Investigations of Physico-Chemical Composition of Groundwater in Otuoke and Environs, Bayelsa State, Nigeria

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Abstract

The study was designed to investigate the groundwater quality in Federal University of Otuoke and environs, Bayelsa State. A total of fourteen groundwater samples were acquired and analyzed for their physico-chemical and heavy metal parameters. Heavy metals were all analyzed with the Atomic Adsorption Spectrometer. The result revealed that for the heavy metals, iron was most predominant, ranging from 0.004 to 10mg/L with mean and SD of 0.95±2.63mg/L. Manganese ranged from 0.01 to 0.91mg/L, with mean and SD of 0.18±0.21mg/L. Copper was below the machine detectable limit in six samples, but ranged from 0.006 to 0.013mg/L, with a mean of 0.01mg/L. All other heavy metal including lead, arsenic, cobalt, boron and barium were below the detectable limit of the machine (< 0.001mg/L).In order of decreasing magnitude, the average cationic concentrations in the groundwater are in the order; Na (101.71mg/L) >Ca (29.04mg/L) > Mg (10.01mg/L) > K (2.31mg/L); and anionic concentrations; Cl (25.88mg/L) > HCO_3 (1.65 mg/L) > PO_4 (0.42 mg/L) > NO_3 (0.08mg/L) > SO_4 (0.05mg/L).Assessment of groundwater in the area for drinking purposes revealed that the water is predominantly acidic (pH=6.37), with iron (0.95mg/L) and manganese (maximum =0.91mg/L) contents exceeding regulatory guidelines (WHO, 2011; NSDWQ, 2007) for potable drinking water in most locations. This shows that the groundwater sources are unsafe for consumption purposes. All other measured chemical parameters were within regulatory requirements. Constant monitoring and quality assessment is necessary to ensure that groundwater in the area is within regulatory requirements.

Keywords: Physico- chemical; Groundwater quality; Heavy metals

Abbreviations: GPS: Geographic Positioning System; AAS: Atomic Absorption Spectrophotometer; SD: Standard Deviation; TDS : Total Dissolved Solids; APHA: American Public Health Association

Introduction

Groundwater quality is determined by the solutes, flow paths and soil gases dissolved in the water, as well as the matter suspended in and floating on the water. Hence, groundwater quality is a consequence of the natural physical and chemical state of the water as well as any alteration factors that may have occurred as a consequence of human activity and microbial activities in soils [1]. The quality of groundwater is of vital concern, since it is directly linked with health and human welfare. Ranjana 2010 clearly stated that the quality of public health depends greatly on the quality of groundwater. Groundwater in the preferred source of potable water in the Niger delta, because it is less prone to contamination as a result of its natural filtration [2]. Contamination of groundwater from heavy metals may occur due to factors including irrigation with contaminated water, transportation, industrial emissions, the use of fertilizers and metal based pesticides, etc. [3]. The presence of heavy metal, even at small concentrations in water is an indication of contamination and the persistent consumption of such water could result to adverse health effects.

Although groundwater quality is more preffered when compared to surface water, its quality is the sum of natural and anthropogenic influences [4]. Water quality parameters reflect the level of contamination in water resources and show whether water is suitable for human consumption, irrigation and/or industrial usage. Drinking contaminated water is unacceptable because of its adverse health effects [5]. There are two basic contaminant indicators whose presence or absence helps determines the quality of water in any given area (elemental and microbial). Microbial contaminants in water includes; fungi, pathogenic bacteria and viruses. Elemental contaminants include; physicochemical parameters, metals as well as organic chemical contaminants such as; pesticides and radioactive contaminants Akunobi and Chibuzor 2012. The quantity of water may not be an issue in a terrain such as Niger Delta but its quality is of utmost importance. A substantial part of the study area is motor able and is close to Yenagoa the State capital. This has led to continuous influx of people and increased business activities in the area over the last decade with strong dependence

on groundwater. Predominant anthropogenic activities in the area which can pose severe risk to the groundwater resources includes gas flaring from exploitation of oil and gas resources, leakages and corrosion of pipelines, septic tanks and possible effluents from industries, open dumping, etc. Therefore, it becomes obligatory to undertake a groundwater hydro chemical survey in the area to ascertain its quality for drinking, domestic use and other purposes.

Description of the Study Area

The study area Federal University Otuoke and environ is located within the lower section of the upper flood plain deposits of the sub-aerial Niger Delta [6]. Geographically, it lies between latitudes 4^0 46'N and 5^0 51'N and longitudes 6^0 15'E and 6^0 23'E (Figure 1). The area is bounded on the North by Yenagoa, the capital of Bayelsa State and on the south by Brass and Nembe Local Government Areas of Bayelsa State, to the West by southern Ijaw and Ahoada-west local government areas of Bayelsa State and Rivers State respectively. The area can be accessed from the north by the Mbiama-Yenagoa road and on the south by the Nembe and Brass Rivers [7]. Most part of the area is motor-able; hence there is a network of roads that links the different parts of the area.
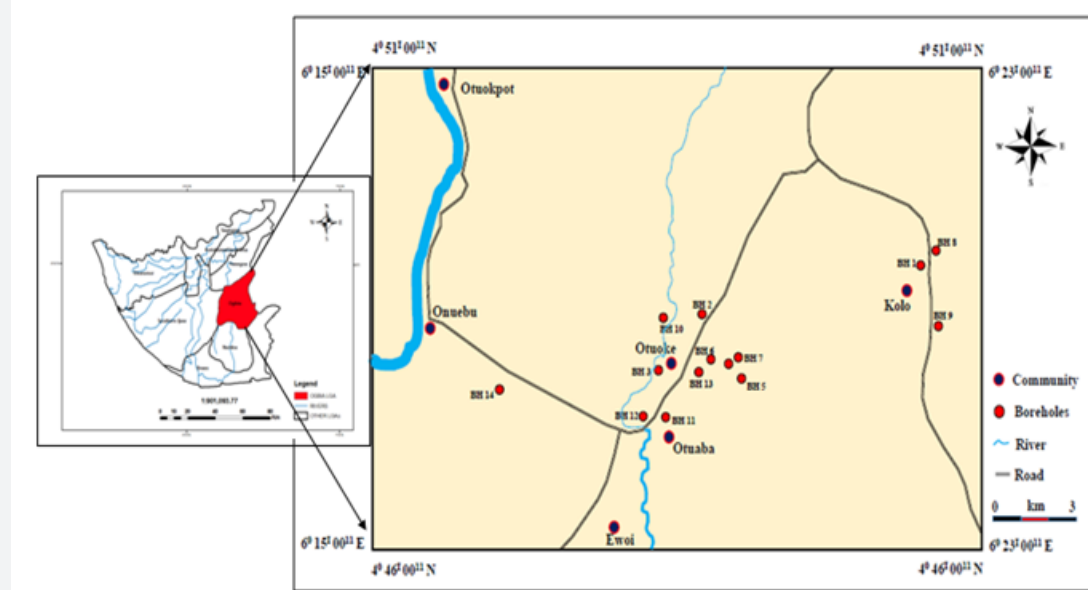

Figure 1: Map of Bayelsa State showing the study area and sample locations.

Brief Geology and Hydrogeology of the Area

The study area lies in the coastal Niger Delta sedimentary basin. The geology of the Niger Delta has been described in details by various authors. The formation of the Delta started during Early Paleocene and resulted mainly from the buildup of fine grained sediments eroded and transported by the River Niger and its tributaries. The Tertiary Niger Delta is a sedimentary structure formed as a complex regressive off-lap sequence of clastic sediments ranging in thickness from 9,000-I2,000m [8]. Starting as separate depocenters, the Niger Delta has coalesced to form a single united system since Miocene. The Niger Delta is a large and ecologically sensitive region, in which various water species including surface and sub-surface water bodies exist in a state of dynamic equilibrium [8]. Stratigraphically, the Niger Delta is sub-divided into Benin, Agbada and Akata Formations in order of increasing age. The Benin Formation is the water bearing zone of the area (Table 1). It is overlain by Quaternary deposits (40-I50m thick) and generally consists of rapidly alternating sequence of sands and silty clays with the latter becoming increasingly more prominent seawards [9]. The clayey intercalations within the Benin formation have given rise to multi-aquifer system in the area [9]. The first aquifer is commonly unconfined while the rest are confined. The study area has been noted to have poor groundwater quality due to objectionable high concentration of certain groundwater parameters and encroachment of saltwater or brackish water into the freshwater aquifers [10-12]. The static water level in the area ranges from 0-2m during the rainy season and I-3m during the dry season [13]. The main source of recharge is through direct precipitation where annual rainfall is as high as 3000mm [14,15]. The water infiltrates through the highly permeable sands of the Benin Formation to recharge the aquifers [16,17]. Groundwater in the area occurs principally under water table conditions [18].

Table 1: Borehole sample locations within the study area.

S/N	Borehole location	Sample code	Latitude	Longitude
1	Kolo1(State Secondary School)	BH1	04° 48′ 27.2″	06° 22′ 31.7″
2	Otuoke 1 (skill acquisition centre)	BH2	04° 48′ 04.8″	06° 19′ 24.8″
3	Otuoke 2 (community hospital)	BH3	04° 47′ 38.4″	06° 18′ 43.3″
4	Fuo 1 (vice-chancellor's lodge)	BH4	04° 47′ 27.8″	06° 19′ 51.8″
5	Fuo 2 (registrar's lodge)	BH5	04° 47′ 39.4″	06° 19′ 50.8″
6	Fuo 3 (business centre)	BH6	04° 47′ 41.0″	06° 19′ 28.1″
7	Fuo 4 (student hostel)	BH7	04° 47′ 35.6″	06° 19′ 42.6″
8	Kolo 2	BH8	04° 48′ 38.1″	06° 22′ 36.2″
9	Kolo 3	BH9	04° 47′ 51.6″	06° 22′ 35.0″
10	Efriwo	BH10	04° 48′ 11.4″	06° 18′ 49.6″
11	Otuaba	BH11	04° 47′ 06.0″	06° 18′ 46.9″
12	Abaye	BH12	04° 47′ 10.0″	06° 18′ 30.9″
13	Elabio	BH13	04° 47′ 34.9″	06° 19′ 18.5″
14	Obruba	BH14	04° 46′ 34.2″	06° 16′ 30.0″

Materials and Methods

Groundwater samples were collected from fourteen boreholes in Federal University of Otuoke and its environs during the rainy season. The boreholes utilized for this study were selected from eight communities at random. Both private and public water sources were sampled in this study. Sterilized water bottles were used to collect representative water samples to prevent contamination. At each borehole location, the sample bottles were washed and rinsed thoroughly with the sample water before being sampled. The samples were collected close to the well head to maintain the water integrity. The boreholes were allowed to flow for about 3 minutes to ensure stable conditions before samples were collected. The bottle was filled to the brim with the sample water, and the lid immediately replaced to minimize oxygen contamination and escape of dissolved gases. Sampling was done using two sets of prelabelled bottles of one litre capacity for ionic and heavy metals analysis respectively. Water samples for the determination of cations were stabilized by adding few drops of diluted HCl to them after collection. To maintain the integrity of the water samples, physico-chemical parameters sensitive to environmental changes such as pH, conductivity and temperature were measured and recorded in-situ using portable digital meters. The co-ordinates of all the sampling locations were recorded using a Garmin 78 model Geographic Positioning System (GPS). The samples were later transported to the laboratory in an ice chest for chemical analysis. Table 1 shows the borehole sampling locations along with the geographic cordinates.

Heavy metals were determined using an Atomic Absorption Spectrophotometer (AAS) as described in APHA 3111B and ASTM D3651 [19-22]. This involved direct aspiration of the sample into an air/acetylene or nitrous oxide/acetylene flame generated by a hollow cathode lamp at a specific wavelength peculiar only to the metal programmed for analysis. For every metal investigated, standards and blanks were prepared and used for calibration before samples were aspirated. Concentrations at specific absorbance displayed on the data system monitor for printing. The equipment limit of detection is <0.001mg/L. Table 2 shows the equipment and analytical methods used for groundwater samples analysis.

Table 2: Equipment and Analytical Methods used for Groundwater Samples Analysis.

Parameter	Type of test	Equipment/Analytical Method	Standard
pH	In-situ	Digital pH meter	APHA 4500H*B
Temperature	In-situ	Mercury-in-glass thermometer	
Conductivity	In-situ	Digital conductivity meter	APHA 2510B
Turbidity	Laboratory	HACH2100AN tubidimeter	APHA2130B
Calcium, Magnesium, Potassium, Alkalinity	Laboratory	Direct atomic absorption	ASTMD511-93
Sodium, Hardness	Laboratory	Titration method	ASTM512B
Total Dissolved Solids	Laboratory	Filtration and evaporation	APHA 2510A
Sulphate and Phosphate	Laboratory	Turbidimetric method	ASTMS-516

Chloride	Laboratory	Silver nitrate titration	ASTM512B
Nitrate	Laboratory	Brucine method	APHA 4500*E
Bicarbonate	Laboratory	Colorimetric method	
Heavy metals	Laboratory	Atomic absorption spectrophotometer	APHA 3111B

Results and Discussion

Groundwater temperature in the study area ranges from 24.60 to 29.5oC with mean of 27.31±1.12°C and variance of 1.25 (Table 3). Groundwater pH which is a measure of acidity or alkalinity, ranges from 4.78 to 7.01 with mean, standard deviation (SD) and variance of 6.27±0.56 and 0.32. The highest pH values were obtained from BH7 (7.01) and BH8 (6.83) whereas the lowest pH was obtained at BH3 (4.98) (Figure 2); (Table 3). This shows that the water in the area is predominantly acidic. The EC ranges from 53.20 - 130.30 µS/cm with mean of 94.81±22.12µS/cm and variance of 489.13. The high standard deviation and variance shows that there is wide degree of variability in the EC of the groundwater resources in the area. Groundwater turbidity ranges from 3.71 - 5.14 NTU, with mean, SD and variance of 4.37±.46 NTU and 0.21 respectively (Tables 3 & 4). Total soluble solids ranged from 4.72 to 13.02mg/L while hardness ranged from 32.0 to 61.0mg/L. Water is said to be hard when it contains large amount of dissolved salts, such as calcium and magnesium ions. Total Dissolved Solids ranges from 4.11 to 92.10mg/L with mean, SD and variance of 36.02±23.30 and 542.92 respectively (Table 4). Alkalinity ranged from 10.34 to 12.01mg/L with mean and SD of 11.19±0.35mg/L.
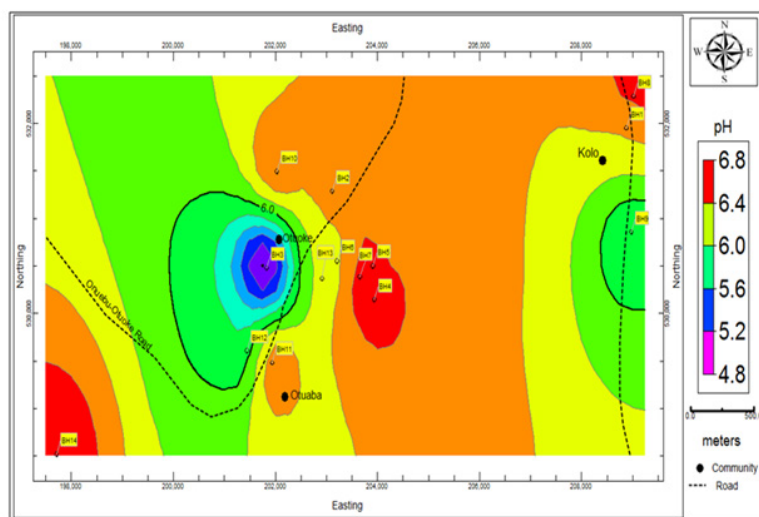

Figure 2: A map showing the pH distribution in groundwater resources in the study area.

Table 3: Results of physicochemical and heavy metals in groundwater from the study area.

Parameters	Units	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	BH10	BH11	BH12	BH13	BH14
Temperature	0C	27.50	27.10	27.30	27.20	27.30	27.2s0	27.10	29.50	28.20	25.90	24.60	27.40	28.30	27.70
pH		6.31	6.52	4.98	6.71	6.53	6.21	7.01	6.83	5.76	6.72	6.90	5.73	6.22	6.77
Conductivity	µS/cm	53.20	118.70	96.30	73.00	75.00	90.50	83.60	120.40	130.30	81.30	98.40	94.50	87.70	124.50
Turdidity	NTU	3.75	4.73	4.16	5.00	5.14	3.71	4.77	3.99	4.55	4.21	4.75	3.88	4.55	4.29
TSS	mg/L	10.60	6.27	13.01	12.75	4.72	5.89	5.99	4.73	12.01	6.77	8.91	11.11	13.02	10.02
TDS	mg/L	22.82	13.51	27.56	12.75	33.55	21.06	4.11	68.00	92.10	53.50	40.10	36.30	40.57	38.30
Chloride	mg/L	23.89	26.71	14.33	15.74	19.51	41.31	25.04	23.90	19.30	16.03	17.89	39.33	47.80	31.51
Bicarbonate	mg/L	3.00	0.40	1.60	0.90	0.80	0.90	1.94	1.60	0.92	2.50	1.20	4.80	1.60	0.90
Hardness	mg/L	51.00	32.00	35.00	37.00	39.00	50.00	61.00	49.00	37.00	32.00	39.00	53.00	50.00	46.00
Calcium	mg/L	25.00	23.10	28.31	26.02	24.10	23.03	26.40	29.01	29.01	28.10	30.01	14.99	55.03	44.41
Magnesium	mg/L	7.82	9.33	9.91	8.88	8.30	7.91	8.33	11.12	11.12	13.14	11.01	15.05	7.93	10.22

Sulphate	mg/L	0.09	0.03	0.05	0.06	0.03	0.07	0.04	0.09	0.09	0.03	0.02	0.01	0.06	0.07
Phosphate	mg/L	5.01	0.03	0.06	0.01	0.02	0.07	0.05	0.21	0.21	0.04	0.05	0.07	0.04	0.01
Alkalinity	mg/L	10.90	10.83	10.44	11.02	12.01	11.05	11.02	11.60	11.60	10.34	11.00	11.08	11.88	11.92
Iron	mg/L	0.07	0.11	1.25	10.00	0.11	0.56	0.00	0.09	0.12	0.32	0.12	0.06	0.01	0.41
Nitrate	mg/L	0.07	0.20	0.10	0.06	0.03	0.04	0.01	0.03	0.02	0.05	0.03	0.11	0.21	0.15
Sodium	mg/L	100.00	102.00	111.00	103.00	93.00	112.00	96.00	100.00	101.00	101.00	103.00	102.00	102.00	98.00
Manganese	mg/L	0.01	0.12	0.15	0.16	0.11	0.10	0.15	0.10	0.91	0.12	0.10	0.15	0.17	0.12
Potassium	mg/L	4.20	1.47	1.55	0.76	1.20	1.43	4.65	1.80	2.62	2.50	1.80	2.25	2.13	4.00
Lead	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	mg/L	0.01	0.003	0.002	0.006	0.035	<0.001	0.021	0.011	<0.001	0.013	0.01	<0.001	<0.001	<0.001
Barium	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic	mg/L	0.0012	<0.001	<0.001	<0.001	<0.001	0.0012	0.0011	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 4: Results of statistical analysis for measured parameters in the area along with regulatory guidelines.

| Parameters	Minimum	Maximum	Mean	SD	Variance	WHO (2011)	NSDWQ (2007)
Physical parameters							
Temperature	24.60	29.50	27.31	1.12	1.25	NA	NA
pH	4.98	7.01	6.37	0.56	0.32	6.5-8.5	6.5-8.5
Conductivity	53.20	130.30	94.81	22.12	489.13	1250.00	1000.00
Turdidity	3.71	5.14	4.39	0.46	0.21	5.00	5.00
TSS	4.72	13.02	8.99	3.18	10.09	NA	NA
TDS	4.11	92.10	36.02	23.30	542.92	1200.00	500.00
Hardness	32.00	61.00	43.64	8.92	79.63	500.00	150.00
Alkalinity	10.34	12.01	11.19	0.53	0.28	400.00	NA
Cations and Anions							
Sodium	93.00	112.00	101.71	5.00	24.99	200.00	200.00
Potassium	0.76	4.65	2.31	1.19	1.41	55.00	200.00
Magnesium	7.82	15.05	10.01	2.14	4.59	50.00	30.00
Calcium	14.99	55.03	29.04	9.77	95.36	75.00	75.00
Chloride	14.33	47.80	25.88	10.46	109.34	250.00	250.00
Bicarbonate	0.40	4.80	1.65	1.15	1.33	600.00	NA
Sulphate	0.01	0.09	0.05	0.03	0.00	500.00	100.00
Phosphate	0.01	5.01	0.42	1.32	1.75	5.00	NA
Nitrate	0.01	0.21	0.08	0.07	0.00	50.00	50.00
Heavy Metals							
Iron	0.00	10.00	0.95	2.63	6.90	0.30	0.30
Manganese	0.01	0.91	0.18	0.21	0.05	0.20	0.20
Copper	<0.001	0.04	0.01	0.01	0.00	1.00	1.00
Lead	<0.001	<0.001	<0.001	<0.001	<0.001	0.01	0.01
Barium	<0.001	<0.001	<0.001	<0.001	<0.001	0.30	0.30
Cobalt	<0.001	<0.001	<0.001	<0.001	<0.001	1.00	1.00
Arsenic	<0.001	<0.001	<0.001	<0.001	<0.001	0.05	0.01
Boron	<0.001	<0.001	<0.001	<0.001	<0.001	0.30	0.30
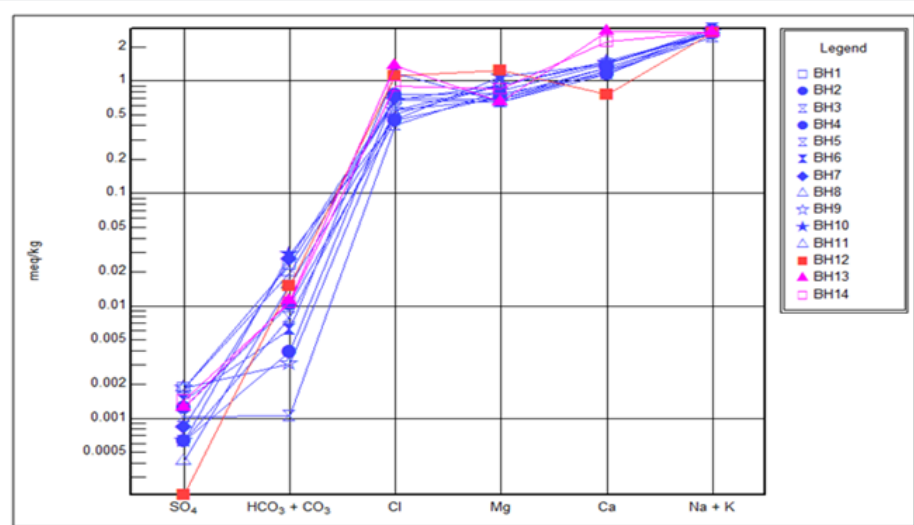
Figure 3: Schoeller diagram showing the concentration of major cations and anions in groundwater of the study area.

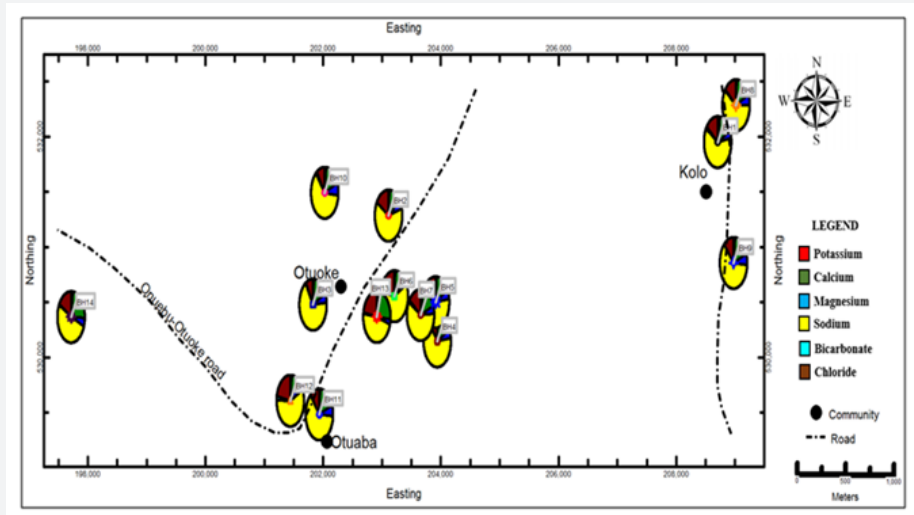**Figure 4:** A map showing the distribution of major ions in groundwater of the study area.

The ionic concentrations in were in the order; Na >Ca> Mg> K, and Cl> PO4> HCO3> SO4> NO3 (Table 4). Schoeller diagram which is a graphical presentation of cations and anions shows that cations predominate over anions in the groundwater (Figure 3). For cations, sodium ranged from 93 to 112mg/L with mean and SD of 101.70±5.0mg/L. Calcium which is the second most dominant cation in groundwater in the area ranged from 14.99 to 55.03mg/L, with mean, SD and variance of 29.04±9.77mg/L and 95.36mg/L respectively. The highest calcium concentration was obtained from BH13 and the lowest was from BH12. Magnesium and potassium ranged from 7.82 to 15.05mg/L and 0.76 to 4.65mg/L, with mean and SD of 10.01±2.14 and 2.31±1.19mg/L respectively (Table 4). Chloride was the most dominant cation in the groundwater, ranging from 14.33 to 47.80mg/L, with mean and SD of 25.88±10.46mg/L. The highest chloride concentration was obtained from BH13 while the lowest was obtained

from BH3. Although the concentrations of bicarbonate were relatively low, it was the second most dominant anion in the groundwater, ranging from 0.40 to 4.80mg/L with mean and SD of 1.65±1.15mg/L. Phosphate concentration ranges from 0.01 to 5.01mg/L, with mean and SD of 0.42±1.32mg/L while Nitrate ranged from 0.01 to 0.21mg/L with mean and SD of 0.08±0.07 mg/L. Sulphate had the lowest anionic concentration, ranging from 0.01 to 0.09mg/L with mean and SD of 0.05±0.03mg/L. A map showing the distribution of cations and anions in the study is presented in Figure 4. The map shows sodium is the most predominant cation while chloride is the most predominant anion in the groundwater.

For the heavy metals, iron was most predominant, ranging from 0.004 to 10mg/L with mean and SD of 0.95±2.63mg/L. Manganese ranged from 0.01 to 0.91mg/L, with mean and SD

of 0.18±0.21mg/L. Copper was below the machine detectable limit in six samples, but ranged from 0.006 to 0.013mg/L, with a mean of 0.01 mg/L. All other heavy metal including lead, arsenic, cobalt, boron and barium were below the detectable limit of the machine (< 0.001mg/L) (Table 4).

Suitability for Drinking Purposes

The suitability of groundwater for drinking purpose was achieved by comparing the acquired groundwater geochemical results with regulatory guidelines for potable water. The average pH of the groundwater shows that the water is acidic (pH=6.37) and deviates from both WHO (2011) and NSDWQ (2007) guidelines of 6.5-8.5 [23,24], and hence is unfit for drinking. Prolonged consumption of acidic water over long periods of time may result in derangement of the balance of acid to base in the human body, which results in metabolic acidosis [25]. Also, the average concentration of iron (0.95mg/L) exceeds both WHO 2011 and NSDWQ 2007 guidelines of 0.30 mg/L,

hence the water is unfit for drinking, unless treated for iron. Manganese is relatively higher than WHO (2011) and NSDWQ (2007) of 0.2mg/L in BH8 (0.91mg/L), and must be treated before consumption. Because of the toxic nature of heavy metals, exposure to a high concentration can kill organisms directly, and while continued exposure over long periods of time to lower concentrations can lead to stunted growth, lower reproduction rates, deformities, and even mortality (Lewis and Clark, 1996). Based on Freeze and Cherry [26] classification scheme, the groundwater samples are classified as soft, with hardness values < 100 in most of the boreholes. Based on total dissolved solids (TDS), Davis, Deweist [27] classify groundwater in the study area as 'desirable for drinking' having TDS values all below 500mg/L. Figure 5 is the cross plot of EC against TDS for the groundwater while Figure 6 is the cross plot of pH against temperature for the groundwater. Figure 7 is the cross plot of Na against Cl for the groundwater in the area [28-31].
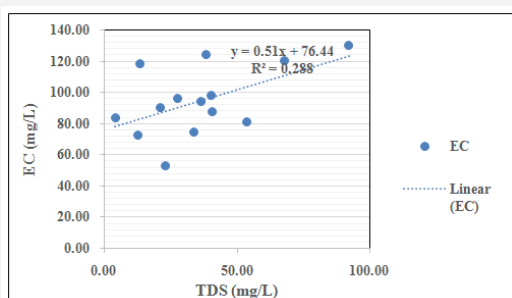

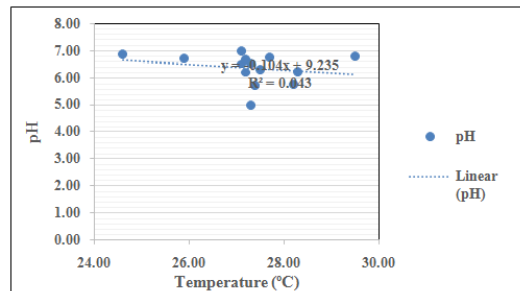**Figure 5:** Cross plot of EC against TDS for the groundwater

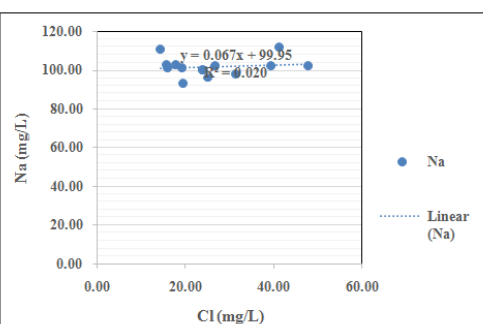**Figure 6:** Cross plot of pH against temperature for the groundwater.

Figure 7: Cross plot of Na against Cl for the groundwater.

Summary and Conclusion

In order of decreasing magnitude, the average cationic concentrations in the groundwater are in the order; Na (101.71mg/L) >Ca (29.04mg/L) > Mg (10.01 mg/L) > K (2.31mg/L); and anionic concentrations; Cl (25.88mg/L) > HCO_3 (1.65mg/L) > PO_4 (0.42mg/L) > NO3 (0.08mg/L) > SO4 (0.05mg/L). For the heavy metals, iron was most predominant, ranging from 0.004 to 10mg/L with mean and SD of 0.95±2.63 mg/L. Manganese ranged from 0.01 to 0.91mg/L, with mean

and SD of 0.18±0.21 mg/L. Copper was below the machine detectable limit in six samples, but ranged from 0.006 to 0.013mg/L, with a mean of 0.01mg/L. All other heavy metal including lead, arsenic, cobalt, boron and barium were below the detectable limit of the machine (< 0.001mg/L). Assessment of groundwater in the area for drinking purposes revealed that the water is predominantly acidic (pH = 6.37), with iron (0.95mg/L) and manganese (maximum = 0.91mg/L) contents exceeding regulatory guidelines WHO, 2011; NSDWQ, 2007 for potable drinking water in most locations. This shows that the groundwater sources are unsafe for consumption purposes. All other measured chemical parameters were within regulatory requirements. Constant monitoring and quality assessment on the groundwater is necessary to ensure that groundwater in the area is within regulatory requirements.

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