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Potability of Groundwater in Itu Local Government Area, South-South of Nigeria

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Abstract: Water samples were obtained from eight (8) different boreholes in Itu local government area, South-South of Nigeria. These samples were treated and analyzed using standard methods for their pH, temperature, turbidity, electrical conductivity (EC), total hardness (TH), dissolved oxygen (DO), biochemical oxygen demand (BOD), iron (Fe), zinc (Zn), copper (Cu), lead (Pb), cadmium (Cd) and nickel (Ni) levels. Mean levels of all the parameters determined in studied groundwater were within their safe limits except lead and cadmium. This study revealed that concentrations of Pb and Cd rendered water from the studied boreholes unsafe for human consumption considering the toxic nature of these metals. Variable correlations were observed among the studied physicochemical properties of water. Pollution index analysis also confirmed the hazardous nature of lead and cadmium in groundwater from studied boreholes. Proper treatment of studied boreholes to eliminate these toxic metals has been recommended as prolong consumption of this untreated water may eventually result in health problems associated with pb and Cd toxicities.

Keywords: Groundwater, Itu Local Government, Water Pollution, Trace Metal and Nigeria

1. Introduction

Water is one of the most common essential resources to human on earth without which there would be no life on earth [1, 2]. Water covers over 70% of the earth surface however; accessibility to potable water by human beings is still a serious problem especially in the developing countries [3, 4, 5, 6, 7]. Despite the gross unavailability of potable water, most people still depend on groundwater for consumption, domestic, agricultural and industrial uses globally [8]. According to UNESCO [9] over 2.5 billion people depend solely on groundwater for their satisfy basic daily water needs, and hundreds of millions of farmers rely on it to sustain their livelihoods and contribute to national security of others. Availability of potable water is one of the most serious environmental and sustainability issues of the 21st century [10]. Anwar and Aggarwal [11] reported that, a greater proportion of the world's population depend on groundwater for drinking and other purposes. In Nigeria, it is estimated that only 58% of Nigerians living in the urban and semi-urban areas and 39% of the rural dwellers have access to potable water supply; others depend exclusively on ground and surface water for their domestic water supply [12]. Water from borehole (groundwater) serves as the major source of drinking water in the local population of Nigeria, as only a few can afford the treated bottled water for consumption [13]. Notwithstanding the near total dependent on borehole water for human existence on earth, water from borehole is rarely treated in most developing nations thereby posing serious health risk to the consumers [14]. Water dissolves most substances than any other solvent thus; a lot of toxic substances which can cause malfunctioning of human body and chronic ailments are present in it [15, 16]. Some chemical substances in water are essential for human body, but at very high concentrations these substances become poisonous to the body [17]. Consequently, untreated borehole water is rarely safe for human consumption; in most cases it causes skin and eye infections, cholera, dysentery, tuberculosis, typhoid, diarrhea, viral hepatitis A and even death to the consumers [18, 19, 20, 21]. Safe drinking (potable) water is that with microbial, chemical and physical properties that meet World health organization (WHO) guidelines of national standards on drinking water quality [10]. Unsafe drinking water can contain high levels diseases causing organisms, organic and inorganic contaminants [22]. Hence, contaminated water can serve as a channel for transmitting disease causing organisms and toxic chemicals into the human body [23]. The World Health Organization estimates that 3.4 million people mostly children, die every year from water-related disease [1]. Report has revealed that, consumption of water with high concentration of iron resulted in formation of goiter in Kenyan adults [24]. A society that lacks potable water and proper sanitation suffers devastating diseases and millions of children die [25]. The World Health Organization estimated that 80% of all diseases are directly or indirectly related to polluted water [26]. It has been reported that, unsafe water kills more people than any other source of death [27, 28]. Due to consequences associated with the consumption of polluted water, quality assessment of drinking water should be an integral aspect of our society. In Niger Delta region of Nigeria, groundwater sources should be examined periodically since the activities of oil companies can significantly affect the quality of underground water [29]. Literature has shown unsafe quality of groundwater in most cities of Nigeria and Akwa Ibom State [20, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40]. Nevertheless, there is scarcity of information on underground water quality in Itu local government of Akwa Ibom state. This work was undertaken to ascertain the quality of water from boreholes within Itu local government area. Hence, the suitability or otherwise of underground water from the studied area will be ascertained.

2. Materials and Methods

2.1. Study Area

Itu local government of Akwa Ibom State lies between latitude 5˚ 10! N and longitude 7˚ 59! E. Itu local government has a population of approximately 127, 856 people based on the 2006 National Census figure [41]. Itu is located in the South-South region of Nigeria and occupies a landmass of approximately 606.10 square kilometers. Itu local government is bounded in the North and North-East by Odukpani in Cross River State and Arochukwu in Abia State, in the West by Ibiono Ibom and Ikono Local Government Areas, in the South and South-East by Uyo and Uruan Local Government Areas respectively (figure 1).

Figure 1. *Map of Akwa Ibom State showing Itu local government area (Study area).*

2.2. Sample Collection and Analysis

Samples were obtained from eight (8) boreholes namely: Ikot Obio Atai; Obong Itam; Mbiatok Itam; Oku Iboku; Mbak Atai Itam; Nung Ukot Itam; Ikot Uso Akpan Itam and Odiok Itam in Itu local government, Akwa Ibom State, Nigeria. Collection of water samples was done in triplicates twice a month for three (3) months (July – September, 2006). Water samples were collected and preserved according to standard methods by APHA [42] and ASTM [43]. pH of water was determined using Hanna pH meter after standardization with buffer solution [42]. Temperature of samples collected was determined in-situ at site using mobile thermometer following standard procedures by APHA [42]. Turbidity, electrical conductivity and total hardness in water samples collected from studied boreholes were determined following standard procedures by APHA [42]. Samples for DO and BOD5 were treated and analysed using standard procedures described by APHA [44] before taken to the laboratory. Water samples for nitrate analysis were collected in dark bottles and analysed in spectrophotometer according to procedures of APHA [45]. Total dissolved solids (TDS) and total suspended solids (TSS) were analysed gravimetrically following the procedures of Ademoroti [46] and APHA [47]. Concentrations of Fe; Zn; Cu; Pb; Cd and Ni in studied borehole water were determined following standard procedures by APHA [44]. Statistical treatment of data and Pearson correlation analysis of physicochemical properties in groundwater were analyzed using SPSS for windows (version 20.0). Pollution index for each water property was determined using the equation (1) below:

$$\text{Pollution index (Pi)} = \frac{\text{Concentration of water property}}{\text{Standard for the individual property}} \quad (1)$$

3. Results

Results for the physicochemical properties of water determines in boreholes within Itu local government area of Akwa Ibom State, Nigeria and their recommended limits by WHO are shown in Table 1. Table 2 shows the Pearson correlation coefficient among the water properties studied. Pollution indices of physicochemical properties studied in borehole water are indicated in Table 3.

Table 1. *Physicochemical properties of groundwater in Itu Local Government.*

	IOA	OBI	MBI	OKI	MAI	NUI	IUI	ODI	Mean	Min	Max	SD	WHO
pH	6.85	6.86	7.10	6.86	6.91	7.00	6.93	7.05	6.95	6.85	7.10	0.10	6.5 – 8.5
EC (µS/cm)	14.00	17.21	20.24	23.51	25.35	12.73	18.45	32.46	20.49	12.73	32.46	6.47	1000
Temp.(˚C)	26.50	27.50	26.60	28.00	27.50	27.50	27.30	26.70	27.20	26.50	28.00	0.54	27 – 29
Turb. (NTU)	0.16	0.23	0.15	0.21	0.26	0.24	0.21	0.22	0.21	0.15	0.26	0.04	5.0
TH (mg/l)	12.04	15.10	19.47	14.84	21.18	24.56	11.63	12.75	16.45	11.63	24.56	4.75	500
NO_3^-(mg/l)	0.09	0.12	0.11	0.07	0.10	0.16	0.13	0.18	0.12	0.07	0.18	0.04	10.0
TSS (mg/l)	0.21	0.24	0.19	0.32	0.37	0.26	0.30	0.25	0.27	0.19	0.37	0.06	28.0
TDS (mg/l)	24.26	27.46	30.86	34.80	42.32	17.46	29.35	48.27	31.85	17.46	48.27	9.85	500
DO (mg/l)	2.30	2.60	1.92	1.68	3.40	1.10	1.50	2.52	2.13	1.10	3.40	0.73	10.0
BOD (mg/l)	0.84	0.76	1.10	1.20	0.74	1.52	1.30	0.83	1.04	0.74	1.52	0.29	6.0
Fe (mg/l)	0.28	0.21	0.17	0.08	0.10	0.18	0.20	0.07	0.16	0.07	0.28	0.07	0.3
Zn (mg/l)	0.11	0.16	0.15	0.23	0.12	0.33	0.26	0.19	0.19	0.11	0.33	0.08	3.0
Cu (mg/l)	0.07	0.04	0.06	0.05	0.02	0.02	0.04	0.03	0.04	0.02	0.07	0.02	2.0
Pb (mg/l)	0.05	0.03	0.03	0.02	0.06	0.04	0.05	0.06	0.04	0.02	0.06	0.02	0.01
Cd (mg/l)	0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.003
Ni (mg/l)	0.01	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.03	0.01	0.02

IOA = Ikot Obio Atai; OBI = Obong Itam; MBI = Mbiatok Itam; OKI = Oku Iboku; MAI = Mbak Atai Itam; NUI = Nung Ukot Itam; IUI = Ikot Uso Akpan Itam; ODI = Odiok Itam.

Table 2. *Pearson correlation coefficient among the water properties studied.*

	pH	EC	Temp	Turb	TH	NO_3	TSS	TDS	DO	BOD	Fe	Zn	Cu	Pb	Cd	Ni
pH	1.000	0.300	-0.471	-0.211	0.350	0.606	-0.380	0.198	-0.209	0.259	-0.293	0.193	-0.171	0.132	-0.393	0.179
EC		1.000	-0.038	0.236	-0.218	0.205	0.342	0.979	0.490	-0.425	-0.847	-0.240	-0.282	0.335	-0.020	0.150
Temp			1.000	0.676	0.269	-0.264	0.720	-0.073	-0.145	0.308	-0.373	0.462	-0.471	-0.411	0.360	-0.176
Turb.				1.000	0.362	0.302	0.744	0.232	0.259	-0.025	-0.462	0.326	-0.920	0.279	0.511	-0.05
TH					1.000	0.118	0.154	-0.257	-0.084	0.332	-0.173	0.269	-0.512	-0.113	-0.083	-0.134
NO_3						1.000	-0.212	0.106	-0.162	0.173	-0.146	0.444	-0.567	0.450	-0.076	0.261
TSS							1.000	0.391	0.266	0.006	-0.550	0.149	-0.595	0.234	0.499	-0.477
TDS								1.000	0.629	-0.554	-0.771	-0.390	-0.244	0.421	-0.101	0.128
DO									1.000	-0.934	-0.214	-0.817	-0.133	0.462	0.423	0.293
BOD										1.000	0.046	0.888	-0.128	-0.351	-0.296	-0.456
Fe											1.000	-0.129	0.509	-0.056	0.100	0.039
Zn												1.000	-0.444	-0.213	-0.151	-0.288
Cu													1.000	-0.385	-0.363	0.052
Pb														1.000	0.232	-0.254
Cd															1.000	0.183
Ni																1.000

Red is significant at $P \leq 0.10$; Green at $P \leq 0.05$; Blue at $P \leq 0.02$; Black at $P \leq 0.01$

4. Discussion

pH: The pH of borehole samples collected from Itu varied from 6.85 to 7.10 (6.95±0.10) indicating that, water from studied borehole ranged from acidic to alkaline. The obtained range is lower than 4.2 – 8.9 reported in groundwater from Uyo, Nigeria by Beka and Udom [35] but, higher than 5.15 – 6.50 reported in groundwater within Uruan, Nigeria by udousoro and Umoren [36]. Water samples from studied boreholes except Mbiatok, Nung Ukot and Odiok Itam were acidic which is typical of ground water within Niger Delta area of Nigeria as reported by Udom et al. [48] and Udom et al. [49]. These boreholes should be treated to reduce their acidity as prolong consumption of acidic water may result in metabolic acidosis [50]. The acidic nature of water from these boreholes may be attributed to excessive gas flaring in the region which eventually results in acid rain [35]. Nevertheless, the pH range reported in this work is within the acceptable range for potability of water (6.5-8.5) by WHO [28]. A significant positive correlation was identified between pH and nitrate in this work ($r = 0.606$ at $P < 0.10$). pH correlated positively but insignificantly with EC; TH; TDS; BOD, Zn; Pb and Ni (at $P < 0.10$ with r values in Table 2).. Though, pH showed weak negative correlation with temperature; turbidity; TSS; DO; Fe; Cu and Cd ($P < 0.10$; r values in Table 2).

Electrical Conductivity: Electrical conductivity (EC) which is a measure of dissolved salts in water ranged between 12.73µS/cm and 32.46µS/cm. This range is similar to 28.00 – 34.00µS/cm reported in groundwater from Benin, Nigeria by Akpovata *et al*. [40]. The range is lower than 60.00 – 120.00 µS/cm recorded in groundwater in Oron, Nigeria by Emeka *et al*. [39] but, higher than 10.10 - 25.40µS/cm reported in boreholes in Port Harcourt, Nigeria by Alex *et al*. [34]. The mean concentration of EC 20.49±6.47µS/cm obtained in this study is lower than 1000.00µS/cm recommended by WHO [28]. Thus, this work has shown the potability of water from studied boreholes with respect to their dissolved salts contents. Results in Table 2 show significant positive correlation between EC and TDS with r value of 0.979 at $P< 0.01$. EC indicated strong negative correlation with iron at $P < 0.05$ with $r = -0.847$. Conductivity in studied boreholes also correlated negatively though insignificantly with temperature, TH, Zn, Cu and Cd. However, EC recorded weak positive correlation between turbidity, nitrate, TSS, DO, Pb and Ni in samples studied.

Temperature: Temperature of borehole water studied varied between 26.50°C and 28.00°C a mean (27.20±0.54°C). The temperature range of the studied boreholes is considered high when compared with 21.50 – 25.42°C obtained by Akpovata *et al*. [40] in groundwater from Benin, Nigeria. However, the range is lower than 26.8 – 29.6°C reported by Akpabio and Ekpo [31] in groundwater within Uyo, Nigeria. High temperature was recorded for each borehole indicating the presence of foreign bodies in these water sources within Itu [31]. Nevertheless, the temperature range obtained in this study is within the safe range of 27 – 29°C by WHO [28]. Thus, these boreholes may be considered as containing potable water suitable for human consumption regarding their temperature range. The temperature of the studied boreholes correlated positively and significantly with turbidity and TSS with r values of 0.676 and 0.720 at $P < 0.05$ and $P < 0.02$ respectively. This study has therefore confirmed that when the quantity of suspended solids in these boreholes is high, their turbidity will increase and this eventually results in high temperature within the studied boreholes. Temperature in studied groundwater also showed positive but weak correlation with TH, Zn and Cd. However, weak negative correlation was indicated by temperature with nitrate, TDS; DO; BOD; Fe; Cu; Pb and Ni in ground water studied.

Turbidity: Turbidity of water measures the degree of suspended particulate matters in water and it hinders the passage of sunlight through the water [51]. The turbidity of boreholes assessed varied between 0.15 NTU and 0.26 NTU. This range is consistent with 0.1 – 0.3 NTU reported in borehole samples from Uyo by [35]. The obtained range is lower than 0.11 – 1.17 NTU recorded in groundwater from Warri, Nigeria by Fovwe *et al*. [20] but higher than 0.1 – 0.2 NTU reported in groundwater from Ibesikpo, Nigeria by Inam *et al*. [52]. The general low levels of turbidity in boreholes investigated revealed confirmed the low level of TSS obtained in this study. It also indicated the absence or minimal level of disease causing organisms in these boreholes and high sanitary practices by inhabitants of studied areas [53]. Results in Table 2 indicate significant positive correlation between turbidity and TSS at $P < 0.02$ with $r = 0.744$ whereas, at $P < 0.01$ copper correlated significantly but negatively with turbidity ($r = -0.920$). Turbidity showed positive but insignificantly correlation with all the studied water properties except Fe and Ni which indicated weak negative relationship. This study has confirmed that, high amounts of suspended solids will ultimately result in elevated turbidity in studied boreholes.

Total Hardness: Total hardness (TH) of water measures the degree of dissolved salts such as calcium and magnesium ions. Total hardness in groundwater assessed varied between 11.63mg/l and 24.56mg/l. This is similar to a range of 10.00 – 23.00mg/l reported by Akpabio and Ekpo [31] in boreholes within Uyo. The range is higher than 12.00 – 16.00mg/l obtained in boreholes within Warri metropolis by Fovwe *et al*. [20] but lower than 3.59 – 381.9mg/l reported by Alex *et al*. [34] in boreholes within Port Harcourt. Using the classifications of Todd [54] water from all the studied boreholes are considered soft which is an indicative of low concentrations of calcium and magnesium ions in these boreholes. The mean TH obtained (16.45±4.75mg/l) is much lower than 500mg/l recommended by WHO [10]. Thus, the level of TH in studied boreholes may not be considered as nuisance and water from these boreholes are fit for domestic use. Pearson correlation coefficients of water properties in Table 2 indicate that, TH exhibited weak positive correlation between nitrate; TSS; BOD and Zn but weak negative correlation between TDS; DO; Fe; Cu; Pb; Cd and Ni.

Nitrate: Nitrate concentrations in boreholes assessed ranged from 0.07 mg/l to 0.18 mg/l which is within the range of 0.11 – 0.20 mg/l obtained in borehole samples from Uruan, Nigeria by Udousoro and Umoren [36]. This range is lower than 0.45 – 4.63 mg/l reported in Uyo by Beka and Udom [35]. Reports have shown that high nitrate concentrations in water indicate organic pollution; women and young babies are more vulnerable to its negative effects [55, 56, 57]. Consequently, the low concentrations of nitrate recorded signified absence of organic pollutants in studied boreholes. The mean concentration of nitrate obtained (0.12±0.04 mg/l) is lower than 10.00 mg/l stipulated for water by WHO [10]. Accordingly, considering nitrate levels obtained it could be asserted that groundwater investigated is potable. Nitrate correlated significantly but negatively with copper at $P < 0.10$ with r value of -0.567. Nitrate correlated positively but insignificantly with TDS; BOD; Zn; Pb and Ni however, nitrate exhibited weak negative relationship with TSS; DO; Fe and Cd.

Total Suspended Solids: Total suspended solids (TSS) measured in studied boreholes varied between 0.19 mg/l and 0.37 mg/l. This range is below 1.0 – 7.0 mg/l reported in boreholes within Oron, Nigeria by Emeka *et al*. [39]. Generally, levels of total suspended solids in all the studied boreholes were low and this may have resulted in the low turbidity in these boreholes recorded in this study. The mean TSS concentration obtained (0.27±0.06mg/l) is far below 28.00mg/l standard for potable water by WHO [10]. Thus, the potability of water from these boreholes had been revealed by their TSS levels. Results in Table 2 indicate that TSS exhibited strong negative relationship between iron and copper at $P < 0.10$ with r values of -0.550 and -0.595 respectively. TSS showed weak positive correlation with TDS; DO; BOD; Zn, Pb and Cd but weak negative relationship with Ni (r values in Table 2).

Total Dissolved Solids: Total dissolved solids (TDS) which according Alex *et al*. [34] signifies the presence of cations and anions in water varied in studied boreholes between 17.46 mg/l and 48.27 mg/l. This is higher than 20.0 – 28.0 mg/l reported in Oron by Emeka *et al*. [39] but lower than 61.33 – 277.0 mg/l recorded in borehole samples from Warri by Fovwe *et al*. [20]. The mean TDS value (31.85±9.85 mg/l) recorded in this study is lower than the standard (500.0mg/l) recommended by WHO [10]. The low TDS in studied boreholes is an indicative of good sanitary habit of the residence and absence of contaminants in these boreholes [58, 59]. Consequently, water from these boreholes may be considered potable and fit for domestic purposes. TDS correlated positively and significantly with DO with r values of 0.629 at $P < 0.10$. Thus, quantity of TDS in studied boreholes was directly proportional to the levels of DO. However, TDS showed strong negative correlation with BOD and iron in studied boreholes with r = -0.554 and -0.771 at $P < 0.10$ and $P < 0.01$. Hence, any thermodynamic or environmental condition in these boreholes that may convert soluble iron ions into insoluble ones or elevate their BOD level will certainly reduce their TDS levels. TDS indicated insignificant positive correlation with Pb and Ni but a weak negative relationship with Zn; Cu and Cd (r values in Table 2).

Dissolved Oxygen: Dissolved oxygen (DO) which is the amount of gaseous oxygen dissolved in aqueous solution plays critical part in the activities of living organisms within the aquatic environment [60]. DO levels in studied boreholes ranged from 1.10 mg/l to 3.40 mg/l which is higher than 0.10 – 0.15 mg/l reported in Uruan by Udousoro and Umoren [36]. However, the obtained range is lower than 4.0 – 5.0 mg/l obtained in boreholes within Bayelsa, Nigeria by Amangabara and Ejenma [30]. DO is one of the most important properties used for assessing the potability of water systems. Dissolved oxygen influences other water properties significantly; it alters chemical and physical properties of both organic and inorganic substances, thereby reducing their harmful potentials on the consumers [61]. The low DO obtained in this study could be a reflection of absence of pollutants in the studied boreholes. The mean DO value obtained (2.13±0.73 mg/l) is lower than 10.00 mg/l recommended for portable water by WHO [10]. Thus, levels of DO recorded may have promoted active life within these boreholes without posing any negative effect on the quality of water. Results in Table 2 strong negative correlation for the pairs: DO/BOD and DO/Zn at $P < 0.01$ with r values of -0.934 and -0.817 respectively. This study therefore affirmed that, the biochemical oxygen demand in studied boreholes was inversely proportional to the level of dissolved oxygen. Insignificant negative relationship was also exhibited by the following pairs of water properties: DO/Fe and DO/Cu with their respective r values of -0.214 and -0.133. Nevertheless, dissolved oxygen exhibited weak positive correlation with lead; cadmium and nickel (r = 0.462; 0.423 and 0.293 respectively).

Biochemical Oxygen Demand: Biochemical oxygen demand (BOD) indicates the amount of oxygen that would be used up if all the organic matters in one liter of water were oxidised by living organisms [53]. BOD values less than 6.0 mg/l implies that the water is less polluted by organic matter and the BOD content of such water body can sustain aquatic life [62]. According to WHO [10] BOD between 1.0 and 2.0 mg/l indicates very clean water, 3.0 – 5.0 mg/l (moderately clean water) while BOD > 5.0 mg/l shows presence of nearby pollution source. BOD recorded in this study varied between 0.74 mg/l and 1.52 mg/l indicating the potability nature of water from these boreholes. The BOD range obtained is consistent with 0.001 – 1.50 mg/l recorded in groundwater Uyo metropolis by Akpabio and Ekpo [31] but, lower than 3.4 – 8.8 mg/l reported by Amangabara and Ejenma [30]) in Bayelsa. Mean BOD recorded (1.04±0.29 mg/l) is below 6.0 mg/l stipulated by WHO [1] hence, water from these boreholes is fit for consumption. The low BOD levels recorded in the studied boreholes indicates the absence of organic pollutants in this water source. BOD exhibited significant positive correlation with zinc at $P < 0.01$ with r =

0.888 but weakly with iron (r = 0.046). Weak negative relationship was recorded for the pairs: BOD/Cu; BOD/Pb; BOD/Cd and BOD/Ni (r = -0.128; -0.351; -0.296 and -0.456 respectively).

Iron: Iron (Fe) concentrations in studied boreholes ranged from 0.07 mg/l to 0.28 mg/l which is lower than 0.00 – 2.72 mg/l obtained by Udousoro and Udoh [37] but higher than 0.045 – 0.08 mg/l reported in Benin by Akpoveta *et al*. [40]. Nutritionally, iron is very essential but if the concentration is higher in the body, it could result in iron toxicity [63]. Iron is abundant in the Earth's crust, but its concentration in water is low due to low solubility [64, 65]. Iron (Fe) concentrations in studied boreholes ranged from 0.07 mg/l to 0.28 mg/l which is lower than 0.00 – 2.72 mg/l obtained by Udousoro and Udoh [37] but higher than 0.045 – 0.08 mg/l reported in Benin by Akpoveta *et al*. [40]. Nutritionally, iron is very essential but if the concentration is higher in the body, it could result in iron toxicity [63]. Iron is abundant in the Earth's crust, but its concentration in water is low due to low solubility [64, 65]. The mean concentration of iron recorded in this study (0.16±0.07 mg/l) is lower than 0.30 mg/l specified by WHO [28]. Thus, water from studied boreholes has not been polluted by iron and the water is fit for domestic purposes. Iron corrected negatively but insignificantly with Zn and Pb with r values of -0.129 and -0.056 respectively. However, iron exhibited weak positive relationship with Cu; Cd and Ni with r values of 0.509; 0.100 and 0.039 correspondingly.

Zinc: Zinc (Zn) concentrations in studied boreholes varied from 0.11 mg/l to 0.33 mg/l which is higher than 0.09 – 0.12 mg/l reported in Benin by Akpoveta *et al*. [40] but lower than 0.32 – 0.73 obtained in borehole samples from Eket by Udousoro and Udoh [37]. Zinc is an essential element that forms a variety of water soluble salts [66, 67]. Zinc is very useful for normal enzymatic and reproductive activities in human but the level is high it can cause nausea, vomiting, dizziness, colics, fatigue, fever and diarrhoea [68]. The mean zinc concentration obtained (0.19±0.08 mg/l) is much lower than 3.0 mg/l recommended for potable water by WHO [28]. Thus, water from studied boreholes is good for human consumption and fit for domestic activities. This low level of zinc in all the boreholes also signifies absence of zinc-containing waste products. The antagonistic nature of zinc against more metals has been confirmed by its negative correlation though weak between Cu; Pb; Cd and Ni (r = -0.444; -0.213; -0.151 and -0.288 respectively).

Copper: Copper concentrations in studied boreholes ranged from 0.02 mg/l to 0.07 mg/l, this is in agreement with 0.033 – 0.07 mg/l reported in boreholes samples from Benin by Akpoveta *et al.* [40]. However, the range is lower than 0.12 – 0.35 mg/l obtained in boreholes within Eket, Nigeria by Udousoro and Udoh [37]. Copper is an essential element for plant, animal and human, in human it is required for proper functioning of organs and metabolic processes [69, 70]. Nevertheless, when the concentration in human body is higher than what is required it may result in nausea, vomiting, liver and kidney problems [71]. The mean copper concentration reported in this study (0.04±0.02 mg/l) is within the normal limit of 2.0 mg/l recommended for potable water by WHO [28]. Concentrations of copper in all the studied boreholes may be considered normal for proper functioning of human body. Thus, water from these boreholes is potable and suitable for domestic purposes with regards to their copper contents. Copper correlated negatively though insignificantly with lead and cadmium with r values of -0.385 and -0.232 ($P < 0.10$). Nonetheless, copper correlated positively and insignificantly with nickel with r = 0.039 at $P < 0.10$.

Lead: The range of lead (Pb) concentrations in studied boreholes varied between 0.02 mg/l and 0.06 mg/l and is consistent with concentrations of lead reported in boreholes within Uyo by Akpabio and Ekpo [31]. However, this range is higher than 0.012 – 0.016 mg/l obtained by Akpoveta *et al.* [40] in boreholes within Benin city, Nigeria but lower than 1.0 – 10.10 mg/l reported by Emeka *et al*. [39] in Oron. The mean concentration of Pb obtained (0.04±0.02 mg/l) is higher than 0.01 mg/l stipulated for potable water. Thus, the lead levels in these boreholes should be reduced for the water to be fit for human consumption. Lead is a rare element but when human is exposed to it for a long time it may result in depression, nausea, abdominal pain, loss of coordination, vomiting, diarrhea, anemia and other health implications reported by Brunton *et al*. [72]; Cleveland *et al*. [73] and Pearce [74].

Cadmium: Concentrations of cadmium in studied boreholes varied from 0.01 mg/l to 0.02 mg/l, this is in agreement with the range (0.011 – 0.015 mg/l) obtained in Oron boreholes by Emeka *et al*. [39]. However, the obtained range is higher than 0.001 – 0.002 mg/l reported by Njar *et al.* [38] in boreholes within Calabar South, Nigeria but lower than 5.0 – 12.6 ppm in Niger state, Nigeria by Oladipo *et al*. [32]. Studies have shown that cadmium is highly toxic even at very low concentration in human body [75, 76, 77]. The mean concentration of cadmium obtained (0.01±0.01 mg/l) is higher than the recommended limit for cadmium in potable water by WHO (2011). Thus, Cd concentrations in these boreholes has rendered water from them unfit for human consumption as this may result in Cd toxicity and its associated health problems reported by ATSDR [75]. Consequently, these boreholes should be properly treated to eliminate this toxic metal thereby making the water healthy for human consumption. The high concentrations of cadmium in studied boreholes may be attributed to the aquifer as there no major anthropogenic source of the element within the area [78]. Cadmium correlated positively but insignificantly with concentrations of nickel in these boreholes.

Nickel: Nickel concentrations in studied boreholes varied between 0.01 – 0.03 mg/l, this is consistent with the Ni range reported in borehole samples from Benin by Akpoveta *et al.* [40]. Though, the range is higher than 0.00 – 0.00 mg/l reported in Uyo by Akpabio and Ekpo (2013) but lower than 0.02 – 0.09 mg/l obtained in Eket by Udousoro and Udoh [37]. Concentration of nickel in each borehole was within the acceptable limit except in Obong Itam borehole. Water from Obong Itam borehole should be treated to eliminate or reduce nickel to a healthy level to forestall its toxicity and health consequences as described by USEPA [78]; Nielsen *et al.* [79] and Chang [80]. The high nickel level in groundwater from Obong Itam may be attributed to PVC pipes used although, as town in Niger Delta high nickel could be from petroleum source [82]. Nevertheless, the mean nickel concentration obtained (0.02±0.01 mg/l) is within the safe limit for potable water by WHO [28]. Consequently, water from studied boreholes except Obong Itam is potable and fit for domestic use.

Table 3. *Pollution Index of physicochemical properties of ground water.*

	IOA	OBI	MBI	OKI	MAI	NUI	IUI	ODI	Mean
pH	0.91	0.92	0.95	0.92	0.92	0.93	0.92	0.94	0.93
EC (µS/cm)	0.01	0.02	0.02	0.02	0.03	0.01	0.02	0.03	0.02
Temp.(°C)	0.95	0.98	0.95	1.00	0.98	0.98	0.98	0.95	0.97
Turb. (NTU)	0.03	0.05	0.03	0.04	0.05	0.05	0.04	0.04	0.04
TH (mg/l)	0.02	0.03	0.04	0.03	0.04	0.05	0.02	0.03	0.03
NO_3^-(mg/l)	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01
TSS (mg/l)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TDS (mg/l)	0.05	0.06	0.06	0.07	0.09	0.04	0.06	0.10	0.07
DO (mg/l)	0.23	0.26	0.19	0.17	0.34	0.11	0.15	0.25	0.21
BOD (mg/l)	0.14	0.18	0.20	0.13	0.25	0.12	0.13	0.22	0.17
Fe (mg/l)	0.93	0.70	0.57	0.27	0.33	0.60	0.67	0.23	0.54
Zn (mg/l)	0.04	0.05	0.05	0.08	0.04	0.11	0.09	0.06	0.07
Cu (mg/l)	0.04	0.02	0.03	0.03	0.01	0.01	0.02	0.02	0.02
Pb (mg/l)	5.00	3.00	3.00	2.00	6.00	4.00	5.00	6.00	4.25
Cd (mg/l)	3.33	6.67	3.33	3.33	6.67	3.33	6.67	3.33	4.58
Ni (mg/l)	0.50	1.50	0.50	0.50	0.50	0.50	0.50	0.50	0.63

Results of pollution indices of physicochemical properties of boreholes studied are indicated in Table 3. Pollution index indicates the relative pollution potential of each water property in an environment. Pollution indices of all the physicochemical properties analysed indicated that, all the properties were in safe limits except lead, cadmium and nickel. Pollution indices of Pb and Cd in groundwater from all the studied locations and Ni at Obong Itam showed high degree of pollution. Thus, Pb, Cd and Ni in groundwater from the affected areas posed serious health risks to the consumers. Thus, water from these boreholes should be treated to avoid health consequences associated with their high intake on the consumers.

5. Conclusion

This research work revealed that levels of all the parameters analysed for in studied boreholes were with their safe limits except lead and cadmium. Thus, groundwater in Itu local government area; Nigeria should be treated to eliminate the high toxic metals (lead and cadmium) presence in the studied boreholes. Consequently, water from the studied boreholes is not suitable for human consumption and domestic use.

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