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Determination of Quality Characteristics Levels in Selected Borehole Water in Nairobi City And its Metro Area

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Abstract: *The main factors influencing the longevity of the life forms are the quantity and the quality of drinking water. Elevated concentrations of quality characteristics such as heavy metal levels, chloride, total dissolved solids, and major ions are known to contribute to cancer, hypertension, kidney failure, lower intelligence, and long-term neurological issues in human beings. Surface water and groundwater are both sources of drinking water. Owing to its low risk of pollution than surface water, groundwater is the more relied-upon of the two sources. Humans have been involved in actions that have contaminated the world for many years. As a result, they permeate the earth's crust until they reach the groundwater aquifer. This study aimed to assess groundwater viability at multiple locations in Nairobi city and its metro zone and compare the to the World Health Organization's (WHO) tolerable limit on drinking water. This study analyzed physiological characteristics, chloride ions, and metal levels in four borehole water samples from Nairobi city and its metropolitan area. The water samples were digested using a wet digestion method. Cd, Zn, Cu, Pb, as well as Mn concentrations were determined using an AAS, while Na^+ and K^+ levels were determined using an AES. Electrical conductivity ranged from 257.4±0.9 µS/cm^3 to 541.70±2.38 µS/cm^3, TDS was 128.7±0.83 mg/L to 270.90±1.79 mg/L, while pH was 6.47±0.31to 7.47±0.42. The concentrations of chloride varied from 0.153±0.016 mg/L to 0.268±0.230 mg/L. K^+ levels varied between 0.31±0.03 mg/L to 1.47±0.03 mg/L, while Pb from BDL-0.167±0.002 mg/L and Zn from BDL- 0.051±0.001 mg/L. The range of Na^+ levels was 1.64±0.03 mg/L-4.67±0.07 mg/L. Mn levels were found to be 0.139±0.06 mg/L-0.155±0.002 mg/L, Cu ranged from BDL-0.046±0.007 mg/L, and Cd levels were found to be below the limits of detection (LOD) of 0.002 ppm. According to the information that was compiled, the following hierarchy of metal concentrations was observed: Na > K > Mn > Pb > Cu > Zn > Cd. The levels of Cd, Zn, Na, K, and Cu are within the World Health Organization's recommended ranges. Unfortunately, the levels of lead and manganese were greater than the WHO's recommendation. Samples from all boreholes had less than 1000 mg/L of total dissolved solids, suggesting fresh water.*

Keywords: *Longevity, life forms drinking water, groundwater, physicochemical parameters, metal ion levels, atomic emission spectroscopy, pollution, and Nairobi city***.**

1. INTRODUCTION

Water has been a precious asset for ecosystem integrity, combating poverty and hunger, and the preservation of the life of humans for ages[1]. The two primary sources of safe drinking water for humans as well as other living species are surface water and groundwater[2]. However, groundwater is desirable for living organisms' consumption when juxtaposed with surface water. This is because groundwater is more convenient, cheap, isn't exposed to the atmosphere is less likely to be polluted[3]. For instance, the majority of the world's arid and semi-arid regions have experienced a growth in the dependency on groundwater due to the whims of the monsoon and a lack of surface water[4].

The term "groundwater" refers to water that has penetrated the earth's lithosphere through cracks and fissures and the openings of soil from the atmosphere[5]. It makes up about two-thirds of the portable water all over the globe. When water falls from the sky, gravitational pull pulls it toward the earth's center. To do this, water seeps down its way through the subsurface of the ground as well as the permeable surroundings of the rocks until it reaches the aquifer. Human consumption and agricultural irrigation are two common uses for groundwater in most nations. Other uses of groundwater are domestic, industrial, and livestock.

For many countries, groundwater is the principal source of potable water and water for agriculture[5]. For instance, it is anticipated that around four-tenths of the public water supply is derived from underground sources. In several other continents, such as Europe, groundwater has historically been an extremely important component of the overall water supply. Groundwater supplies in several European Nations are shown in Table 1.1, which shows the magnitude relationship in 1998.

Natural activities such as weathering, and anthropogenic activities such as mining, food production, home, and commercial wastes[6] have led to the soil, air, and surface water pollution around the globe. Although the earth's outermost crust is an excellent filter of particulate matter, the soluble chemicals and gases in soil, water, and air find their way into groundwater. When these soluble chemicals are introduced into the environment they are transported from the site where they were administered to the aquifers.

Over the span of years, this cohort of activities has left a trail of contaminants such as heavy metals and major ions such as chlorides, calcium, and potassium. These contaminants have downgraded the quality signatures of groundwater. These quality signatures of groundwater are pH, heavy metals, TDS, major ions, and chloride levels. The quality signature of groundwater is determined by the layer of earth above the aquifer as well as the kind of toxins. This signifies that groundwater signatures differ from one geographic region to the next[6].

Heavy metals are metals having densities greater than that of water by five times and a molar mass exceeding 40.04 grams[7]. Heavy metals are released into the environment by natural as well as anthropogenic processes. Mining, surface runoff, industrial discharges, municipal discharge, and agrochemicals applied to plants are sources of environmental contaminants[7]. Heavy metals like Pb, Cd, Hg, as well as As are the most prevalent and hazardous heavy metals and have no discernible effect on the human body, and no recognized homeostasis mechanism exists for them[8].

Table1. *Percentage of water supply in different Countries in Europe.*

Country	Percentage	Country	percentage
Denmark	98	Netherland	67
Portugal	94	Luxembourg	66
Germany	89	Sweden	49
Italy	88	UK	35
Switzerland	75	Spain	20
Belgium	67	Norway	15

(WHO, 1996)

The toxicity of heavy metals can result in long-term observable top worldwide health implications such as impairing metabolic functions, central nervous system damage, hormonal disruption, and cancer[9]. For instance, high lead levels result in serious brain and kidney damage or even death. It is also linked to miscarriages in women who are pregnant[10]. Cadmium has been shown to have carcinogenic properties[11]. Zinc damages nasal nerve receptors, and causes anosmia, according to the FDA[12]. High levels of Mn also suppress immune systems by affecting granulocyte regeneration and activities such as phagocytic and pro-phenoloxidase stimulation[13]. Copper causes poisoning which is presented by the following symptoms a rusty sensation in the mouth, salivation and searing pain in the stomach, uneasiness and upset stomach blue-colored debris, hair loss, and male sexual dysfunction[14].

Major ions such as sodium play a crucial role in the control of blood circulation and pressure[2], nerve impulse transmission, and muscular contraction and relaxation, all of which are essential for the body's smooth working, however, excessive sodium levels, on the other hand, raise the risk of hypertension and cardiovascular disease in people[15]. High levels of potassium might cause health issues in humans, such as hyperkalemia[16].

The quality of water is a window into the healthiness of most ecosystems. As a consequence, safe and clean water for human consumption is required that lacks deleterious impacts on people or sea life health. Groundwater quality signatures are consistently degrading[17]. Environmentalists have articulated concerns about the reliability of groundwater resources as well as the products made from them. Because of the prevailing increment of contamination as well as changes in climate patterns, groundwater is no longer feasible for farm animals and household utilization. Therefore, this paper aims to assess groundwater viability at multiple locations in Nairobi city and its metro zone and compare it to the world health organization's tolerable limit on drinking water. The study's results will benefit the Governments, Non-Governmental organizations, and enterprises in using groundwater for water and goods delivered from it without harmful imparts health impacts. To achieve this, the specific objectives were to:

1. Assess the presence of heavy metals in selected borehole water samples from Nairobi County in Kenya.

2. Examine the Physico-chemical parameters; pH, electrical conductivity, and total dissolved solids in selected borehole water samples from Chiromo, Githurai, Kikuyu, and Kashie in Nairobi County and its metropolitan region and compare them with the recommended standard levels from World Health Organization (WHO) and Kenya Bureau of Standards (KEB).

3. Determine the levels of heavy metals Pb, Mn, Cd, Cu, and Zn in selected borehole water samples from Chiromo, Githurai, Kikuyu, and Kashie in Nairobi County and compare them with the recommended standard levels from WHO and KEBS.

2. MATERIALS AND METHODS

2.1. Study Area

Nairobi, Kenya's Capital, is located in the Country's most populous area. It is located in the highlands of the Country's southern central region, at an elevation of 1600 to 1800 meters above sea level[18]. It's roughly between 01º17'11" South and 36º49'02" East longitude. According to 2019 census statistics (GoK, 2019), the City's population was 4.397 million, while the metropolitan region's population was 9.354 million. Nairobi is surrounded by four Counties, and a portion of those Counties comprise its metropolitan region[19]. The Counties include Kiambu (in the northern metropolitan region), Murang'a (in the northern-eastern metropolitan area), Kajiado (in the southern metropolitan area), and Machakos (in the central metropolitan area). Although the majority of industrial activity is focused in the South-East, economic and business operations are localized mostly in the central business area. Nairobi has four distinct seasons: the dry and hot seasons (January through March), the heavy downpours season (April through June), the cool and dry season (July through September), and the brief rainy season (October through December). The typical temperature range is 11°C from June to July to around 29°C from December to March[18].

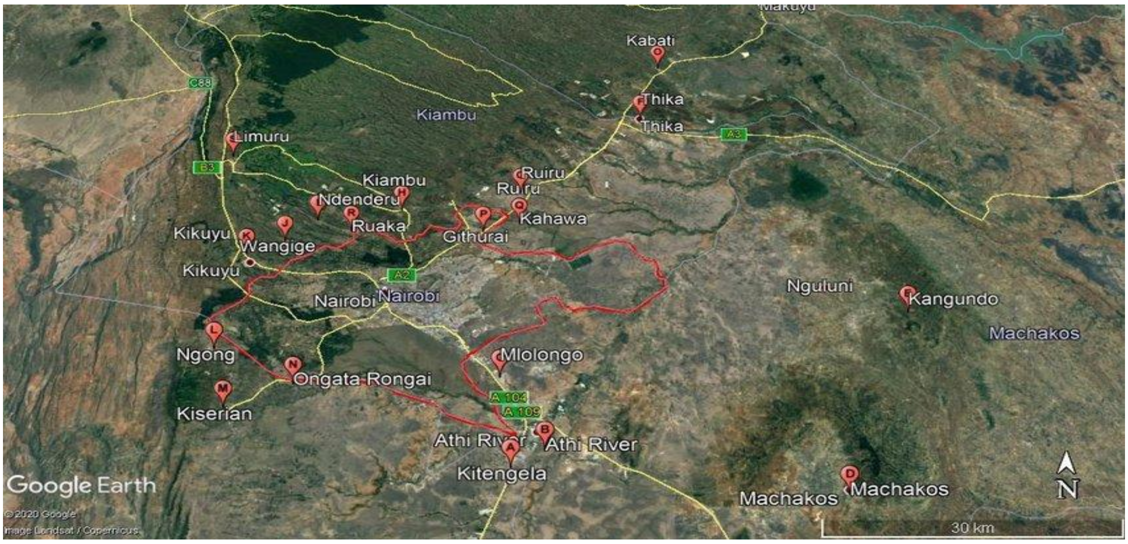

Figure1. *GIS description of the study area.*

2.2. Project Design and Sample Collection.

Before the study, fieldwork was conducted to determine the best sampling sites. The sampling sites were strategically selected to cover all the social classes of people living in Nairobi and its metropolitan area. Groundwater was sampled by a grab method taking necessary precautions from four boreholes located in different locations in Nairobi and its metropolitan region. The sampling locations are illustrated in Table 2. Each borehole was sampled twice, each time with 1 liter of water. HDPE (highdensity polyethylene) containers were used since they limit the metal ions from being absorbed into container walls as well as the absorption of the metal ions from the bottle into the species. These containers were washed with diluted nitric acid. After that, the containers containing the sampled water were tagged according to the location of the boreholes. The various samples were taken to the analytical laboratory at the Department of Chemistry at the University of Nairobi in a portable ice chest, where 1 ml of concentrated nitric acid was added to every 100 ml of water sample obtained for preservation. This was done to ensure that the water would not deteriorate. The samples were stored in the fridge at 4ºC for 24 hours after which wet digestion was performed.

2.3. Wet Digestion and Preparation of the Sample.

Digestion was carried out using aqua regia which was made by mixing aqua regia HCl and HNO3 in a ratio of 3:1. Aqua regia (20 ml) and perchloric acid (1 ml) were added to a conical flask containing 30 ml of the water sample. On a hot mantle, the solution was heated for approximately an hour and a half at a temperature of 109 °C, until only about 5 to 10 mL of it was left. It was then cooled and filtered into another Erlenmeyer flask. The filtrate was put into a volumetric flask and filled up with distilled water to the 100 ml mark. To prevent adsorption or desorption of HNO3, the volumetric solution was stirred well and then poured into clean, 100 ml LDPE bottles that were washed using dilute HNO3. All samples are run using the same methodology. To identify the sample contained in each bottle, each bottle was labeled.

2.4. Chemicals, Apparatus, and Instruments.

Apparatus utilized in this investigation were filter funnels, water bottles, 100-ml volumetric flasks, Erlenmeyer flasks of various sizes, and 250-ml beakers. These apparatuses were soaked in 5% (v/v) analytical grade nitric acid overnight and thoroughly cleaned using detergent and water. They were then rinsed with deionized water, acetone, and methylene chloride after which they were oven-dried at 110 ºC for 12 hours before they were used. An analytical balancing scale, a hot plate, an Atomic Absorption Spectrophotometer (AAS), pH meter, Lovibond Datronix, and an Atomic Emission Spectrometer (AES) were the instruments that were utilized. The reagents that were utilized were Analar grade (99.99 % purity) HNO_3, HCL, perchloric acid, deionized water, Pb standards, Cd standards, Mn standards, Cu standards, and Zn standards.

Table2. *A summary of the sampling locations*

Site number	Name	Deepness (m)	Longitude	Latitude	Altitude (m)
1	Tuition area (Chiromo)	97	36.7977081	-1.2752112	1703.03
2	Kikuyu	76	36.73564	-1.26569	1976.51
3	Kashie	79	36.77889	-1.22135	1823.02
4	G 45	124	36.9137	-1.2062	1621.7

2.5. Physio-Chemical Parameter Analysis.

The pH meter's electrode was checked for damage or contamination. After that, it was cleaned with distilled water. The extra water was blotted off using a paper towel after that. The electrode was dipped in a 4.0 pH buffer solution. After allowing the value to settle, the reading was adjusted to read 4.0 on the display. Distilled water was used to wash away any residue, then the operation was repeated using a buffer solution of 7.7 pH value instead. The pH meter electrode was then submerged into 25 ml of the water sample.

Conductivity and TDS values were taken using a Lovibond Datronix. Analyzing the sample's electrical conductivity required connecting an electrode to a meter. The meter was calibrated by immersing it in a solution with known electrical conductivity. After placing the electrode in each sample and waiting for it to settle, the EA data were recorded. The meter's scale was changed to TDS at this time. The meter was calibrated using a solution with a known TDS. It was done one sample at a time, with the electrode dipped into each one.

2.6. Analysis of Major ions Employing Flame Photometry.

The flame was kindled, the air supply and the fuel cylinder were activated, and then the flame photometer was prepared for operation. Afterward, the flame quality was enhanced until ten cones of blue flames were formed. Deionized water (black sample) was used at zero on the flame photometer, that is, the emission measurement was set to zero. The equipment was calibrated for the analysis of potassium and sodium using the standard solutions of those elements.

2.7. Determination of Heavy Metal Levels in Borehole Water Samples.

Before analysis, the acetylene was allowed to burn for approximately ten minutes in a flame. Deionized water was used to zero, recalibrate, and flush the instrument when switching from one analyte to the next. The absorbance of each standard solution of a given metal at varying concentrations was determined by analyzing the solutions. Calibration curves were then created using the concentrations and absorbance data. The absorbance of the digested samples and the blanks was measured using an AAS instrument. The calibration curves were then used to establish the concentration of the metal ions in each sample.

2.8. Analysis of the results.

Using MS Excel, the prediction error was calculated as well as the means for each characteristic, including metal ion concentration. Metal calibration curves were actualized using MS Excel. The interplay of numerous factors, such as pH, TDS, electrical conductivity, and so on, on the water quality parameters was portrayed using writing, statistical tables and charts, and graphs as a consequence of these data analyses.

Figure2. *A picture of the AAS instrument used to analyze samples.*

3. RESULTS AND DISCUSSION

3.1. Introduction

The levels of metals such as sodium, potassium, manganese, zinc, lead, cadmium, and copper, as well as physicochemical variables like chloride ions, total dissolved solids (TDS), pH, and electrical conductivity, were assessed in the groundwater samples taken from Kikuyu, Githurai, Kashie, and Chiromo. The findings from the duplicate samples were used to calculate the average groundwater quality tested in the study. Those average levels of the heavy metals and the physicochemical parameters analyzed are displayed in Table 4 and Table 3 respectively. According to the results, which ranged from Below Detection Levels (BDL) to detectable amounts, there is proof that the research region was truly contaminated by heavy metals. Additionally, the outcomes of this study were evaluated against the WHO and KEBS Water Quality Standards.

3.2. Physical and Chemical Characteristics

Research sites were examined for Physio-chemical characteristics, particularly the potential of hydrogen, electrical conductivity, chloride concentration, and total dissolved solids.

Samples from four distinct locations were tested for pH, and the results varied from 6.47±0.31 to 7.47±0.42. Kikuyu borehole site had the least pH value of 6.470 while the G 45 borehole site had the greatest pH value of 7.470.42 (Table 3 and Figure 3). Each of the four boreholes tested had a pH of between 6.0 and 8.5, as the World Health Organization recommended. Additionally, the measured concentrations of TDS varied from 128.7±0.83 mg/L to 270.9±1.7 mg/L as shown in Table 3 and Figure

4. G 45 had the greatest amount (128.7±0.83 mg/L), whereas Chiromo Campus had the least (128.7±0.83 mg/L).

Table3. *Physical and chemical characteristics of the samples from the four borehole sources explored.*

	Chloride levels	pH levels	TDS levels	EA levels
Kikuyu	0.153±0.016	6.47±0.31	175.9±0.41	351.8±1.78
Tuition area (Chiromo)	0.251±0.047	6.53±0.07	128.7±0.83	257.4±0.9
Kashie	0.234±0.033	6.51±0.21	191.7±1.09	383.4±2.25
Githurai 45 (G 45)	0.268±0.230	7.47±0.42	270.9±1.7	541.70±2.38

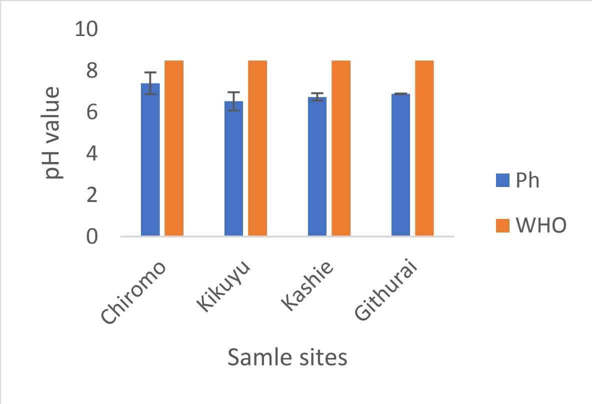

Figure3. *pH of groundwater from the four sample sites compared to the WHO recommended pH value.*

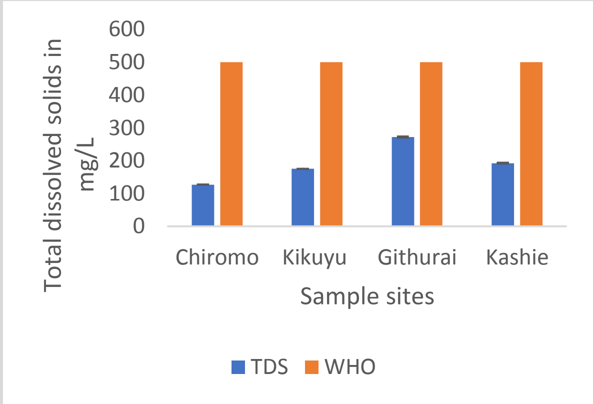

Figure4. *Total dissolved solids of groundwater water samples from the four sites.*

The electrical conductivity of water samples varied between 257.4±0.9 S/cm to 541.70±2.38 S/cm, according to the results gathered from the study of water samples as shown in Figure 5 and Table 3. The electrical conductivity levels found in the borehole water samples from the tuition area (Chiromo), Kikuyu, G 45, and Kashie were all within the range recommended by WHO (WHO, 2011).

After water samples were analyzed for chloride ions, chloride ion concentrations varied between 0.153±0.016 mg/L to 0.268±0.230 mg/L (Table 3 and Figure 6). According to WHO standards (250mg/L), chloride ion levels in all borehole locations were within the WHO permissible limit (WHO, 2011).

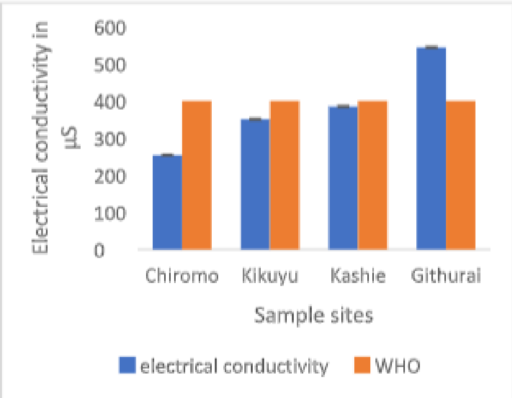

Figure 5: Electrical Conductivity in both ole water samples from the four sites.

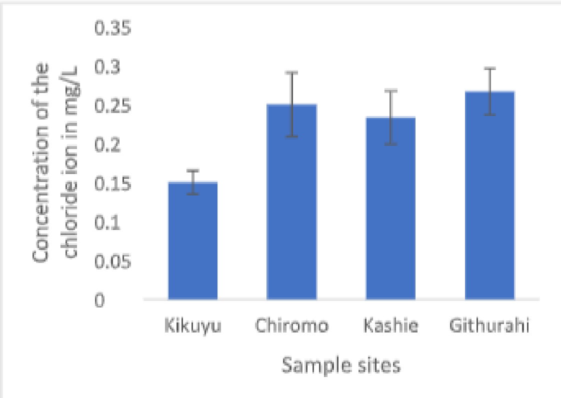

Figure 6: Chloride ions levels in borehole water samples from the four sites.

3.3. Metal ion Concentrations in the Collected Samples.

According to the data collected from water sample analysis, the sodium ion concentration varied between 1.64±0.03 mg/L and 4.154±0.008 mg/L as illustrated in Figure 7 and Table 4. The potassium content in the samples collected varied from 0.31±0.03 mg/kg to 1.47±0.03 mg/kg. All of the amounts of potassium and sodium are far below the World Health Organization's safe limit. K^+ was found in water samples from tuition area (Chiromo), Kikuyu, Kashie, and G 45 with values of 0.31±0.03 mg/kg, 1.47±0.03 mg/kg, 1.18±0.03 mg/kg, and 1.07±0.01 mg/kg, respectively. The samples obtained from the tuition area (Chiromo), Kikuyu, Kashie, and G 45 contained levels of Na^+ of 3.93±0.01 mg/kg, 4.154±0.008 mg/kg, 4.67±0.07 mg/L, and 1.64±0.03 mg/L, respectively (Table 4).

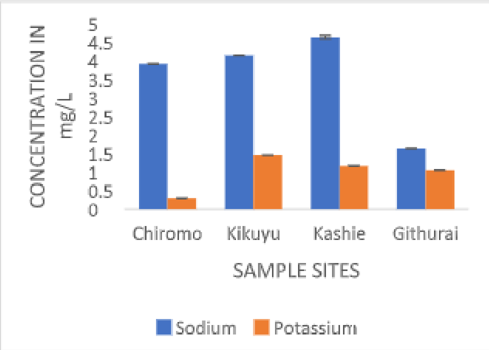

Figure 7: Sodium and potassium ion levels and in four borehole water samples

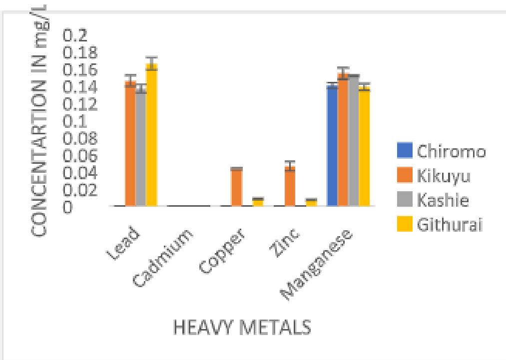

Figure 8: Lead, manganese, cadmium, zinc, copper levels in four borehole water samples

Table4. *The concentration of metal ions in four borehole water samples*

	Kikuyu	Tuition area (Chiromo)	Kashie	G 45	BD
Sodium	4.154±0.008	3.93±0.01	4.67±0.07	1.64±0.03	-
Potassium	1.47±0.03	0.31±0.03	1.18±0.03	1.07±0.01	-
Manganese	0.155±0.002	0.141±0.009	0.152±0.005	0.139±0.06	0.01
Lead	0.156±0.008	BDL	0.142±0.004	0.167±0.002	0.05
Cadmium	BDL	BDL	BDL	BDL	0.002
Copper	0.046±0.007	BDL	BDL	0.006±0.001	0.01
Zinc	0.051±0.001	BDL	BDL	0.006±0.002	0.005

Cadmium concentrations were found to be lower than the limit of detection (LOD) of 0.002 mg/L of the AAS in all samples analyzed. Pb levels ranged from BDL to 0.167±0.002, Mn from 0.139±0.06 to 0.155±0.002, Zn levels from BDL to 0.051±0.001, Cu levels from BDL to 0.046±0.007 mg/L (Table 4 and Figure 8). The levels of Cd, Cu, Mn, and Zn ions were all within the acceptable ranges suggested by the WHO guidelines for their elements. Samples from Kikuyu, Kashie, and G 45 had Pb levels significantly over the WHO permissible limit of 0.01 mg/L. While it was found in a borehole water sample taken from the tuition area (Chiromo), it was not detectable.

4. DISCUSSION.

Human activities such as household garbage disposal and battery leakage from nearby parked automobiles might have resulted in high levels of Pb in water samples collected from those study areas. Several health issues, including high blood pressure, decreased intellect in youngsters, and attention deficit disorder, have been associated with it[20]. These high-lead areas have a dense population, inadequate drainage, and a lack of proper facilities for disposing of solid waste. Environmental exposure might have occurred since lead-based fossil fuels are a primary source. After being dissolved by runoff water, lead seeps through the earth's crust till it reaches groundwater. Some industrial effluents may make their way into the soil, where they may dissolve in water and seep into groundwater due to inadequate waste management and drainage.

The Cd, Cu, Zn, and Mn ions agreed with the WHO limits for safe levels in water for drinking (Table 4). This can be ascribed to the fact that the manufacturing processes that utilize Cd, Cu, Zn, and Mn as building ingredients are not carried out in Nairobi or the metro area that surrounds the city. Despite this, Mn levels in the water samples are greater than the other heavy metals. This can be linked to the widespread use of fertilizers in which Mn is a nutrient, as well as ceramic industry effluents[21].

The results of electrical conductivity that the water samples collected from the research locations contained a low concentration of ionic species. Water's total amount of inorganic and organic material is quantified by assessing TDS (total dissolvable solids). TDS levels in water samples taken from G 45 were the greatest (270.90±1.79 mg/L), while TDS levels in water samples collected from the tuition area (Chiromo) were the lowest (128.7±0.83 mg/L). It has minimal bearing on human existence[22].

Due to G 45's mild alkaline pH, oxyanion-forming components may be mobile in the subsurface water. The water in the tuition area (Chiromo), Kikuyu, and Kashie was slightly acidic, implying that heavy metals and other cation-based contaminants could be mobile in water[23]. The low levels of chloride ions that were quantified in this study signified that water treatment facilities and food processing factories in Nairobi and the surrounding area have excellent pollution control policies or are still not well established in Nairobi and its metropolitan area[24].

Both potassium and sodium levels were well within the WHO (WHO, 2011) recommended ranges, with an average value of 3.5985 and 1.0075 micrograms per liter, respectively. The amounts of the metals did not differ significantly from one research location to the next. Low potassium and salt levels in the research locations imply environmental processes such as weathering of rocks and human activities discharge like industrial effluents from companies such as food companies, agrochemical industries, pharmaceutical companies, and laboratories were not and are still not well established in Nairobi and its metropolitan area[24].

5. Conclusion and Recommendation.

5.1. Conclusion

This assessment provided a clearer picture of the state of groundwater quality characteristics as well as pollution since contamination of groundwater is invisible as compared to surface water. Groundwater around Nairobi and its metropolitan area is contaminated with lead and manganese except in Chiromo (tuition area). The levels of these contaminants increased with the concomitant increase in the human population in areas without good pollution management policies.

Other quality characteristics assessed such as pH, major ions (chloride, potassium, and sodium), TDS, and electrical conductivity were within the recommended WHO values. This provided hope that with little effort and resources, groundwater quality can be improved to satisfy human needs.

5.2. Recommendation.

According to the findings of this research, we should:

Further investigation should be done to determine the cause of the lead pollution in the above-mentioned locations and the environment of the boreholes.

General population should be made aware of the advantages of sound farming methods.

Immediate action should be taken to address lead poisoning of boreholes in Githurai, Kashie, and Kikuyu to reduce Pb contamination in the area.

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