



Groundwater Quality Assessment in a University Sub-Urban Community in Delta State, Nigeria: Part A-Physicochemical Analysis

OWAMAH, HI

Department of Civil Engineering, Faculty of Engineering, Delta State University, PMB1, Abraka, Oleh Campus, Delta State, Nigeria
Email: owamah.hilary@gmail.com; hiowamah@delsu.edu.ng
Tel: +2348035705814

Abstract: This study provides detailed scientific information on the physicochemical properties of drinking water from groundwater in a Nigerian university sub-urban community. Water samples from boreholes (BHs) and hand-drawn wells (HDWs) in the community were collected and analyzed for their biological and physicochemical parameters, and the metals from July 2016 to January 2017 for wet and dry seasons. Results obtained, showed that the physicochemical factors complied with the World Health Organization (WHO) guidelines, except for pH being lower in some locations. In the wet and dry seasons, pH varied from 4.4 to 6.2 and from 4.8 to 6.7 respectively. While the mean value for wet season was 5.7, dry season was 5.9; to give a seasonal mean difference of 0.2. Cd and Pb, in both wells, for many locations, were slightly higher than the prescribed limits. The slight elevated concentrations of Pb and Cd could be attributed to oil exploration activities in the study area. The study recommends the provision of improved drinking water in the community.

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The need to regularly monitoring of the quality of groundwater used as drinking water in rural and sub-urban communities of developing countries cannot be over-emphasized (Owamah *et al.*, 2013; Sojobi, 2016). This is because, inadequate access to potable water and unavailability of reliable information on quality are major contributors to frequent outbreak of pathogenic diseases in the region. Oleh is one of such communities in Nigeria but peculiar in this circumstance as it houses one of the major campuses of the Delta State University, Abraka. The provision of water in Nigeria is constitutionally, the sole function of government. However, the inability of government to meet with the daily demands of water for the people has forced millions of Nigerians to seek alternatives such as drilling of their own boreholes and hand-drawn wells. Inadequate hygiene, poor sanitation and unsafe drinking water cause over one million global annual deaths and about eighty percent of all ailments in developing nations (WHO, 2012). Furthermore, about 50% of the global number of persons without access to clean water live in sub-Saharan Africa. At the moment, those who live in the area of study, basically, depend on water from boreholes and hand-drawn wells (groundwater) since there is no pipe-borne water supply. A lot of water wells were installed without adherence to the

standards of the supervising ministry thereby leading to compromised water quality. This study was therefore carried out to evaluate the physicochemical parameters of groundwater in a university sub-urban community in Delta State, Nigeria.

MATERIALS AND METHODS

Study area description: Oleh is the administrative head of the Isoko South Local Government Area (ISLGA), Delta State. The 2016 census of Nigeria put the population of ISLGA at 323,800 and indicates that ISLGA is one of the most populated LGAs in Delta State (NPC, 2018). Oleh community is the most populated of all the communities in the ISLGA. The coordinates of ISLGA is 5.43° N, 6.20° E (Fig. 1). ISLGA resides within the tropical rainforest belt and does experience tropical wet and dry climate.

The main economic activities are food crop farming, animal hunting, trading, and artisan and civil service jobs. Oleh has several primary, secondary and a tertiary schools (Faculties of Law, and Engineering of the Delta State University) with Christianity as the predominant religion.

Water Sampling: Sampling of the borehole and hand-drawn well waters were carried out using one and half

(1.5L) capacity high-density PET screw-capped containers from June 01, 2016 to January 31, 2017. Before collection of the actual sample, bottles were washed for three times and thereafter stoppered, labeled, ice-cooled and transported to Jacio Environmental Limited, Effurun, Delta State, Nigeria.

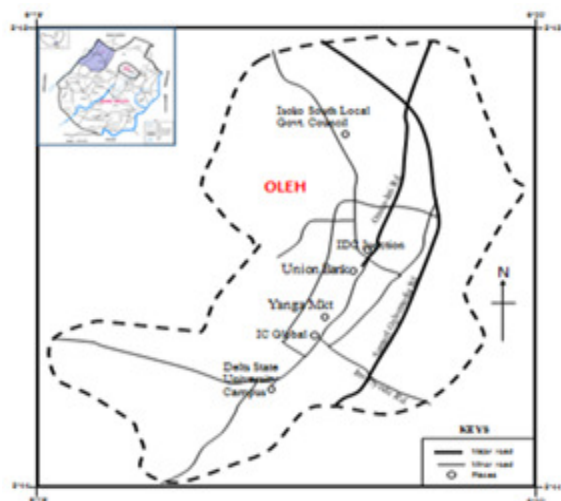


Fig. 1: Map of area of study

Following the work of Owamah *et al.* (2013), at each sampling point, acidified and non-acidified samples were collected. Autoclave-sterilized bottles were utilized for the collection of samples for bacterial analysis. Eighteen (18) raw water samples, three (3) from each district, were collected every month to amount to a total of eight (108) samples.

Analytical procedures: The parameters; total dissolved solids (VSI 22, India), temperature (HI 98517), pH (HI 9024-C), electrical conductivity (HI 2315) and salinity (HI 19311) were determined on site using the portable meters. Dissolved oxygen was determined using the prescribed methods in APHA (2012). Through the use of a UV spectrophotometer (DR 2800, HACH, Washington, USA) and adopting ultraviolet spectrophotometer screening method, the anions were determined in accordance with the methods prescribed in APHA (2012). The enumeration of the total coliform bacteria was done according to the guidelines in the analyses of metals was done using atomic absorption spectrophotometer (Sens AA 3000) and in accordance with the methods in APHA (2012).

Statistical analyses: Analyses of data obtained were done using Microsoft Office Excel 2010 software and the Analysis of Variance (ANOVA) statistical tool at $P < 0.005$. The mean and standard deviation of the parameters analyzed were computed for both seasons.

Seasonal variations were then computed as the difference between the wet and the dry season mean values taking the wet season as the reference point.

RESULTS AND DISCUSSION

Physicochemical parameters: Table 1 and Figs. (2a - 2e) show the values of some of the physicochemical parameters obtained in this study. From this study, pH was found to range from 4.90 to 6.20 in hand-drawn wells and 4.40 to 6.70 in borehole water samples (Table 1). In the wet and dry seasons, pH varied from 4.4 to 6.2 and from 4.8 to 6.7 respectively. While the mean value for wet season was 5.7, dry season was 5.9; to give a seasonal mean difference of 0.2.

This indicates that the pH of groundwater sources in the community was fairly constant, season notwithstanding. Granted this, pH values in the wet season were however, generally, higher than dry season values. This could be associated with the rise of water level during wet seasons, which brings with it some level of dilution. The most acidic values were got from YM district borehole and Old OER district hand-drawn well water samples. For both wet and dry seasons, borehole water samples were found to be more acidic than the hand-dug well water samples.

A maximum pH of 6.7 was obtained from a borehole in GRA district in the month of September (Table 1, Fig. 2b). The pH values obtained in this study are similar to reported values for groundwater sources in neighboring Isoko North communities (Owamah *et al.*, 2013). Since the WHO prescription for pH lies between 6.5 and 8.5, groundwater sources in the community, may need to be treated with lime to raise it to the desired level. Though pH is not a major health related water quality parameter, low levels of it affect the state of other water quality parameters like solubility of metals and pathogen survival and hence could be capable of causing indirect health problems to humans (Khan *et al.* 2013).

Drinking water with low pH could also cause gastrointestinal irritations. The lower than permissible pH range obtained from the different water sources can be linked to the geological formation in the community (Sojobi, 2016). Similar findings of low pH values were obtained for groundwater sources of neighboring Isoko North Local Governmental Area communities by Owamah *et al.* (2013). There was no significant difference ($p > 0.05$) in pH among the sampling sites, wells and across the seasons. The highest EC was obtained from a hand-drawn well (HDW) within FL district ($486 \mu\text{S cm}^{-1}$) in the month of October.

Table 1. Mean concentrations of some physiochemical parameters of groundwater samples from the study area for wet and dry seasons (N=18)

Location, Water Source	pH	EC ($\mu\text{S cm}^{-1}$)	DO (mg L^{-1})	BOD ₅ (mg L^{-1})	Temperature ($^{\circ}\text{C}$)	TDS (mg L^{-1})
^w OER,BH	6.1±0.1	72±3.3	10±2.1	7±1.5	24.6±0.3	14±1.4
^w OER,HDW	6.2±0.1	450±41.5	12±0.4	6±0.4	28.4±0.6	134±18.0
^d OER ,BH	5.8±0.0	51±2.1	10±2.1	8±1.3	28.7±0.7	10±1.2
^d OER, HDW	5.9±0.1	382±96.5	11±0.4	6±0.5	29.6±0.6	130±6.1
^w OEF ,BH	5.5±0.2	135±2.9	12±1.5	5±0.4	25.2±0.8	45±6.6
^w EF, HDW	5.9±0.2	138±5.2	11±1.0	6±1.1	28.1±1.2	43±6.5
^d EF,BH	4.8±0.1	287±4.2	10±1.5	5±1.3	25.6±1.0	40±3.1
^d EF, HDW	6.1±0.3	92±4.1	12±1.0	6±0.4	26.3±0.2	38±1.2
^w YM,BH	5.6±0.2	39±2.0	13±1.3	7±1.3	26.4±0.8	10±1.0
^w YM, HDW	6.2±0.4	153±41.1	10±2.6	5±0.9	26.6±0.5	39±21.1
^d YM, BH	5.9±0.1	43±7.2	13±1.3	7±1.5	27.6±0.9	12±3.3
YM,HDW	6.2±0.3	100±29.5	9±2.6	6±1.3	28.0±0.9	33±15.4
^w IT,BH	5.9±0.1	42±1.8	9±2.1	5±1.1	27.4±0.8	11±0.9
^w IT, HDW	6.1±0.1	141±2.3	10±1.7	5±1.9	27.9±0.6	53±2.9
^d IT, BH	5.7±0.1	35±1.7	10±2.1	6±1.0	27.5±0.5	12±0.5
^d IT, HDW	5.9±0.1	151±8.7	10±1.7	4±1.3	26.4±0.6	52±3.2
^w LF, BH	5.6±0.2	115±2.4	12±1.8	6±0.7	24.2±1.2	24±1.8
^w LF, HDW	5.3±0.1	486±9.5	13 ±0.8	5±0.2	24.4±0.7	110±11.3
^d LF, BH	6.7±0.6	109±2.0	9±1.4	4±0.6	26.0±1.2	22±3.2
^d LF, HDW	5.4±0.1	320±45.1	8±0.7	5±0.4	25.1±1.3	111±3.9
^w GRA, BH	4.4±0.3	54±3.3	12±1.4	7±0.6	28.3±0.6	10±2.4
^w GRA, HDW	5.4±0.4	246 ±21.2	10±2.3	5±1.6	24.6±0.7	55±2.1
^d GRA, BH	5.8±0.6	55±18.0	11±1.2	4±1.4	25.2±0.5	21±7.0
^d GRA, HDW	4.9±0.3	133±53.1	9±1.6	3±0.9	24.2±0.7	86±3.1

DO = dissolved oxygen; EC=Electrical conductivity; Results are expressed as mean \pm standard deviation; ^w = wet season; ^d = dry season

This was closely followed by another HDW at OER district ($450 \mu\text{S cm}^{-1}$) (Table 1). The values are in accordance with the stipulated limit of $1000 \mu\text{S cm}^{-1}$ by the SON (2007) and the WHO (2006) for drinking water. There was no significant variability ($p > 0.05$) among the different sources, locations and seasons. EC results obtained are consistent with findings from other parts of Nigeria; while a maximum and minimum EC of $500 \pm 41.5 \mu\text{S cm}^{-1}$ and $75 \pm 3.3 \mu\text{S cm}^{-1}$ were obtained for neighboring Isoko North LGA communities by Owamah *et al.* (2013), Dahunsi *et al.* (2014) obtained $308.33 \pm 1.53 \mu\text{S cm}^{-1}$ and $22.4 \pm 0.53 \mu\text{S cm}^{-1}$ as maximum and minimum EC for selected communities in Ogun and Lagos States. In all water samples collected, values of TDS obtained were found to be lower than the stipulated maximum value of 500 mg L^{-1} set by the WHO (2005) and the SON (2007) for drinking water. While TDS is a function of the sum total of ions in solution, EC is a function of the ionic activities (LENNTECH, 2016). Mean TDS values obtained for wet and dry seasons are 54 and 52 mg L^{-1} respectively, with a seasonal mean variation of -2 mg L^{-1} (wet-dry). It ranged from 10 to 134 mg L^{-1} in the wet season and 12 to 134 mg L^{-1} in the dry season.

Hand-drawn well water samples from OER district had the maximum dry and wet season TDS of 134 and 130 mg L^{-1} , respectively (Fig. 2e). Compared with borehole water samples (Table 1), water samples from

the hand-drawn wells had higher values and this can be linked to the intrusion of runoff into them, following the absence of borehole casings and caps. It could also be the result of soil disturbance within the well during water withdrawals (Mkwate *et al.*, 2017). Similar values of higher TDS for shallow wells were obtained by Dahunsi *et al.* (2014) for selected communities in the South-Western Nigeria and Owamah *et al.* (2013) for communities in the neighboring Isoko North Local Government Area.

The seasonal average values for DO are 9 and 8 mg L^{-1} for wet and dry seasons respectively. It ranged from 10 to 13 mg L^{-1} for wet season and 10 to 12 mg L^{-1} for the dry season. Fig. 2c shows the values of DO obtained from boreholes and hand-drawn wells in both seasons. The DO values obtained in the study area are above the WHO (2006) desired value of 4 mg L^{-1} and hence in order. BOD ranged from 5–7 and 4–8 mg L^{-1} for wet and dry seasons, respectively (Fig. 2d). For both seasons, the seasonal mean value is 6 mg L^{-1} (Table 1). Ademoroti (1996) and Owamah *et al.* (2013) reported that the maximum allowable BOD₅ is 6 mg L^{-1} ; as higher values mean organic contamination.

Anions: Table 2 contains the average values of the anions gotten in this study. Chloride concentration obtained ranged from 3 to 58 mg L^{-1} and 5 to 65 mg L^{-1} for the wet and dry seasons respectively. Seasonal

mean values of 17 and 13 mg L⁻¹ were recorded for wet and dry seasons, respectively. In line with the report of Egboh and Emeshili (2008) of higher chloride concentrations in wet season for

communities in the neighboring Ndokwa East Local Government Area, chloride values obtained were higher in hand-drawn wells and during the wet season.

Table 2. Mean values (mg L⁻¹) of anions of groundwater samples from the study area for wet and dry seasons (N=18)

Location/Water Source	NO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
^w OER,BH	1±0.5	4±0.2	5±0.1
^w OER,HDW	3±2.1	58±3.4	28±4.8
^d OER ,BH	1±0.2	5±1.2	4±0.6
^d OER, HDW	2±0.5	33±14.6	19±12.0
^w OEF ,BH	2±0.6	4±0.1	3±0.5
^w EF, HDW	BD ^a	7±1.3	5±0.8
^d EF,BH	2±1.6	15±3.2	8±3.3
^d EF, HDW	2±0.7	8±0.2	5±0.4
^w YM,BH	1±1.2	3±0.3	2±1.1
^w YM, HDW	2±1.2	11±3.0	5±2.2
^d YM, BH	1±0.3	6±1.5	2±0.6
^d YM,HDW	1±0.2	10±4.6	6±1.8
^w IT,BH	BD ^a	4±0.2	2±0.9
^w IT, HDW	2±0.5	11±1.6	7±1.6
^d IT, BH	BD ^a	2±0.5	2±0.2
^d IT, HDW	1±0.6	11±2.0	8±1.4
^w LF, BH	BD ^a	10±0.9	7±1.3
^w LF, HDW	2±1.1	65±1.6	31±2.0
^d LF, BH	3±1.5	12±4.3	7±2.2
^d LF, HDW	2±1.6	45±20.1	22±10.8
^w GRA, BH	3±2.1	3±1.1	2±0.6
^w GRA, HDW	1±0.8	18±2.1	13±2.7
^d GRA, BH	1±0.8	5±1.2	4±1.6
^d GRA, HDW	2±1.2	14±4.4	7±0.9

Results are expressed as mean ± standard deviation; ^w = wet season; ^d = dry season; ^a below detection limits.

While the minimum Cl⁻ concentration of 2±0.5 mg L⁻¹ was obtained from a bore-hole in IT district, during the dry season, the maximum of 65±1.6 mg L⁻¹ was from a hand-drawn well in GRA district in the wet season. The small values of the standard deviation imply minor variability in the concentration of Cl⁻. The values of Cl⁻ concentration obtained are below the stipulated maximum permissible limit of 250 mg L⁻¹ by the SON (2007). This indicates that chloride is of no health concern in groundwater of the study area. A previous study by Dahunsi *et al.* (2014) on some major cities in Ogun and Lagos States, Nigeria also reported low concentration of chloride of the range of 1.97-9.04 mg L⁻¹ for boreholes and wells showing that chloride may not be a major source of worry for groundwater used as drinking water in Nigeria. For wet and dry seasons, the mean concentrations of NO₃⁻ obtained were 1 and 3 mg L⁻¹ respectively, and are similar to values obtained for neighboring Ndokwa East, and Isoko North Local Government Areas of Delta State by Egboh and Emeshili (2008) and Owamah *et al.* (2013), respectively.

NO₃⁻ concentrations were significantly higher ($p < 0.005$) in the water samples of the hand drawn-wells than boreholes'. It also varied across the districts for the hand-drawn wells and boreholes. Though nitrate

was not detected in the water samples of one hand-drawn well and two boreholes from three different districts (Table 2), its concentration of (1-3 mg L⁻¹) in the rest other water samples is below the stipulated level of 50 mg L⁻¹ set by SON (2007). There was no significant ($p < 0.05$) variation of nitrate concentration among all the sampling locations and among the wells. For wet and dry seasons, the concentration of SO₄²⁻ obtained ranged from 2 to 28 mg L⁻¹ with seasonal mean values of 10 and 7 mg L⁻¹ for wet and dry seasons respectively. The observed seasonal mean variation is 3 mg L⁻¹. Much higher values were obtained during the wet season and from hand-dug wells. Though sulfate is one of the least toxic anions, ingestion of excess sulfate could cause dehydration and laxative action (Dahunsi *et al.*, 2014). Sulfate values in this study area are below the WHO (2006) and SON (2007) stipulated guidelines of 500 mg L⁻¹ and 100 mg L⁻¹ respectively (Table 5).

Metals: The mean concentrations of metals (Na, K, Mg and Ca, Pb, Cd, Zn, Cu, Fe and Ba) detected in this study are shown in Table 3. Na concentration range of 2,200±110 to 72,100±13340 µg L⁻¹ from this present study, is below the prescribed limit of 200,000 µg L⁻¹ set by the WHO (2006) and SON (2007) (Table 5) and hence not considered a contaminant.

Table 5. Drinking water quality guidelines of the WHO and SON

S/N	Parameter	^a WHO (2006)	^b SON (2007)
1	pH	6.5–8.5	6.5-8.5
2	Cadmium (Cd)	0.003	0.003
3	Chloride (Cl ⁻)	-	250
4	Chromium (Cr)	0.050	0.050
5	Copper (Cu)	2.00	1.00
6	Iron (Fe)	0.30	0.30
7	Lead (Pb)	ND1	0.01
8	Zinc (Zn)	-	3.00
9	Nickel (Ni)	0.020	0.02
10	Barium (Ba)		
111	Nitrate (NO ₃ ⁻)	10	50.0
12	Nitrite (NO ₂ ⁻)	1.0	0.2
13	Sulphate (SO ₄ ²⁻)	500	100
14	Total coliform (TC)	0x10 ²	10
15	<i>E. coli</i> count	0x10 ²	-
16	Electrical Conductivity (EC) (μS/cm)	1000	1000
17	Total Suspended Solid (TSS)	-	-
18	Total Solid (TS)	-	-
19	Total Dissolved Solid (TDS)	500	500
20	Salinity (%)	-	-
22	Turbidity	1	5
22	Magnesium (Mg)	200	0.2
23	Calcium (Ca)	200	-
24	Sodium (Na)	200	200
25	Potassium (K)	30	-
26	Dissolved Oxygen (DO)	4	7.5
27	BOD ₅	-	6
28	Total Alkalinity (mg/L CaCO ₃)	-	-
29	Hardness ((mg/L CaCO ₃)	500	150
30	Colour apparent (Hz)	15 -apparent (Hz)	15 (TCU)

Notes: Apart from pH and parameters with indicated units, the unit of parameters is mg/L *World Health Organization; ^bStandard Organization of Nigeria. Sources: Adapted from Dahunsi et al. (2014) and Sojobi (2016) following minor adjustments

Apart from water samples of HDW in YM district with Fe concentration of $850 \pm 290 \mu\text{g L}^{-1}$, above the $300 \mu\text{g L}^{-1}$ of SON (2007), the rest other values of Fe obtained across the districts (Table 3) were below the specified maximum permissible level. High levels of Fe in water could lead to characteristic reddish staining and increased turbidity (Mkwate *et al.*, 2017). The value of potassium obtained, is in line with the claim of Mkwate *et al.* (2017) that potassium concentration in natural waters has been widely reported to be low ($0-15,000 \mu\text{g L}^{-1}$). Potassium levels obtained in this study are below the recommended limits of $25,000-50,000 \mu\text{g L}^{-1}$ (Sojobi, 2016) for drinking water. From Table 3, the seasonal mean concentrations of Na, K, Mg, and Ca are $17,700 \mu\text{g L}^{-1}$ – $15,300 \mu\text{g L}^{-1}$, $12,100 \mu\text{g L}^{-1}$ – $9,000 \mu\text{g L}^{-1}$, $11,000 \mu\text{g L}^{-1}$ – $4,000 \mu\text{g L}^{-1}$ and $10,000 \mu\text{g L}^{-1}$ – $8,000 \mu\text{g L}^{-1}$ (wet –dry) respectively, indicating that the distribution of Na, K, Mg, and Ca concentrations decreased from wet to dry season. These reported values in this study are within the acceptable WHO and SON limits (Table 5). The reason for the higher values of Na, K, Mg, and Ca in the wet season could be attributed to the higher dissolution of rock containing the minerals of these metals during the rains. Na, K, Mg and Ca were also detected in the groundwater samples of selected communities in the

Isoko North Local Government Area, at lower than specified limits of the WHO and SON (Owamah *et al.*, 2013).

The highest concentration of Zn ($3410 \pm 1500 \mu\text{g L}^{-1}$) was obtained in July from a hand-drawn well water sample in GRA district of the study area. The concentration of Zn ranged from $60 \pm 30 \mu\text{g L}^{-1}$ to $3410 \pm 1500 \mu\text{g L}^{-1}$ and $60 \pm 10 \mu\text{g L}^{-1}$ to $2510 \pm 1300 \mu\text{g L}^{-1}$ for the wet and dry seasons respectively. For the seasonal mean values of Zn, $1320 \mu\text{g L}^{-1}$ and $275 \mu\text{g L}^{-1}$ were respectively obtained for wet and dry seasons. Only Zn of a HDW ($3410 \pm 1500 \mu\text{g L}^{-1}$, wet season) and borehole (3010 ± 1400 , dry season) of GRA district surpassed the WHO (2006) and SON (2007) maximum acceptable limit of $3000 \mu\text{g L}^{-1}$. Zinc usually comes into the groundwater through the erosion of Zn containing rock and soil minerals. Zinc is majorly introduced into ground water by artificial pathways. Though Zn is an important nutrient for body growth and development, high levels of zinc can lead to nausea, vomiting and stomach cramps (Owamah *et al.*, 2013). The maximum concentrations of Pb of $300 \pm 20 \mu\text{g L}^{-1}$ was obtained from a borehole in OER district in the month of December. The minimum concentration of $10 \mu\text{g L}^{-1}$ was obtained from borehole and hand-drawn well water samples

from YM, IT, GRA and LF districts. Pb was detected in various water samples of the boreholes and hand-drawn wells across the six representative districts. Seasonal average concentrations of 28 $\mu\text{g L}^{-1}$ and 41 $\mu\text{g L}^{-1}$ for wet and dry seasons were respectively obtained. The concentration of Cd ranged from 10 $\mu\text{g L}^{-1}$ to 80 $\mu\text{g L}^{-1}$ for both wet and dry seasons with mean concentrations of 20 $\mu\text{g L}^{-1}$ for wet season and 10 $\mu\text{g L}^{-1}$ for the dry season. The concentration of Cu

ranged from 20 \pm 20 $\mu\text{g L}^{-1}$ to 2110 \pm 700 $\mu\text{g L}^{-1}$ in the wet season and from 10 \pm 20 $\mu\text{g L}^{-1}$ to 1370 \pm 150 $\mu\text{g L}^{-1}$ in the dry season. The seasonal mean concentrations are 18 $\mu\text{g L}^{-1}$ for wet season and 310 $\mu\text{g L}^{-1}$ for dry season. Ba concentration ranged from 50 \pm 10 $\mu\text{g L}^{-1}$ to 2510 \pm 440 $\mu\text{g L}^{-1}$ in the wet season and from 40 \pm 20 $\mu\text{g L}^{-1}$ to 1540 \pm 1540 $\mu\text{g L}^{-1}$ in the dry season. The seasonal mean values for Ba are 1275 $\mu\text{g L}^{-1}$ and 380 $\mu\text{g L}^{-1}$ for wet and dry seasons respectively.

Table 3. Mean values ($\mu\text{g L}^{-1}$) of metals of groundwater samples from the study area for wet and dry seasons (N=18)

Location/ Water Source	Pb	Cd	Zn	Cu	Fe	Ba	Na	K	Mg	Ca
^w OER,BH	70 \pm 30	30 \pm 20	1900 \pm 120	1500 \pm 80	30 \pm 20	1150 \pm 50	5500 \pm 2220	2600 \pm 1120	5300 \pm 213	8400 \pm 34
^w OER,HDW	60 \pm 20	80 \pm 10	2000 \pm 11	2110 \pm 70	20 \pm 20	1700 \pm 14	72100 \pm 133	34800 \pm 205	23600 \pm 14	36700 \pm 17
^d OER ,BH	300 \pm 20	60 \pm 10	1800 \pm 120	60 \pm 20	BD ^a	260 \pm 160	2200 \pm 110	1700 \pm 280	5000 \pm 710	2000 \pm 27
^d OER, HDW	200 \pm 15	80 \pm 14	1900 \pm 10	500 \pm 220	160 \pm 1	330 \pm 530	35500 \pm 212	5700 \pm 1060	16500 \pm 29	25200 \pm 50
^w OEF ,BH	BD ^a	BD ^a	60 \pm 30	20 \pm 20	20 \pm 10	1110 \pm 62	23300 \pm 645	5500 \pm 3060	10800 \pm 69	12300 \pm 65
^w EF, HDW	200 \pm 15	60 \pm 10	250 \pm 410	350 \pm 15	20 \pm 20	1430 \pm 40	14800 \pm 750	8600 \pm 2570	10300 \pm 37	21000 \pm 27
^d EF,BH	BD ^a	BD ^a	500 \pm 10	50 \pm 30	30 \pm 10	700 \pm 400	17800 \pm 247	7200 \pm 1050	6300 \pm 148	5800 \pm 118
^d EF, HDW	BD ^a	BD ^a	360 \pm 330	50 \pm 80	40 \pm 20	650 \pm 780	10700 \pm 202	5700 \pm 1050	5300 \pm 179	6600 \pm 357
^w YM,BH	190 \pm 24	30 \pm 20	1500 \pm 59	490 \pm 42	60 \pm 30	900 \pm 550	3800 \pm 750	1600 \pm 530	1900 \pm 770	3400 \pm 112
^w YM, HDW	50 \pm 10	40 \pm 20	1500 \pm 115	900 \pm 50	90 \pm 50	1300 \pm 67	13400 \pm 943	7700 \pm 6690	14300 \pm 15	16200 \pm 98
^d YM, BH	10 \pm 20	30 \pm 30	1300 \pm 69	120 \pm 10	150 \pm 1	70 \pm 110	4800 \pm 920	2100 \pm 6690	2000 \pm 50	2000 \pm 30
^d YM,HDW	30 \pm 30	10 \pm 20	1500 \pm 11	670 \pm 34	30 \pm 10	250 \pm 660	10900 \pm 654	3800 \pm 1840	7200 \pm 255	7000 \pm 212
^w IT,BH	10 \pm 10	BD ^a	80 \pm 10	50 \pm 10	BD ^a	50 \pm 10	5100 \pm 200	2500 \pm 670	2300 \pm 830	3300 \pm 900
^w IT, HDW	30 \pm 10	10 \pm 10	1770 \pm 11	600 \pm 30	230 \pm 2	1300 \pm 20	19900 \pm 620	9700 \pm 3010	9500 \pm 472	10800 \pm 45
^d IT, BH	10 \pm 10	BD ^a	60 \pm 10	90 \pm 80	30 \pm 10	40 \pm 20	4200 \pm 600	1700 \pm 250	2700 \pm 100	1500 \pm 114
^d IT, HDW	10 \pm 10	20 \pm 20	1680 \pm 12	120 \pm 10	850 \pm 2	1000 \pm 12	15500 \pm 132	6500 \pm 2130	8910 \pm 275	7620 \pm 420
^w LF, BH	10 \pm 10	BD ^a	70 \pm 30	50 \pm 10	40 \pm 20	700 \pm 500	12600 \pm 280	4400 \pm 2250	5100 \pm 140	6200 \pm 166
^w LF, HDW	BD ^a	BD ^a	1170 \pm 69	1300 \pm 13	30 \pm 10	2510 \pm 44	52400 \pm 167	25700 \pm 717	25800 \pm 85	28800 \pm 78
^d LF, BH	BD ^a	10 \pm 10	60 \pm 10	10 \pm 20	30 \pm 10	870 \pm 976	8600 \pm 860	4400 \pm 980	5600 \pm 181	7600 \pm 165
^d LF, HDW	10 \pm 10	10 \pm 0	1170 \pm 69	360 \pm 400	20 \pm 10	1540 \pm 15	32800 \pm 112	13600 \pm 429	16100 \pm 60	18600 \pm 16
^w GRA, BH	BD ^a	10 \pm 10	3010 \pm 14	1800 \pm 60	50 \pm 20	1900 \pm 15	3400 \pm 700	1800 \pm 690	4000 \pm 201	6300 \pm 330
^w GRA, HDW	15 \pm 10	30 \pm 10	3410 \pm 15	1100 \pm 10	30 \pm 10	2350 \pm 78	25100 \pm 55	18600 \pm 121	13000 \pm 44	16100 \pm 76
^d GRA, BH	BD ^a	20 \pm 12	2110 \pm 15	380 \pm 300	200 \pm 2	440 \pm 330	6100 \pm 235	4000 \pm 1140	5500 \pm 215	1800 \pm 880
^d GRA, HDW	45 \pm 11	BD ^a	2510 \pm 13	1370 \pm 15	150 \pm 1	80 \pm 70	22800 \pm 11	10400 \pm 630	5000 \pm 125	3900 \pm 300

Results are expressed as mean \pm standard deviation; ^w = wet season; ^d = dry season; ^a = below detection limits.

Apart from Pb and Cd, the seasonal mean concentrations of the other metals found in the groundwater of the selected districts were below the WHO (2006) and SON (2007) stipulated limits for potable water (Table 5). Using ANOVA, no significant difference ($P < 0.005$) in the values of metals for hand-drawn well and bore-hole water samples was obtained. The presence of slightly elevated levels of lead in a few samples in the study area could be as a result of the various oil explorations and processing activities within the sub-region and careless disposal of various forms of electronic wastes and spent batteries on the soil (Owamah *et al.*, 2013). The community also houses a flow station. According to Owamah *et al.* (2013), exposure to high levels of Pb can cause damage to the kidney and brain, and sometimes, make pregnant women to miscarry. Reports also show that elevated levels of Pb in kids could cause convulsion and neurological damages (USEPA 1991; Khan *et al.* 2013). In men, high concentration of lead can damage reproductive organs. Cd and its various compounds

are reportedly, carcinogenic (Dahunsi *et al.*, 2014; Khan *et al.*, 2013). At high levels of exposure, Cd can cause vomiting and diarrhea but lower levels for longer period, can cause kidney impairment (USEPA 1977, Mkwate *et al.*, 2017). Other health challenges associated with drinking water containing high levels of Pb and Cd are contained in Sojobi (2016).

Conclusion: Groundwater in the community was found to be slightly polluted with metals of Pb and Ca, and with coliform bacteria. Samples from the hand-dug wells were noted to have higher values of these contaminants. Bacteria contamination was attributed to the poor disposal of solid waste (open dumps) and sewage, and the location of bore holes and hand-drawn wells close to pit-latrines and septic tanks. The slight metals contamination was linked to oil explorations and processing activities within the area of study and improper disposal of electronic wastes. While the concerned agencies and authorities should consider providing potable water for the people very important, household water treatment is

recommended in the interim for the residents of the community.

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REFERENCES

- Ademoroti, CMA (1996). *Environmental Chemistry and Toxicology*. Ibadan: Foludex Press Ltd.
- APHA (1992). “Standard Methods for Examination of Water and Waste-water”; 18th Edition, Washington DC: American Public Health Association.
- APHA (2012). “Standard Methods for Examination of Water and Waste-water”; 22nd Edition, Washington DC: American Public Health Association.
- Dahunsi, S O; Owamah, H I; Ayandiran, T A; Oranusi, U S (2014). Drinking water quality and public health of selected communities in South Western Nigeria. *Wat. Qual. Exp. Heal.* 6, 143–153.
- Egboh, SHO; Emeshili, EM (2008). The fluoride content of drinking water samples from Ndokwa Area, South-South Nigeria. *J. Chem. Soc. Nig.* 33(2): 54-61.
- Khan, S; Shahnaz, M; Jehai, N; Rehman, S; Shah, M T; Din, S (2013). Drinking water quality and human health risk in Charsadda district, Pakistan. *J. Cleaner Prod.* 60:93–101.
- LENNTECH (2016). Water Conductivity. Available on. <http://www.lenntech.com/applications/ultrapure/conductivity/water-conductivity.htm>.
- Mkwate , R C; Chidya, RCG; Wanda, EMM (2017). Assessment of drinking water quality and rural household water treatment in Balaka District, Malawi. *Phys. Chem. Earth* 100:353-362.
- National Population Commission of Nigeria (NPC). <http://www.informationng.com/tag/national-population-commission>. Accessed on the 25th of December, 2018 at 14.22 Nigerian time.
- Owamah, IH, Asiagwu, AK, Egboh, SHO; Phil-Usiayo, S (2013). Drinking water quality at Isoko North communities of the Niger Delta Region, Nigeria *Toxi. Environ. Chem.* 95(7), 1116–1128.
- Sojobi, SO (2016). Evaluation of groundwater quality in a rural community in North Central of Nigeria. *Environ Monit Assess.* 188:192.
- SON (2007). Standard Organization of Nigeria. Nigerian Standard for Drinking Water Quality, Nigeria, NIS 554: 2007.
- USEPA (1977). “Toxicology of metals in: *Environmental Health Effects Research Series*”; Vol. II, Washington, DC: United States Environmental Protection Agency.
- USEPA (1991). “Lead in drinking water; *Public Education, National Primary Drinking Water Regulations, Control of Lead and Copper*”; 40CFR Part 141.85 Federal Register: United States Environmental Protection Agency.
- WHO (2006). “Guidelines for Drinking Water Quality”, 3rd Edition, Vol. I Recommendations. First addendum to 3rd Edition, Geneva: World Health Organization.
- WHO (2012). World Health Organization (WHO). Global Burden of Disease. WHO Press, Geneva, Switzerland.