shape of the eroded surface at the time of deposition.

Table 1 : Geologic profile and summary of thickness ranges of geological units in Nairobi City

Age	Geologic unit	Thickness range (m)	Total thickness range (m)
Quaternary	Alluvium, clays and swamp soils	1.5-22	
Pleistocene	Limuru Quartz Trachytes	0-25	
Tertiary	Karura Trachytes	0-40	
	Kabete Trachytes	0-32	
	Kerichwa Valley Series	8-45	
	Nairobi Trachytes	0-91	
	Ngong Volcanics	0-58	
	Nairobi Phonolites	0-110	
	Kandizi Phonolites	0-60	
	Mbagathi Phonolitic Trachyte	0-100	
	Athi Series Tuffs and Lake Beds	16-305	
	Kapiti Phonolite	0-53	50-430
Precambrian	Crystalline Rocks of Mozambique Belt	Extending beyond drilled depths	

The role of groundwater in the overall water supply of Nairobi City was discussed by Foster and Tuinhof (2005). They state that surface water supply for Nairobi is undertaken by Nairobi Water and Sewerage Services Company. Most of the water is conveyed by gravity from Ndakaini and Sasumua Dams located more

than 50 kilometres away. The bulk water supply is not reliable during periods of drought, and is also endangered by reservoir siltation associated with catchment deforestation. The supply problem is further aggravated by the inadequate distribution system, which results in about 50% losses due to leakage and illegal connection. Groundwater is thus an important element of the overall city water supply through a large number of publicly and privately-operated boreholes.

Sikes (1934) found out that Nairobi boreholes abstracted water from unconfined, confined and perched aquifers with variable chemical quality. The difference in geochemistry of the groundwater relates not only to the localized geochemical processes but also to compartmentalization due to faulting (Mohamed and Worden (2006). Gevaerts (1964) investigated among other things, the relationship between the chemistry of the rocks and the geochemistry of groundwater. After it was found that the major problem of the groundwater was its characteristic high fluoride content, the World Health Organisation (WHO) carried out a feasibility study on the possibility of augmenting the Nairobi surface water supply with groundwater (Hove, 1973). It was recommended that the groundwater be mixed with surface water in a ratio of 1:1 to make it suitable for drinking purposes. Mailu (1987) related the high fluoride content in the groundwater to the geothermal gases transported through the faults connecting the study area and the rift valley as well as the feldspathoids within the Nairobi volcanic rocks.

In the former and the current Government of Kenya Water Acts, submission of chemical analysis report is a requirement for commissioning a production well. Bacteriological analysis is not mandatory despite the existence of open sewers, unlined septic tanks, waste disposal sites and pit latrines in the vicinity of many of the producing wells. Foster &Tuinhof (2005) recommended the determination of trace elements (arsenic and selenium) in the Nairobi Groundwater in addition to the major and minor element analysis. Onyancha (2012) discusses groundwater head variation that is partly controlled by the N-S trending faults in study area. She states that the faults are deeply buried in the east. Onyancha et al. (2012) modelled spatial and temporal variation of groundwater rest levels in Nairobi City using Geographic Information System and Prod-uced maps and schematic cross-sections. Groundwater level contours were found to correspond to the topography only to change at fault zones or in the vicinity of rivers. Rest level drops and structural control on rest levels were also clearly visualized. The objective of this study was to analyse the geochemistry of groundwater from various aquifers for major and minor elements, heavy metals as well as the presence of pollutants.

II. Materials and Methods

In this study, 30 groundwater samples were collected at the wellhead for chemical and bacteriological analysis. The sampling locations are shown in Figure 1. For chemical analysis, previously cleaned sample bottles were rinsed with groundwater and then filled to the top. Airtight caps were fitted to each bottle prior to transportation to the laboratory. Dissolved oxygen, alkalinity, carbon dioxide, pH, electrical conductivity and temperature were measured immediately upon sample delivery. The samples for chemical analysis were preserved and analysed within the holding period (wood, 1981). Ion chromatography was used for major anions and atomic absorption and inductively coupled plasma (ICP) techniques were used major cations. Samples for bacteriological analysis were collected in sterilized bottles and tightly sealed. Bacteriological tests were carried out within 6 hours of sample collection. For this reason most samples were delivered in the laboratory before 10 am. The bacteriological quality involved assessment of non-pathogenic bacteria of faecal origin i.e. the *E.colli* and *Enterococcus spp.* All the samples were examined using Membrane Filter Technique according to APHA (1998) and United States Pharmacopeia (1995).

Atomic Absorption Spectrometry (AAS) is based on the phenomenon that an atom in the ground state absorbs light of wavelengths that are characteristic of each element when light is passed through the atoms in vapour state. Because this absorption of light depends on the concentration of atoms in the vapour, the concentration of the target element in the water sample is determined from the measured absorbance (L'vov, 2005). In flame atomic absorption spectrometry (FAAS), a sample is aspirated into a flame and atomized. A light beam from a hollow cathode lamp of the same element as the target metal is radiated through the flame and the amount of absorbed light is measured by a detector. This method is much more sensitive than other methods and free from spectral or radiation interference by co-existing elements. Pre-treatment is either unnecessary or straightforward. However, it is not suitable for simultaneous analysis of many elements because the light source is different for each target element (Becker-Ross, 1996).

Inductively coupled plasma (ICP) method for determination of metals is as follows: an ICP source consists of a flowing stream of argon gas ionized by an applied radio frequency. A sample aerosol is generated in a nebulizer and spray chamber and then carried into the plasma through an injector tube. The sample is heated and excited in the high-temperature plasma (Broekaert, 1998). The high temperature of the plasma causes the atoms to become excited. On returning to ground state, the excited atoms produce ionic emission spectra. A monochromator is used to separate specific

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wavelengths corresponding to different elements, and a detector measures the intensity of radiation of each wavelength.

III. Results and Discussion

The physical and chemical content of water samples taken from 30 sampling points including results for some heavy metals were summarised; Table 2 presents the physical parameters and bacteriological content at selected sites while Table 3 present major anions and cations content at some selected sites. The samples in Table 2 and 3 were for testing of major and minor elements as well as bacteria and were selected from areas where contamination in water has been reported in monitoring boreholes in the past. In the tables are also given the WHO limits and the ranges of values obtained in past reports submitted after well completion.

Table 2 : Physical parameters and bacteriological content at selected sites

Site	TDS	pH	Turbidity (NTU)	Elec cond	Mn^{-4}	Total hardness	Total alkalinity	*E.coli*	General *coli*
SW16	163.7	7.64	4	264	4.7	12	100	0	31
SW17	544	7.42	2	879	<0.4	214	174	649	>2420
SW18	163.7	7.82	2	264	<0.4	50	118	0	1
SW18	156.9	7.21	1.o	253	<0.4	18	29	0	2
SW15	200.8	7.65	3	324	3.16	38	126	0	2
SW27	60.64	7.18	1	97.8	3.16	34	30	0	0
Sw26	181.7	8.5	1	293	<0.4	10	108	0	9
SW21	511.2	8.0	2	9.22	6.32	16	223	26	>2420
SW25	398.7	8.48	2	643	3.16	14	220	0	11
SW24	180	8.38	1	290	3.9	6	94	0	0
WHO limit	600	6.5-8.5	4		0.4	200		0	0
Previous ranges	59-679	7.2-9.5	0 -148	274-1095		6 - 140	52- 354	0-501	0-1300

Table 3 : Major anions and cations content at some selected sites

Site	Fe	Mn	Ca	Mg	Na	K	NO_3^-	SO_4^-	Cl	F
SW16	0.14	0.06	3.2	0.97	54	1.8	2.1	2.5	14	4.8
SW17	0.07	0.03	39.2	28.2	99	7	27	5.7	114	0.64
SW18	0.07	<0.01	11.2	5.32	35.8	3	1.5	1.7	3	0.9
SW18	<0.01	<0.01	3.2	2.4	47.6	4	<0.01	3.4	11	6.2
SW15	0.05	<0.01	9.6	3.4	55	3.2	2.3	8.86	11	1.4
SW27	<0.01	<0.01	6.4	4.4	6.5	0.4	1.35	3.2	8	0.14
Sw26	0.06	<0.01	3.2	0.5	62	1.6	1.5	2.6	3	7.2
SW21	0.06	0.12	3.2	2.0	203.4	3.4	0.25	1.4	167	0.13
SW25	<0.01	<0.01	2.4	2	140	3	2	5.14		20
SW24	<0.01	<0.01	1.6	0.44	63.5	1.2	1.8	3.14	8	11.5
WHO limit	0.3	0.4	300		200			50	250	250	1.5
Previous ranges	0.01-2.87	0- 2.0	1.6-38.4	0.5-18	15.1-222	1.0-58	0.1- 41.7	0-4.7	2-99	0.5-11

Physical parameters such as TDS, pH and conductivity have a major influence on bacterial population growth (WHO, 2011). TDS represents the amount of inorganic substances (salts and minerals) in the water. High TDS is commonly objectionable or offensive to taste. Except for one sample taken from a borehole next to Karen College (SW13), all the samples had TDS values below WHO recommended limit of 600 mg/l for domestic use. Hove (1973) also observed that the TDS in Nairobi were within the limits stipulated in the international standards for portable water. Data obtained from monitoring wells between January 2006 and January 2009 indicates higher values of TDS in boreholes drilled in Karen area.

Electrical conductivity measures the ability of water to conduct electrical current and is directly related to TDS. Elevated levels indicate higher probability for bacterial contamination. For instance, the water from Kanungaga borehole (SW17) in Table 2 may be contaminated because the shallow borehole is in the

vicinity of a leaking sewer line. Higher values of electrical conductivity were also obtained at the Unilever (MW7) and Trufoods (MW6) boreholes in Industrial Area and Kabansora (MW8) borehole in Embakasi during monitoring signalling the presence of pollutants.

The pH values for most of the tested water range between 7.18 and 8.5 well within the range of 6.5 and 8.5 recommended for domestic use in the international standards. A pH value range of 8.7-9.5 was obtained in samples collected from Kenya Polytechnic Men's Hostel (MW9) and Unilever Industries (MW7) during monitoring showing that it could favour both indicator and pathogenic microorganism growth (WHO, 1996). The tested turbidity values for majority of the sites are below the 4 NTU recommended by WHO for domestic supplies. Such water can be easily treated with 2 ppm of chlorine to clear and reduce the turbidity to less than 0.3 NTU. High values of turbidity were measured at Boulevard Hotel (MW5) with a range of 20-148 NTU, Jorgen Mbagathi Ridge (MW1) with a range of 18-36 NTU and Trufoods (MW6) with a range of 18 NTU. Records from sites across the city show average turbidity values of 1-12 NTU. Turbidity in water is caused by suspended particles or colloidal matter that obstructs light transmission through the water. It may be caused by inorganic or organic matter or a combination of the two (WHO, 2011). Turbidity therefore acts as an indicator of possible sources of microbial contamination. Boreholes with high turbidity are located either within the Industrial Area or along/nearby faults.

Except for one borehole, the total hardness of the water is below the recommended threshold for domestic use. The study got informed that the SW17 water (with total hardness of 214 ppm) at Kanungaga borehole is not normally used for domestic purposes except for floor cleaning because of the scum that it forms with soap. Hardness is usually indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning. A total hardness above approximately 200 ppm may cause scale deposition in the treatment works, distribution system and pipe work and tanks within buildings. The taste threshold for the calcium ion is in the range of 100–300 ppm, depending on the associated anion while the taste threshold for magnesium is probably lower than that for calcium (WHO, 2011). Generally, groundwater is harder than surface water and the hardness is mostly due to carbonates of sodium and calcium (Hove, 1973). Alkalinity values mainly indicate the water's aggressiveness to pipes and appliances. Corrosion resulting from attack by alkaline water would affect the taste and appearance of the water. Gevaerts (1964) observed that all water struck in Tertiary formations contains sodium bicarbonate and are usually alkaline. He also observed that high degree of hardness and free CO_2 are introduced into the Kamiti Kahawa area by

water of the deeper aquifer near the base of the upper Athi series.

Water in many boreholes is not tested for bacteriological content during well development so no data could be obtained for comparison. Data obtained from the monitoring wells indicate the presence of *General coli* in majority of the monitoring boreholes. The general the coli were also detected in 8 of the 10 samples tested as shown in Table 1. The source of the coli is currently unknown but could be related to contaminated surfaces surrounding the wells. *Escherichia coli (E.coli)* were detected in two samples taken from the two shallow wells at Kanungaga (SW17) and Kabiria (SW21). The source of the coliform could be the nearby pit latrines and unlined septic tanks. In addition, the borehole at Kanungaga was subject to overflowing open sewer line. E.coli is usually present in large numbers in the normal intestinal flora of humans and animals, where it generally causes no harm. However, in other parts of the body, *E. coli* can cause serious disease, such as urinary tract infections, bacteraemia and meningitis (Aydin, 2007).

The heavy metals tested for included lead, zinc and copper. Lead was detected in 16 out of 20 samples, with values ranging between 0.01-0.07 ppm. The action level for lead recommended by EPA (2002) is 15 µg/l. A major source of environmental lead, particularly in urban areas, is due to the combustion of leaded petrol. Lead is discharged by vehicles into air, and then adsorbed from the air by environmental samples such as soil and plants. Lead then enters the waterways from soil, thus affecting the levels of lead in natural waters (Oclay,*et al*., 2011). Concentrations of Zinc were detected in 15 samples with ranges of 0.03-7.41 ppm. WHO provides a safe limit of 4 ppm for drinking water. All the samples tested have values below this limit except the sample collected from a borehole at Kwarara Road in Karen (SW14) that contained 7.41 ppm of lead. Since the sample was collected from the tap at the surface (although the water was allowed to run to 20 minutes before the sample was collected) the elevated zinc could be related to the corrosion in old galvanized materials used in the distribution system (WHO, 2011). Zinc imparts an undesirable stringent taste to water at a threshold concentration of about 4 ppm (as zinc sulphate). Water containing zinc at concentrations in excess of 3–5 ppm may appear opalescent and develop a greasy film on boiling (WHO, 2011). Copper was detected in three samples and contents in the samples were in the range of 0.01-0.02 ppm. These values were considerably lower than 1 ppm permitted by WHO for drinking water. The health- based guideline value for copper is 2 ppm. Therefore no copper contamination is detected in water samples collected across Nairobi City. Staining of sanitary ware and laundry may occur at copper concentrations above 1 ppm. At levels above 5

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ppm, copper also imparts a colour and an undesirable bitter taste to water.

The major cation concentrations tested were below the thresholds recommended by the health standards. These cations are not usually related to any health hazards but presence of their salts sometimes imparts bad taste on water. For instance, at levels above 0.3 ppm, iron stains laundry and plumbing fixtures. There is usually no noticeable taste at iron concentrations below 0.3 ppm, although turbidity and colour may develop. The presence of manganese in drinking-water, like that of iron, may lead to the accumulation of deposits in the distribution system. At levels exceeding 0.1 ppm, manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry. Concentrations below 0.1 ppm of manganese are usually acceptable to consumers. Even at a concentration of 0.2 ppm, manganese will often form a coating on pipes, which may slough off as a black precipitate. The health-based value of 0.4 ppm for manganese is higher than this acceptability threshold of 0.1 ppm (WHO, 2011). Records indicate high values of iron (0.45-2.45 ppm) and manganese (0-2.0 ppm) in the water. The borehole at Boulevard Hotel (MW5) has particularly high values of iron (1.03-2.87 ppm) and manganese (0.06-2.0 ppm).

The anions tested for in the water included nitrates, sulphates and chlorides. Of these anions, nitrates have been found to affect health directly. All the samples collected in the study are had nitrate values below the Who guideline of 50 ppm and are therefore safe for use. However the concentration of 27 ppm in the Kanungaga (SW17) borehole is of concern. The presence of excessive nitrogen in the form of NO3- is an index of pollution (Hove, 1973). Too much nitrate in water has a major effect on infants less than 6 months old and leads to "blue-baby syndrome. It also leads to diuresis, an increase in starchy deposits and haemorrhaging at the spleen (EPA, 2002).

The levels of sulphate and chloride in the water are far below the taste limits. Values from the study and those in records indicate chloride ranges below 99 ppm and therefore not of concern. Taste thresholds for the chloride anion depend on the associated cation and are in the range of 200–300 ppm for sodium, potassium and calcium chloride. Concentrations in excess of 250 ppm are increasingly likely to be detected by taste. However, the samples from the Kanungaga (SW17) and Kabiria (SW21) boreholes had a significant salty taste regardless of the fact that the values are far below the threshold. Gevaerts (1964) notes that high chloride and sulphate content is encountered in water from Kapiti Phonolite series. Since the phonolite itself does not contain remarkable amounts of these ions, it is obvious that it is derived from the intercalated lacustrine sediments. Borehole C-1413 reached basement and struck unportable water with carbonate hardness of 346-357 ppm, Cl of 1220 ppm and SO_4^{2-} of 720 ppm. The presence of sulphate in drinking-water can cause noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers. Taste impairment varies with the nature of the associated cation; taste thresholds have been found to range from 250 ppm for sodium sulphate to 1000 ppm for calcium sulphate. It is generally considered that taste impairment is minimal at levels below 250 ppm.

The fluoride content measured in many samples is high above the recommended threshold of 1.5 ppm. The area underlain by Tertiary phonolites east of Nairobi City Centre have mean values of fluoride concentration of 7.6 ppm. The possible sources of the concentrations above the recommended limit are thought to be feldspathoids (Mailu, 1987). Fluoride in groundwater can also be derived from CaF_2 or volcanic gases. High fluoride in water is the cause of dental fluorosis and has some toxic effect on the skeleton (Hove, 1973). The presence of hot springs and geysers and fumaroles in the rift valley supports the possibility that the fluoride results from volcanic gases. The highest concentrations are around Nakuru and Naivasha (Hove, 1973).

IV. Conclusions and Recommendations

Results of this study as well as those of past chemical analyses indicate that major anions and cations concentrations are within the limits recommended by WHO. Of the 2000 boreholes drilled in Kenya before 1960, only 20% had available records for chemical analysis. In general bacteriological pollution was considered unimportant in groundwater, except in very shallow, coarse aquifers because percolation through them is an effective means of filtration and purification (Hove, 1973). High nitrate concentrations were detected in the shallow wells. Fluoride content is above internationally recommended limits in majority of the boreholes sampled. Past records indicate fluoride contents in the range of 0.5-13.7 ppm against the WHO recommended threshold value of 1.5 ppm. Gevaerts (1964) also documented high fluoride concentrations in the City Centre and low concentrations in Kahawa and Kamiti. Since most boreholes tap from more than one aquifer, it is recommended that the fluoride content for every aquifer be investigated so as to isolate those with high fluoride content. Faulting conducts the fluoride to areas where it may not be expected (Saggerson, 1991). Defluoridation or mixing with water of low fluoride content is normally recommended. Four trace elements are that known to endanger life if they occur in drinking water above certain limits (selenium 0.05 ppm, arsenic 0.2 ppm, chromium 0.05 ppm and cyanide 0.01 ppm) have not been investigated. The presence of general coli and E. coli in eight out of the ten tested samples underlines the importance of disinfecting the water for

domestic use. Shallow wells within the city should be discouraged since the two sampled at Kanungaga and Kabiria indicate chemical and bacteriological contamination. The water is unfit for domestic use. The physical parameters of the groundwater across the study area range from those below the recommended WHO limits, to those that raise concern such as the high turbidity, pH and electrical conductivity values in boreholes in Embakasi, Industrial area, and Karen. Since these parameters signify potential for microbial contamination, a research should be carried out to analyse their variation and the relationship with lithology and structural geology of the area.

V. ACKNOWLEDGEMENTS

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