Pak. j. sci. ind. res. Ser. A: phys. sci. 2016 **59** (1) 43-51

Evaluation of Groundwater Quality of Selected Boreholes in Ohaozara and Ivo Council Areas of Ebonyi State, Nigeria

Omaka Ndukaku Omaka[a], Ifeanyi Francis Offor [a]*, David Obasi Igwe[b] and Ewuzie Ugochukwu[c]
[a]Department of Chemistry, Federal University, Ndufu-Alike, Ikwo, P.M.B. 1010, Ebonyi State, Nigeria
[b]Department of Industrial Chemistry, Ebonyi State University, P.M.B. 053,
Abakaliki, Ebonyi State, Nigeria
[c]Department of Pure and Industrial Chemistry, Abia State University, P.M.B. 2000, Uturu,
Abia State, Nigeria

(received October 13, 2014; revised January 26, 2015; accepted January 31, 2015)

Abstract. Groundwater quality in study areas was evaluated by measuring the physicochemical parameters including selected ions in water samples collected from 12 boreholes in Akaeze, Okposi and Uburu towns of Ebonyi State, Nigeria in April, 2013 and analysed using standard methods. Results obtained showed that, except for As^{5+} content, all other parameters investigated fall within WHO standards for potable water. Regression analysis showed that conductivity, SO_4^{2-} and As^{5+} levels are important variables in predicting the TDS values of the samples while NO_3^-, Cl^-, PO_4^{3-} and TDS are important in predicting the As^{5+} content of the water samples. One-way ANOVA at $P < 0.05$ showed F_{cal} (1.862) > F_{tab} (0.619), implying a significant difference between the parameters for all locations.

Keywords: borehole water, water quality, physicochemical parameters

Introduction

Water is essential for the sustenance of life. It occupies 71% of the entire earth's surface and biologically makes up a large percentage of the total body fluids of all living things (Obasi and Akudinobi, 2013). Quality of water is determined by its physicochemical makeup and the amount of trace contaminants it contains.The use of poor quality water is associated with significant health implications hence, require adequate treatment before use (Centeno *et al*., 2005; Carter and Stewart, 2000; Smith *et al*., 2000). The human health is directly related to the quality of water used for drinking and other purposes, because about 75% of all diseases suffered by human beings may be partially caused by consumption of contaminated water (Pink, 2006).

Review of relevant literature reveals that, geogenic and anthropogenic processes both contribute to the degradation of natural water quality (Jan, 2011; Ayeni *et al*., 2009; Obasi and Balogun, 2001; Ovrawah and Hymore, 2001; Ojekunle, 2000).

According to available statistics, an average water consumption rate of 10 L per person per day has been recommended for small rural communities (UNICEF, 1989). However, this quantity still falls below the WHO recommended standard of at least 20 L per person per day (WHO, 1984). According to relevant statistics, only about 61% of urban dwellers in developing countries have access to safe water supply sources (Igwenyi and Aja-Okorie, 2014). It is also estimated that 1.2 billion people around the world lack access to safe water, and close to 2.5 billion people are not provided with adequate sanitation (WWC, 2003). In Nigeria, 75-80% of the total population of about 160 million people live in rural areas, and less than 50% of that number have access to potable water (Obasi and Akudinobi, 2013).

In most local investigations of groundwater quality, physicochemical parameters are mostly measured and in some cases, trace metal constituents. However, it has been observed that most of these local researches on groundwater quality in Nigeria tend to neglect the possible contamination of the water by arsenic from both natural and anthropogenic sources.

Arsenic occurs in various forms in nature but its most toxic forms are arsenate and arsenite which comes from anthropogenic sources such as application of As-containing herbicides/pesticides, phosphorus fertilizers on cultivated lands and the discharge of industrial effluents containing As into water bodies (Okorie, 2010; Feng *et al*., 2009; Jung *et al*., 2009; Williams and Silver, 1984).

---

*Author for correspondence; Email:offorifeanyi@gmail.com

Therefore, the aim of this study is to determine the physicochemical parameters and ionic (including As^{5+}) content of selected boreholes within Uburu, Okposi and Akaeze Communities in Ohaozara and Ivo Council Areas of Ebonyi State, Nigeria and to compare data obtained with existing permissible limits set by different regulatory bodies.

Materials and Methods

Study area. Okposi, Uburu and Akaeze are all rural communities in Ebonyi South Senatorial zone of Ebonyi State. Okposi and Uburu are located in Ohaozara Local Government Area (LGA) while Akaeze is located in Ivo LGA; both LGAs forming part of the 13 LGAs that make up Ebonyi State. Okposi, Uburu and Akaeze communities are located within longitudes 5° 52' N and 6° 07' N and latitudes 7° 40' E to 7° 54' E and they all fall within the Imo-Cross River Basin province of Southeastern Nigeria. The study site consists mainly of undulating land and sedimentary rocks from the Albian age. The introduction of As into drinking water can occur as a result of its natural geological presence in local bedrock (Garelick *et al.,* 2008). Ground waters are generally more vulnerable to As contamination than surface water because of their interaction with aquifer minerals, and the increased potentials in aquifer for the generation of physicochemical conditions favourable for As release (Smedley, 2008). The lithology of Uburu Salt Lake shows that it consists of sandstone beds with intercalation of fine-grained bands of silts and shales, whereas, that of Okposi Salt Lake is a mud filled depression surrounded by sandstone exposures (Okoyeh and Egboka, 2013). Smedley and Kinniburgh (2002) stated that the highest arsenic concentrations (20–200 mg/kg) are typically found in organic-rich and sulphide-rich shales, sedimentary iron stones, phosphatic rocks, and some coals. This is definitely a source of As in the water samples within the study sites. They further opined that in sedimentary rocks, As is concentrated in clays and other fine-grained sediments. High concentration of naturally occurring As are also found in oxidizing conditions where groundwater pH values are high (ca. >8) (Smedley and Kinniburgh, 2002). The pH results (8.3-8.8) of this study, lucidly support the above finding, and buttress the rationale for high As level of the samples. Also, salt harvesting by the rural women, could as well lead to increasing As concentration.

Mechanisms by which As is released from minerals are varied, and are accounted for by many (bio)geochemical processes: oxidation of As-bearing sulphides, desorption from oxides and hydroxides, reduction dissolution, evaporation concentration, leaching from sulphide by carbonates, and microbial mobilisation (Garelick *et al.,* 2008).

Surface drainage pattern within the area consists of small rivers such as Asumgbom, Atte, Azuu, Ovum, Enu and Oshi rivers which tends to dry up by flowing into the larger Asu river (Obasi and Akudinobi, 2013; Okoyeh and Egboka, 2013). A map of the study area indicating the 12 sampling locations is shown in Fig. 1.

Sampling and laboratory analyses. Groundwater samples were collected from 12 hand-dug boreholes in April, 2013 from various locations within the study areas. Six samples were collected from Akaeze town in Ivo LGA and three samples each were collected from Uburu and Okposi towns both located in Ohaozara LGA of Ebonyi State. Sampling was done at the beginning of the dry season under good weather conditions in order to avoid rain water contamination, which would have impacted on the quality of the water samples. All chemical reagents used were of analytical grade and purchased from Fisher Scientific UK. Ltd. (Loughborough, Leicestershire). All sample vessels were first washed, soaked overnight in 5% nitric acid and rinsed in high purity deionised water (Okorie, 2010). To maintain the integrity of the water samples, parameters that are sensitive to environmental changes, which include pH, dissolved oxygen (DO), electrical conductivity (EC) and temperature were measured and recorded *in-situ* using portable digital meters.

Furthermore, water samples used for determination of SO_4^{2-}, NO_3^-, Arsenate (As^{5+}) and selected physical parameters were collected in plastic containers while those for the determination of chemical oxygen demand (COD), biochemical oxygen demand (BOD) and PO_4^{3-} were collected in specialised glassware. The samples were transported to the laboratory in ice chest and then analysed for different parameters such as physicochemical properties [total hardness, total alkalinity, total dissolved solids (TDS), turbidity], Arsenate (As^{5+}) and anions (SO_4^{2-}, Cl^-, NO_3^-, PO_4^{3-}) using standard methods.

Analyses of water samples were carried out using either the American Public Health Association (APHA *et al*., 2012) or the American Standard for Testing Material (ASTM, 2012) standard procedure.

The pH was determined *in-situ* using Jenway pH meter, model 350 after calibration with buffers 4 (potassium hydrogen phthalate) and 9 (sodium borate decahydrate) (ASTM D1293-12). TDS determination was performed using APHA 2540C method, while EC was determined using APHA 2510B.

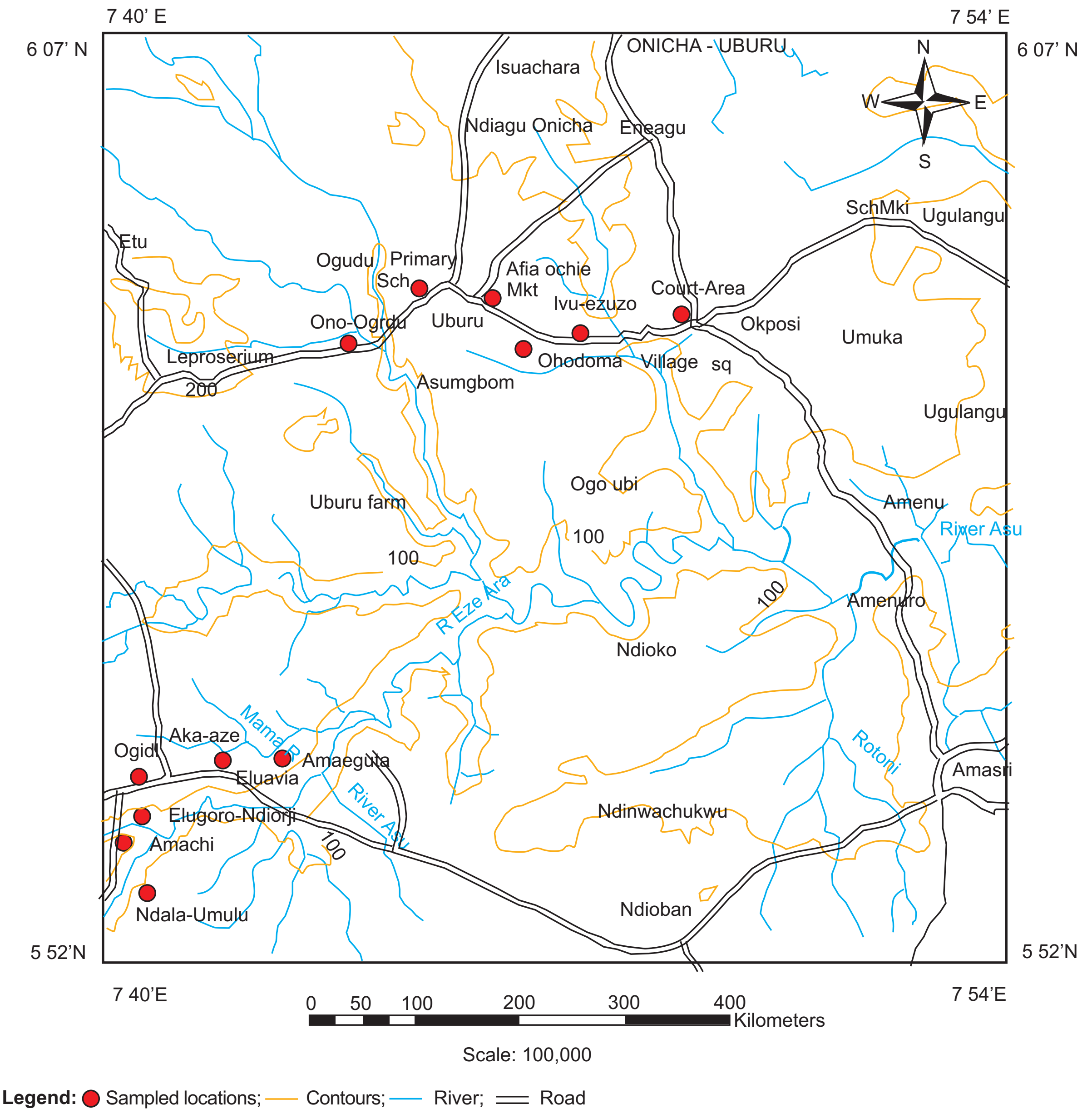

Fig. 1. Map of the study area showing 12 sampling stations in Uburu, Okposi and Akaeze towns, Nigeria.

Determinations of SO_4^{2-}, Cl^- and PO_4^{3-} were performed according to ASTM D 4327-03 method, while temperature and NO_3^- were determined following APHA 2550 and ASTM D3867-90A methods, respectively. Analysis of water samples for As^{5+} determination was done by Atomic Absorption Spectrophotometry–Hydride Generation (ASTM D2972-08B). APHA 2130B and 2340-B methods were employed in the determination of turbidity (HACH 2100AN turbidimeter) and total hardness of water samples, respectively. COD, BOD and alkalinity determinations were done according to ASTM D6238-98 and D1067-11 standard methods, respectively.

Statistical analysis. Statistical analyses of data were carried out using SPSS 16.0 for windows (SPSS Inc., Polar Engineering and Consulting 2007) and Excel 2007 statistical package programmes. For regression analysis, simultaneous method of the multiple linear regression was adopted while for ANOVA, one-way ANOVA approach was chosen.

A multiple linear regression model of the form: $Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots\ldots\ldots\ldots + \beta_m X_{mi} + \xi_1$ was obtained;

where:

Y_i = dependent variable as predicted by regression model; β_0 = intercept or constant; β_1 = i^{th} coefficient of X_i, X_i = i^{th}

independent variable from total set of m variables and ξ_1 = random errors.

The multiple linear regression analysis was conducted to investigate the effects of arsenic (V) content and total dissolved solids (TDS) as dependent variables on independent variables such as electrical conductivity (EC), Cl^-, NO_3^-, SO_4^{2-} and PO_4^{3-} levels in order to predict the water quality of different boreholes while analysis of variance test was conducted to check for significant differences between the physicochemical parameters of borehole water from different locations.

Results and Discussion

Physicochemical analysis. A comparison of analytical data generated in this study with national and global drinking water standards like the Nigerian Institute of Standards (NIS, 2007) and World Health Organization (WHO, 2011) water standards for drinking and public ~~health purposes are presented in Table 1. Also, a summary~~ of the data for physicochemical parameters, arsenate, sulphate, chloride, nitrate and phosphate contents of the borehole water samples are given in Table 2.

The pH of the water samples ranged from 8.3-8.8 with a mean value of 8.5, which was within the WHO stipulated tolerable pH range of 6.5-8.5 for potable water (WHO, 2011). This indicated that most of the groundwater samples were mildly alkaline, which can be attributed to the nature of bedrock geology of the study sites. Comparable pH ranges: 5.8-6.9, 3.84-7.72 and 8.3-9.6 were observed in similar researches by Okiongbo and Douglas (2013), Talabi *et al*. (2013) and Nwankwoala and Udom (2011), respectively.

Furthermore, reports from Iran (Mosaferi *et al.,* 2014), Pakistan (Iqbal *et al.,* 2013) and South Africa (Mpenyana-Monyatsi *et al*., 2012) had indicated pH values of 6.09-8.02, 6.44-7.27, and 7.1-8.0, respectively, which were all less than the result of this study. In the same vein, Nag and Lahiri (2012) reported pH values ranging from 6.1 to 7.9 for both pre- and post- monsoon periods.

The temperature of the water samples ranged between 22 and 28 °C, with mean temperature of 25 °C, which was below the mean atmospheric temperature of 28 °C. This relatively low temperature implied that the concentration of dissolved oxygen in the water samples was higher than normal, which might improve the water's taste (Olajire and Imeokparia, 2001; Deas and Lowny, 2000). The result of this study was comparable with that of Mpenyana-Monyatsi *et al*. (2012) which ranged from 19.4 to 24.9.

Table 1 shows that the electrical conductivity (EC) of the water samples ranged from 0.370-1.722 dS/m. OVSOB had the lowest EC value (0.370 dS/m) while, OOUB recorded the highest EC value (1.722 dS/m). Two out of twelve samples of locations namely; OVSOB (0.370 dS/m) and NUIAB (0.418 dS/m) had EC values below the WHO minimum limit of 0.500 dS/m, while all other locations had EC values above the WHO minimum limit. However, only three locations (OOUB, OPSUB and EIUB) recorded EC values that were above the WHO maximum limit of 1.250 dS/m (WHO, 2011). Nevertheless, electrical conductivities (0.110-1.750 dS/m) and (0.040-3.400 dS/m) reported by Nag and Lahiri (2012) and Mosaferi *et al.* (2014), respectively were relatively comparable with our study, whereas the EC ranged of 2.860-3.860 dS/m reported

Table 1. Descriptive statistics of analysed borehole water samples compared with NIS and WHO Standards for drinking water quality

Parameter	Minimum	Maximum	Mean± SD	NIS (2007) limit	WHO (2011) limit
Temp. (°C)	22.0	28.5	24.65±0.56	25	-
pH	8.3	8.8	8.53±0.04	6.5-8.5	6.5-8.5
DO (mg/L)	9.82	10.04	9.92±0.04	-	4
TDS (mg/L)	204	947	517.33±74.14	500	1200
EC(dS/m)	0.370	1.722	0.940±0.135	1.000	1.250
TA (mg/L)	60.70	578.70	272.48±47.87	-	-
TH (mg/L)	43.30	222.00	113.39±16.61	150	-
As^{5+} (mg/L)	2.63	5.53	4.53±0.33	0.01	0.01
Cl^- (mg/L)	100.53	147.89	130.08±3.41	250	250
SO_4^{2-} (mg/L)	16.59	65.41	38.17±4.18	100	500
NO_3^- (mg/L)	0.65	0.86	0.78±0.02	50	50
PO_4^{3-} (mg/L)	0.02	0.19	0.10±0.01	-	10

by Mosaferi *et al.* (2014) was above that of our study and WHO limit.

All the borehole water samples contained dissolved oxygen (DO) ranging from 9.55-10.04 mg/L with an average DO of 9.92 mg/L. In each case, the WHO maximum allowable limit for DO in water (4 mg/L) was exceeded (WHO, 2011). The high level of DO concentration in the water samples may be attributed to the absence of organic matter in the underground water samples, thus, improving the water taste while also posing as a source of corrosion to water pipes in these areas (Narasimha *et al*., 2011; Adekunle *et al*., 2007).

Total dissolved solids (TDS) of the water samples varied from 112 to 832 mg/L. All the samples recorded TDS values below the WHO recommended maximum limit of 1200 mg/L (WHO, 2011). Appreciable concentrations of carbonates, bicarbonates, cations and anions might have contributed to the presence of TDS in the samples (Adejuwon and Mbuk, 2011). Of similar studies in South Africa. (Mpenyana-Monyatsi *et al*., 2012) Iran, (Mosaferi *et al.,* 2014), Pakistan (Iqbal *et al.,* 2013), and India (Nag and Lahiri, 2012), only TDS values (107.1-439 mg/L) of samples studied in South Africa were comparable with our result; others: 71.5-1137.5 mg/L, 1916-2586 mg/L and 30-1365 mg/L, respectively, were averagely higher than the result of this study.

All the borehole water samples were clear (turbidities were very low) implying that there were little or no suspended solids in the samples. They were all below the WHO recommended turbidity limit (5 NTU) in drinking water (WHO, 2011).

Total alkalinity values of the water samples ranged between 60.7 and 574.7 mg/L with a mean value of 272.5 mg/L. The samples showed total alkalinity values that were within the WHO acceptable limits (WHO, 2011). Presence of carbonates, bicarbonates and hydroxides in the samples might have contributed to the concentration of total alkalinity recorded. Chloride content in the water samples ranged from 100.53 mg/L to 147.89 mg/L, implying that they all fell within the WHO recommended chloride limit of 250 mg/L in drinking water. Sources of chloride in drinking water include natural sources, sewage and industrial effluents, urban run-off containing de-icing salt and saline intrusion. Total alkalinity affects the chloride content of potable water, which may lead to a detectable taste if chloride is in excess (WHO, 2011).

Sulphate content in the water samples varied from 16.59 mg/L to 65.41 mg/L, which was well below the WHO maximum recommended limit of 500 mg/L in drinking water. The low values recorded for SO_4^{2-} in these water samples could be due to its removal from the water by bacteria (Freeze and Cherry, 1979). Sulphates are discharged into water through industrial wastes and atmospheric depositions, however their highest concentrations are found in groundwater and from natural sources. Drinking of potable water with high sulphate levels may lead to gastrointestinal effects (WHO, 2011). Mosaferi *et al.* (2014) and Nag and Lahiri (2012) reported SO_4^{2-} concentrations of 11.6-163.9 and 1.8-220.5 mg/L, respectively, which were relatively higher than sulphate contents of this study but less than the WHO limits.

In the case of nitrates, its level in the water samples varied from 0.65 mg/L to 0.86 mg/L, which was relatively low

Table 2. Hydrogeochemical analysis of groundwater samples from selected boreholes within Ivo and Ohaozara LGAs, Ebonyi State, Nigeria

S. no.	Sample location	Temp. (°C)	pH	DO	TDS	EC (dS/m)	TH	TA	SO_4^{2-}	Cl^-	NO_3	PO_4^{3-}	As^{5+}
				(mg/L)					(mg/L)				
1.	Afia Ochie (AOUB)	26.2	8.6	10.0	441	0.801	43.3	60.7	16.59	133	0.81	0.11	4.59
2.	Onu-Ogudu (OOUB)	22.0	8.3	10.0	947	1.722	207.4	304.2	45.04	125	0.84	0.11	5.01
3.	Ogudu Primary School (OPSUB)	26.1	8.6	9.99	913	1.659	97.0	315.7	45.46	138	0.78	0.09	4.47
4.	Obodoma Village Square (OVSOB)	22.4	8.6	9.89	204	0.370	93.0	86.2	17.74	132	0.79	0.10	3.58
5.	Ivu-ezuzor Okposi-Okwu (IOOB)	23.3	8.7	9.92	356	0.648	222.0	183.7	22.26	127	0.76	0.13	2.98
6.	Court Area Isi-Okposi (CAIOB)	24.8	8.3	9.55	315	0.573	83.0	183.7	50.39	148	0.66	0.14	2.63
7.	Amaeguta, Akaezeukwu (AAB)	28.5	8.5	10.0	408	0.742	90.0	311.7	38.95	100	0.86	0.03	6.66
8.	Eluavia Ihenta, Umoihe (EIUB)	25.4	8.8	10.0	810	1.472	101.0	578.7	65.41	141	0.82	0.02	3.74
9.	Ogidi Omoihe (OUB)	26.0	8.6	9.94	636	1.156	183.0	479.0	28.56	130	0.84	0.19	5.53
10.	Elugoro Ndiorji Umoihe (ENUB)	25.0	8.5	9.88	562	1.022	92.0	454.2	38.22	131	0.83	0.02	5.00
11.	Amachi Umoihe (AUB)	23.5	8.4	9.82	386	0.701	85.0	211.2	45.25	134	0.68	0.12	5.25
12.	Ndala Umulu, Iyioji Akaeze (NUIAB)	22.6	8.4	10.04	230	0.418	64.0	100.7	44.20	122	0.65	0.09	4.96

DO = dissolved oxygen,; EC = electrical conductivity; TDS = total dissolved solids; TA = total alkalinity; TH = total hardness.

as compared to the WHO limit of 50 mg/L. Sources of nitrate contamination of surface and groundwater include agricultural activities like excess application of inorganic nitrogenous fertilizers and manures, wastewater disposal, oxidation of nitrogenous waste products and leaching from natural vegetation (WHO, 2011). Nitrate concentrations of 0.4-59.4 and 21-127 mg/L were reportedly obtained by Mosaferi *et al.* (2014) and Iqbal *et al.* (2013) from the study of groundwater samples in Iran and Pakistan, respectively. In a similar study in India, nitrate concentration in 73.68% of samples exceeded the guideline value (50 mg/L) (Balakrishnan *et al*., 2011).

Table 3. Regression statistics for predicting total dissolved solids (TDS) in selected boreholes from Ohaozara and Ivo LGAs

Water quality predictor variable	Unstandardised coefficients		Standardised coefficients (Beta)	t-values	Sig.	95% confidence interval for B (P-values)	
	B	Std. error				Lower bound	Upper bound
Constant	-3.482	3.780	-	-0.921	0.399	-13.199	6.236
EC	0.239	0.149	0.01	1.602	0.170	-0.145	0.623
NO_3^-	-2.252	2.962	0.00	-0.760	0.481	-9.867	5.363
Cl^-	-0.861	2.951	0.00	-0.292	0.782	-8.447	6.726
SO_4^{2-}	0.029	0.016	0.001	1.818	0.129	-0.012	0.070
PO_4^{3-}	-0.01	0.014	0.000	-0.752	0.486	-0.046	0.025
As^{5+}	0.550	0.00	1.000	1.199	0.000	0.549	0.551
R	-	-	-	1.000	-	-	-
R square	-	-	-	1.000	-	-	-
Adjusted R square	-	-	-	1.000	-	-	-
Standard error	-	-	-	0.348	-	-	-
F-test Statistics	-	-	-	9.985	-	-	-
Overall significance	-	-	-	0.000	-	-	-

Table 4. Regression statistics for predicting arsenic (V) content in selected boreholes from Ohaozara and Ivo LGAs

Water quality predictor variable	Unstandardised coefficients		Standardised coefficients (Beta)	t-values	Sig.	95% confidence interval for B (P-values)	
	B	Std. error				Lower bound	Upper bound
Constant	6.308	6.876	-	0.917	0.401	-11.368	23.984
EC	-0.435	0.272	-0.001	-1.601	0.170	-1.133	0.263
NO_3^-	4.104	5.384	0.000	0.762	0.480	-9.736	17.943
Cl^-	1.583	5.364	0.000	0.295	0.780	-12.207	15.372
SO_4^{2-}	-0.053	0.029	-0.001	-1.815	0.129	-0.127	0.022
PO_4^{3-}	0.019	0.025	0.001	0.755	0.484	-0.045	0.083
As^{5+}	1.818	0.002	1.000	1.199	0.000	1.814	1.822
R	-	-	-	1.000	-	-	-
R square	-	-	-	1.000	-	-	-
Adjusted R square	-	-	-	1.000	-	-	-
Standard error	-	-	-	0.633	-	-	-
F-test statistics	-	-	-	9.984	-	-	-
Overall significance	-	-	-	0.000	-	-	-

Phosphate levels in the water samples ranged from 0.02 mg/L to 0.19 mg/L, which was relatively low as compared to the WHO limit of 10 mg/L in drinking water (WHO, 2011). This implied that phosphate pollution due to percolation of agricultural fertilisers, detergents and pharmaceuticals were very minimal. In addition, it showed that the underlying rocks of the study area contained little or no phosphate (Edeogu, 2007).

Arsenic content of the water samples ranged from 2.63 mg/L to 6.66 mg/L, which was above the WHO limit of 0.01mg/L (WHO, 2011). Thus, with respect to As (V) content, the water samples are not too safe for consumption. Arsenic is mainly present as As (V) in water but in anaerobic conditions, it is likely to be present as As (III). In natural waters, they are found in concentrations of less than 1-2 µg/L but in groundwater, they are found at slightly elevated concentrations due to sulphide mineral deposits and sedimentary deposits derived from volcanic rocks (WHO, 2011).

A Schoeller diagram depicting logarithmic data plots for the major ions investigated in the study, is shown in Fig. 2 with the peaks and troughs of the individual water samples indicating their dominant and less dominant ions, respectively. In Fig. 2, chloride is depicted as the most abundant ion followed by sulphate and arsenate while nitrate and phosphate ions are the least dominant ions.

Regression analysis. The multiple linear regression models for predicting TDS and As (V) content of boreholes around Ohaozara and Ivo LGAs of Ebonyi State were shown in equation (1) and (2), respectively:

$$\text{TDS} = -3.482 + 0.239\ \text{EC} - 2.252\ \text{NO}_3 - 0.861\text{Cl}^- + 0.029\ \text{SO}_4 - 0.01\ \text{PO}_4^{3-} + 0.550\ \text{As} \text{ ---------------------------- } (1)$$

$$\text{As} = 6.308 - 0.435\ \text{EC} + 4.104\ \text{NO}_3^- + 1.583\ \text{Cl}^- - 0.053\ \text{SO}_4 + 0.019\ \text{PO}_4^{3-} + 1.818\ \text{TDS} \text{ -------------------------- } (2)$$

Equation (1) showed that positive relationships existed between TDS and EC, as well as between TDS-SO_4^{2-} and TDS-AS^{5+} constituents of the water samples, while a negative relationship was maintained between TDS and other parameters (NO_3^-, Cl^- and PO_4^{3-}). However, from equation (2), it could be deduced that positive relationship existed among the pairs of As^{5+}-NO_3^-, As^{5+}-Cl^-, As^{5+}-PO_4^{3}, and As^{5+}-TDS, while negative relationship existed between the pairs of As^{5+}-EC and As^{5+}-SO_4^{2-}. This is in line with literature assertion that in oxidising conditions where groundwater pH values are high, inorganic As (V) predominates, and arsenic concentrations are positively correlated with those of other anion-forming species such as F^-, Cl^-, etc (Smedley and Kinniburgh, 2002). The regression statistics for the models represented in equations (1) and (2) have been summarised in Tables 3- 4. The high *t*-values and low P-values suggested that EC, SO_4^{3-} and As^{5+} levels were important factors in the prediction of the TDS value for different water samples (Table 3). Similarly, high *t*-values and low P-values indicated that NO_3^-, Cl^-, PO_4^{3-} and TDS were important variables in the prediction of As (V) content of different water samples. Furthermore, comparison of the adjusted R square and the R square values for the two regression models (Tables 3- 4) indicate that they accounted for almost 100% of the variance (except for minimal errors) in the TDS and As (V) levels of the water samples.

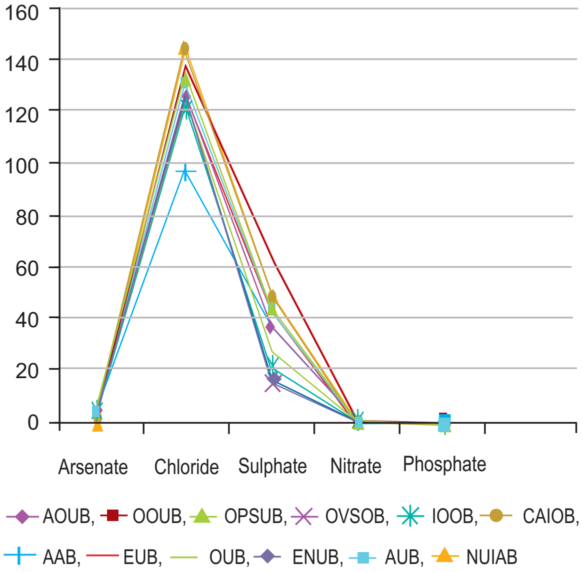

Fig. 2. Schoeller diagram depicting ionic species investigated.

Analysis of variance. One-way ANOVA at $P < 0.05$ (95% confidence level) showed that F_{cal} (1.862) was greater than F_{tab} (0.619) implying that a significant difference existed among the physicochemical parameters in water samples from the 12 different locations investigated. This might be due to the influence of natural and anthropogenic factors on the physicochemical parameters found in the aquatic environment.

Conclusion

The hydrochemical assessment of groundwater resources in Ivo and Ohaozara LGAs, Nigeria revealed that the water in these areas was generally alkaline, non-turbid, moderately hard and saline in nature. With the exception of arsenic content level, all other physicochemical parameters investigated in the water samples were within the stipulated NIS and WHO limits for contaminants in potable water. This implied that the water in these areas might be fit for other domestic uses apart from drinking, and would require further standard treatment before it could be fit for drinking purposes. It is recommended that certain strategies such as proper sewage disposal, proper siting of boreholes and installation of point-of-use water treatment devices be adopted in order to improve the quality of groundwater located in the study areas. Generally, the water samples are deemed fit for domestic uses; though its high arsenic level may pose potential health threats for children. Point-of-use water treatment devices should be installed in the boreholes to improve water quality.

References

Adejuwon, J.O., Mbuk, C.J. 2011. Biological and physiochemical properties of shallow wells in Ikorodu town, Lagos, Nigeria. *Journal of Geology and Mining Research,* **3:** 161-168.

Adekunle, I.M.N., Adetunji, M.T., Gbadebo, A.M., Banjoko, O.B. 2007. Assessment of groundwater quality in a typical rural settlement in Southwest, Nigeria. *International Journal of Environmental Research and Public Health,* **4:** 307-318.

APHA, AWWA, WPCF, 2012. *Standard Methods for the Examination of Water and Wastewater.* 22th edition, American Public Health Association. American Water Works Association. Water Pollution Control Federation. Washington DC., USA.

ASTM, 2012. *American Society Testing Materials*. Annual Book of (ASTM) Standards. vol. **11.01**. Available in: http://www.astm.org. Access in: Oct. 2014.

Ayeni, A.O., Soneye, A.S.O., Balogun, I.I. 2009. State of water supply sources and sanitation in Nigeria: Implication of Muslims. In Ikare-AKOKO Township. *The Arab World Geographer,* **12:** 95-104.

Balakrishnan, P., Saleem, A,. Mallikarjun, N.D. 2011. Groundwater quality mapping using geographic information system (GIS): A case study of Gulbarga City, Karnataka, India. *African Journal of Environmental Science Technology,* **5:** 1069-1084.

Carter, E., Stewart, A.G. 2000. Environmental geochemistry and health: an integrated future in medical and geochemical studies, the example of Iodine. *Journal of the Geological Society of London,* **157:** 835-836.

Centeno, A., Millic, F.G., Finkleman, R.I., Sellinus, O. 2005. Medical geology. *Military Medical Technology online,* **9:** 1-5.

Davies, S.N., De-Wiest, R.M.J. 1966. *Hydrogeology,* 463 pp. John Wiley & Sons, Inc., New York, USA.

Deas, M.L., Lowney, C.L. 2000. *Water Temperature Modeling Review,* Technical Report to Bay Delta Modeling Forum, 113 pp.

Edeogu, C.O. 2007. Nitrate, sulphate, phosphate and chloride status of stable food crops, soils and water as indicator of environmental base anion pollution load in Ebonyi State, Nigeria. *Journal of Biological Sciences,* **7:** 745-751.

Feng, L., Yuan-Ming, Z., Ji-Zheng, H. 2009. Microbes influence the fractionation of arsenic in paddy soils with different fertilization regimes. *The Science of the Total Environment,* **407:** 2631-2640.

Freeze, R.A., Cherry, J.A. 1979. *Groundwater,* pp. 250-263, Prentice-Hall, Englewood Cliffs, New Jersey, USA.

Garelick, H., Jones, H., Dybowska, A., Valsami-Jones, E. 2008. Arsenic pollution sources. *Reviews of Environmental Contamination Toxicology,* **197:** 17-60.

Igwenyi, I.O., Aja-Okorie, 2014. Physicochemical properties and heavy metal analysis of major water sources in Dhaozara, Ebonyi State, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology,* **8:** 41-44.

Iqbal, F., Ali, S., Tauqeer, H.M., Shakoor, M.B., Farid, M., Iftikhar, U., Nazir, M.M. 2013. Assessment of ground water contamination by various pollutants from sewage water in Chakera village, Faisalabad. *International Journal of Environmental Monitoring and Analysis,* **1:** 182-187.

Jan, M.H. 2011. Characterization of the inorganic chemistry of surface waters in South Africa. *Water S.A,* **37:** 401-410.

Jung, U.L.S., Sang, W.L., Hyo, T., Kyoung, W.K., Jin, S.L. 2009. Enhancement of arsenic mobility by indigenous bacteria from mine tailings as response to organic supply. *Environment International,* **35:** 496-501.

Mosaferi, M., Pourakbar, M., Shakerkhatibi, M., Fatehifar, E., Belvasi, M. 2014. Quality modeling of drinking groundwater using GIS in rural communities, northwest of Iran. *Journal of Environmental Health Science & Engineering,* **12:** 99.

Mpenyana-Monyatsi, L., Onyango, M.S., Momba, M.N.B. 2012. Groundwater quality in a South African rural community: A threat to public health. *Polish Journal of Environmental Studies,* **21:** 1349-1358.

Nag, S.K., Lahiri, A. 2012. Hydrochemical characteristics of groundwater for domestic and irrigation purposes in dwarakeswar watershed area, India. *American Journal of Climate Change,* **1:** 217-230.

Narasimha, R.C., Dorairaju S.V., Bujasendra, R.M., Chalapathi, P.V. 2011. Statistical analysis of drinking water quality and its impact on human health in Chandragiri near Tirupati, India. Retrieved October 05, 2014 from www.ecowbeb.com/edi/11121.

NIS, 2007. *Nigerian Industrial Standard for Drinking Water Quality.* Standards Organization of Nigeria, Abuja, Nigeria.

Nwankwoala, H.O., Udom, G.J. 2011. Hydrogeochemical evaluation of groundwater in parts of eastern Niger Delta, Nigeria. *Journal of Academic and Applied Studies,* **1:** 33-58.

Obasi, P.N., Akudinobi, B.E. 2013. Hydrochemical evaluation of water resources of the Ohaozara areas of Ebonyi State, southeastern Nigeria. *Journal of Natural Sciences Research,* **3:** 75-80.

Obasi, R.A., Balogun, O. 2001. Water quality and environmental impact assessment of water resources in Nigeria. *African Journal of Environmental Studies,* **2:** 228-231.

Ojekunle, I.A. 2000. *Transport and Urban Environmental Quality in Nigeria in Contemplary to AD 2000,* Frankad Publishers, Lagos, Nigeria.

Okiongbo, K.S., Douglas, R. 2013. Hydrogeochemical analysis and evaluation of groundwater quality in Yenagoa city and environs, Southern Nigeria. *Ife Journal of Science,* **15:** 209-222.

Okorie, I.A. 2010. Determination of potentially toxic elements (PTEs) and an assessment of environmental health risk from environmental matrices. *PhD. Thesis,* pp. 20-35, Northumbria University, UK.

Okoyeh, E.I., Egboka, B.C.E. 2013. Evaluation of hydrochemical parameters of Okposi and Uburu salt lakes, Nigeria. *International Journal of Scientific and Engineering Research,* **4:** 2882-2889.

Olajire, A.A., Imeokparia, F.E. 2001. Water quality assessment of Osun River: Studies on inorganic nutrients. *Environmental Monitoring and Assessment,* **69:** 17-28.

Ovrawah, I., Hymore, F.K. 2001. Quality of water from hand-dug wells in the Warri environs of Niger delta region. *African Journal of Environmental Studies,* **2:** 169-173.

Pink, D.H. 2006. *Investing in Tomorrow's Liquid Gold,* Retrieved October 03, 2014 from: www. finance. yalow.com

Smedley, P.L. 2008. Sources and distribution of arsenic in groundwater and aquifers. In: *Arsenic in Groundwater: A World Problem,* Appelo, Tony (ed.) pp 4-32.IAH, Utrecht, The Netherlands.

Smedley, P.L., Kinniburgh, D.H. 2002. A review of the source, behaviour and distribution of arsenic in natural waters. *Applied Geochemistry,* **17:** 517-568.

Smith, A.H., Lingas, E.O., Rahman, M. 2000. Contamination of drinking water by arsenic in Bangladesh. Public *Health Emergency Bulletin of World Health Organization,* **78:** 1093-1103.

Talabi, A.O., Afolagboye, O.L., Tijani, M.N., Aladejana, J.A., Ogundana, A.K. 2013. Hydrogeochemical assessment of surface water in the central part of Ekiti-State, Southwestern Nigeria. *American Journal of Water Resources,* **1:** 56-65.

WWC, 2003. Third World Water Forum and Ministorial Conference. World Water Council and Government of Japan. 16-23 March, Kyoto, Osaka and Shiaga, Japan. *Forum Bulletin,* **30:** 35-37.

Williams, J.W., Silver, S. 1984. Bacterial resistance and detoxification of heavy metals. *Enzyme and Microbiology Technology,* **6:** 530-537.

WHO, 2011. *Guidelines for Drinking Water Quality,* 4th edition, World Health Organization (WHO), Geneva, Switzerland.

WHO, 1984. *Guidelines for Drinking Water Quality,* pp. 99-102, World Health Organization (WHO), Geneva, Switzerland.