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(Research Article)

Comparative analysis of borehole water quality and heavy metal pollution in Etinan and Uyo local government areas of Akwa Ibom State, Nigeria

Uwem Udosen Ubong, Akanimo Dianabasi Akpan * and Ufikairom Gershon Isotuk

Department of Chemistry, Akwa Ibom State University, Ikot Akpaden, Akwa Ibom State, Nigeria.

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Abstract

This study assessed and compared the water quality of selected boreholes in Uyo and Etinan Local Government Areas of Akwa Ibom State, Nigeria, using the Water Quality Index (WQI) and Heavy Metal Pollution Index (HPI). Borehole water samples were collected from five locations in each area and analysed for physicochemical and heavy metal parameters using standard analytical procedures. The WQI was computed based on eight key parameters, while the HPI was calculated for cadmium (Cd), iron (Fe), lead (Pb), and copper (Cu). Results revealed that the WQI values ranged from 113.62 to 263.04, classifying the water as unsuitable for drinking according to the WHO standards. The low pH values indicated acidity, while elevated Total Dissolved Solids (TDS) and Electrical Conductivity (EC) in some Uyo samples suggested anthropogenic influence. In contrast, Etinan samples exhibited relatively better quality. The HPI values ranged between 23.64 and 646.59, significantly above the critical threshold of 100, indicating serious heavy metal contamination in some sites. Overall, the study concludes that although heavy metal pollution is low, the borehole water from both Local Government Areas requires proper treatment before domestic use. Continuous monitoring and sustainable management strategies are recommended to safeguard groundwater quality in the region.

Keywords: Water Quality Index; Heavy Metal Pollution Index; Borehole; Pollutant; Contamination

1. Introduction

Water is a chemical substance essential to all known forms of life[1]. All living things on earth depend on water for various purposes. Water quality is the physical, chemical and biological characteristic of water. It is the measure of the condition of water relative to the requirement of one or more biotic species and to any human need or purpose. Water quality is determined by the concentration of physical, chemical and biological contaminants. Water quality index depend on water composition influenced by natural process and human activities [2]. Such water must be free from toxic biological, physiological and chemical contaminations [3]. Due to human health risk attached to the contamination of water, it is imperative to monitor its presence in the environment. Water pollution has both short and long term effects [4]. The importance of potable water, both for domestic and industrial uses, has created concern for water quality analysis. Groundwater bodies are prone to contamination from both anthropogenic and natural activities [5].

The importance of potable water, both for domestic and industrial uses, has created concern for water quality analysis. Groundwater bodies are prone to contamination from both anthropogenic and natural activities [6]. Boreholes, though more protected as a result of inherent chemical constituents of permeable bricks through which the water flows, can limit the quality of the water as they may have dissolved impurities which come from rock and sand strata through which the water flowed or passed [7]. According to [8], Metals constitute a proportion of wastes generated by domestic and industrial processes, Metals after entering the water may precipitate, be adsorb on solid surfaces, remain soluble or suspended in water or may be taken up by fauna and flora.

* Corresponding author: Akanimo Dianabasi Akpan

Groundwater appears as vulnerable as surface water due to water table being near the soil surface and layers topping the table being permeable, and superficial sources of pollution being numerous [9]. According to [10], Polluted groundwater has a great potential for transmitting a wide variety of diseases. Indiscriminate waste disposal, poor agricultural practices, septic tanks, pit latrines and graves near boreholes, poor well construction, contribute to borehole water contamination [11]. These account for the presence of coliform bacteria in borehole water. According to [12], the increased use of metal-based fertilizer in agricultural revolution of government could result in continued rise in concentration of metal pollution in fresh water reservoir due to water run-off. According to [13], metals such as nickel, cadmium and lead have no function in biological system and are potentially toxic, even at trace concentration.

Monitoring of the physicochemical water quality parameters play a pivotal role in assessing the water environment, ecosystem and hydrochemistry, several scientific procedures and tools have been developed to assess the water contaminants [14]. A vital aspect of public health and a fundamental human right is having access to clean, safe water. Boreholes are the main source of drinkable water in Akwa Ibom State, particularly in rural and peri-urban areas. However, a number of man-made and natural variables have led to worries about the quality of the water from these sources. The purpose of this study is to evaluate and contrast the water quality indices of a few chosen boreholes in the LGAs of Etinan and Uyo in order to shed light on their safety and portability. Previous studies have tested groundwater quality in various sections of the state, establishing a baseline for understanding regional variances. The study adds to the body of knowledge on groundwater quality in Akwa Ibom State, providing data that can be used for future research and comparative analysis.

2. Materials and methods

2.1. General description of area

The description of the study locations is presented on Tables 1 and 2 and seen on Figures 1 and 2.

Table 1 Global Positioning System (GPS) Coordinates for the Etinan and Station Code

Stations codes	Sampling Location	Latitudes	Longitudes	Description of Area
S1	Etinan Road	4°59'49.57"N	7° 51'8.958" E	Market/Business
S2	Ukwa Road	4°53'51.02"N	7°50'15.648"E	Residential
S3	Udua Etinan	4°50'37.272"N	7°50'41.922"E	Residential
S4	Mbiotio Road	4°47'45.51"N	7°49'43.884"E	Residential
S5	Ikot Ete Ekpo	4°43'7.538"N	7°51'8.328"E	Residential

Table 2 Global Positioning System (GPS) Coordinates for the Uyo and Station Code

Stations codes	Sampling Location	Latitudes	Longitudes	Description of Area
S1	Udo Ekpo Mkpo Street	5°1'22.14"N	7° 57'34.278"E	Residential
S2	Stadium Road	5°2'28.308"N	7°56'7.452"E	Business
S3	Abak Road	5°2'3.102"N	7°55'36.528"E	Residential
S4	Ikot Ekpene Road.	5°2'13.488"N	7°55'12.99"E	Residential
S5	IBB Avenue	5°1'24.114"N	7°54'21.126"E	Residential

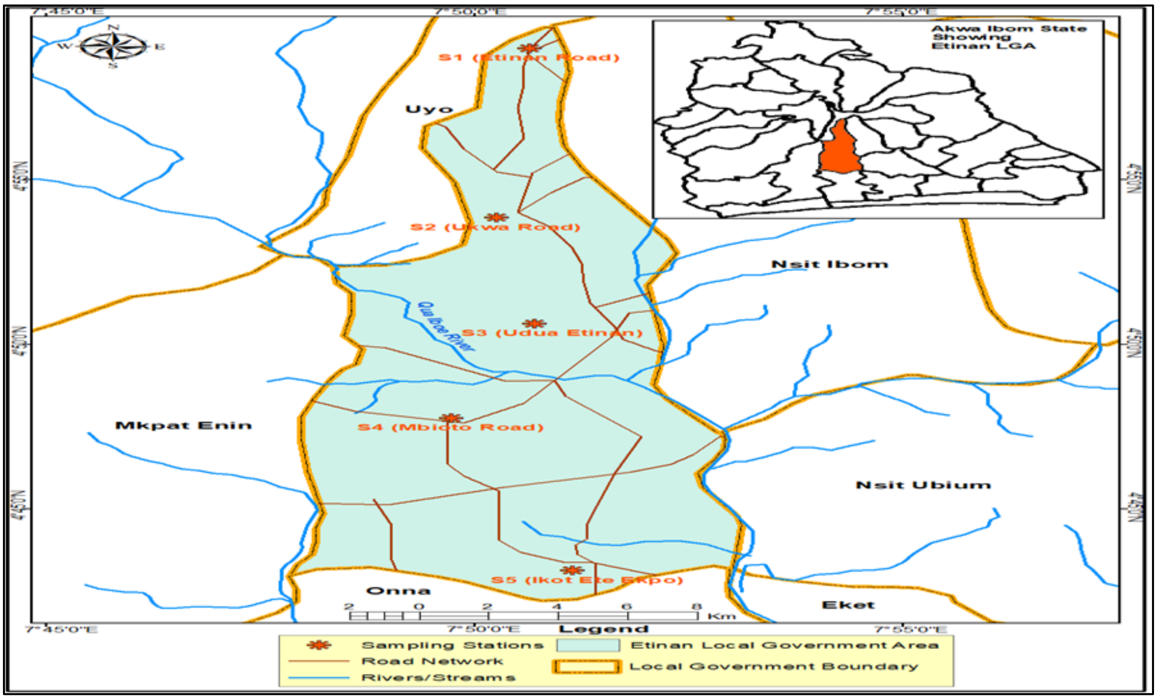

Figure 1 Map of Etinan Local Government Area Showing Sampling Stations Source: Compiled using open street map database and fieldwork

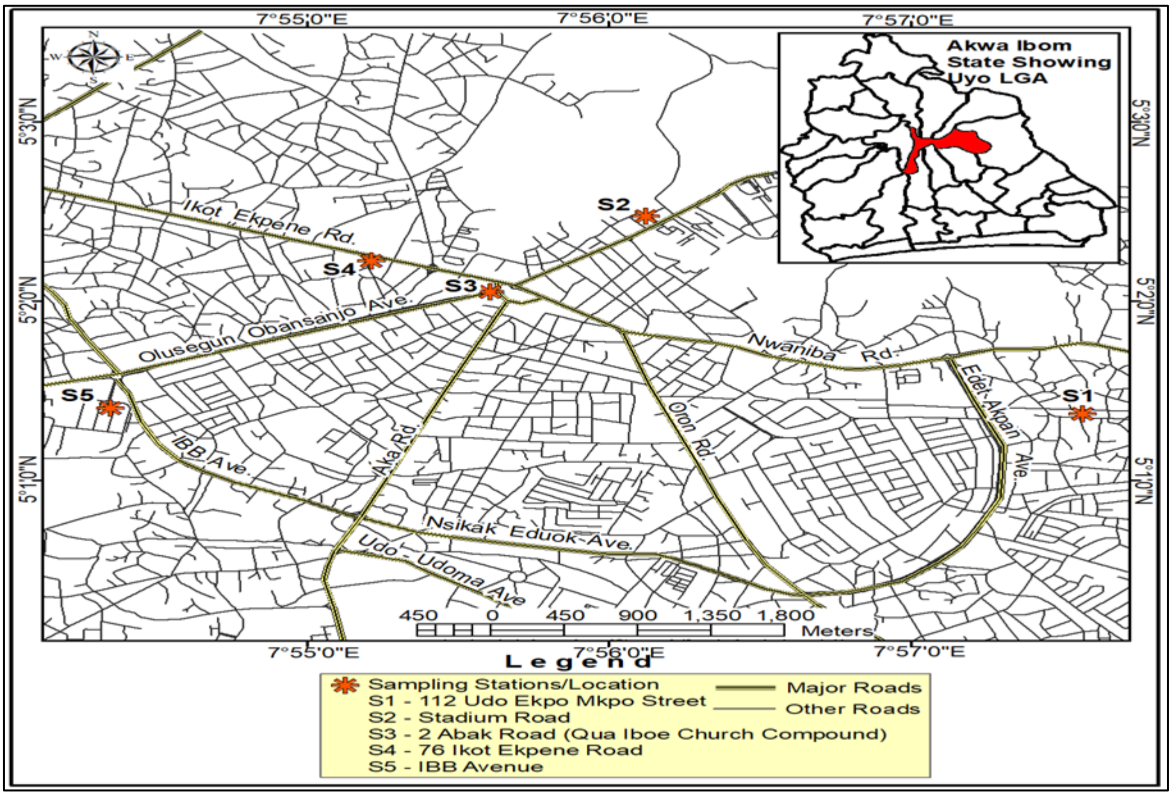

Figure 2 Map of Uyo Local Government Area Showing Sampling Stations Source: Compiled using open street map database and fieldwork

2.2. Experimental work

One litre of borehole water samples were collected at different sampling stations in Etinan and Uyo Local Government Area. Samples were transported to the laboratory for analysis. The physico-chemical parameters were measured using standard methods. Temperature (using HANNA digital thermometer), pH(pH meter), Electrical conductivity and Total Dissolved Solids (conductivity meter), DO & BOD (Dissolved Oxygen analyzer), pH (pH meter from HANNA company), total hardness (EDTA titrimetric method), and elemental composition (spectrophotometry). WQI and HPI were calculated using weighted arithmetic index method.

2.3. Water quality index (WQI) computation equations

WQI is defined as a rating reflecting the composite influence of different water quality parameters [15]. WQI is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water. The importance of various parameters depends on the intended use of water. Therefore, several steps of the weighted arithmetic index method are given [16] in the following steps.

2.3.1. Calculation of sub index of quality rating (q_i)

Let (i) there be the water quality parameters and (q_i) the quality rating or sub-index corresponding to i^{th} parameter is a number reflecting the relative value of this parameter in the polluted water with respect to its standards permissible value). The q_i value of is calculated using equation 1.

$$q_i = 100 \frac{V_i - V_o}{S_i - V_o} = 100 \left[{(V_i - V_o)}/{S_I - V_o} \right] \qquad (1)$$

Where: V_i is estimated concentration of i^{th} parameter in the analysed water, V_o is the ideal value of this parameter in pure water. V_o = 0 (except pH =7.0 and DO = 14.6 mg/L), S_i is recommended standard value of i^{th} parameter.

2.3.2. Calculation of unit weight (Wi)

Calculation of unit weight (W_i) for various water quality parameters is inversely proportional to the recommended standards S_i for the corresponding parameters (equation 2) [16]:

$$W_i = {K}/{S_i} \qquad (2)$$

Where: W_i = unit weight for the ith parameters; S_i = standard value for ith parameter; K = constant for proportionality and $K = \frac{1}{\frac{1}{s1}+\frac{1}{s2}+\frac{1}{s3}+\frac{1}{s4}+\frac{1}{s5}+\frac{1}{si}}$

2.3.3. Calculation of WQI

In the study, for the calculation of water quality index, eight (8) parameters were used. Weighted arithmetic water quality index method classified the water quality according to the degree of purity by using the most commonly measured water quality variables. The calculation of WQI was done using equation 3[17,18].

$$\text{WQI} = \frac{\Sigma q_i W_i}{\Sigma W_i} \qquad (3)$$

2.3.4. Assessment of water quality

Table 3 represents the 5 classes of water quality based on WQI of arithmetic WQI method.

Table 3 Water quality index (WQI) range and status

WQI Value	Rating of Water Quality	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very poor water quality	D
Above 100	Unsuitable for drinking purpose	E

Source: [16, 19]

2.4. Heavy Metal Evaluation Methods

Heavy metal was evaluated in this study using heavy metal pollution index (HPI) proposed by Prasad.

2.4.1. Heavy metal pollution index (HPI)

The HPI represent the total quality of water with respect to heavy metal. The HPI is based on weighted arithmetic quality mean method and developed in two steps. First by establishing a rating scale for each selected parameter giving weightage and second by selecting the parameter on which the index is to be based. Computing the HPI, [20] considered unit weightage (W_i) as a value inversely proportional to the recommended standard (S_i) of the corresponding parameter. In computing the HPI for the present study, Cd, Fe, Pb and Cu were used.

The HPI model [21] is given by equation 4:

$$HPI=\frac{\sum_{i=1}^{n} W_i\,Q_i}{\sum_{i=1}^{n} W_i} \qquad (4)$$

Where Q_i is the sub-index of the ith parameter, W_i is the unit weightage of the i_{th} parameter and n is the number of parameters considered. The sub-index (Q_i) of the parameter is calculated by equation 5.

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i\,(-)I_i\}}{(Si-I_i)} \times 100 \text{ and } W_i = \left(\frac{1}{S_i}\right) \Big/ \sum\left(\frac{1}{S_i}\right) \qquad (5)$$

Where: M_i is the monitored value of heavy metal of i^{th} parameter, I_i is the ideal value of the i^{th} parameter and S, is the standard value of the i^{th} parameter. The sign (-) indicates numerical difference of the two values, ignoring the algebraic sign. Low heavy metal pollution (HPI<100), heavy metal pollution on the threshold risk (HPI=100) and high heavy metal pollution (critical pollution index) (HPI>100). If the samples have heavy metal pollution index values greater than 100, water is not potable [22].

Table 4 Standards for drinking water and relative weight of parameters

S/No.	Parameters	standard permissible value (WHO, 2022) (S_i)	$1/S_i$	K	Relative weight (W_i)
	pH	8.5	0.117647	0.179647	0.654879
	TDS	500	0.002		0.011133
	EC	1000	0.001		0.005566
	Ca	75	0.013333		0.07422
	Cl^-	250	0.004		0.022266
	Mg	30	0.033333		0.185549
	Alkalinity	200	0.005		0.027832
	Hardness (mg/L $CaCO_3$)	300	0.003333		0.018555
	Pb	0.01	100		0.228746
	Cd	0.003	333.33		0.762486
	Fe	0.3	0.5		0.007625
	Cu	2	3.33		0.001144

All values are in mg/L, except pH, EC (µS/cm)

3. Results and discussion

The analytical results obtained for different study parameters summarised in Table 6 are discussed below.

The comparative concentrations of the water sample pH collected from the two study areas are given in Table 5. The pH values in the present study were below the recommended value of 6.50-8.50 by [23]. It indicated that the water was acidic in nature. According to [24], the acidic nature of the ground water is due to the leaching of altered rocks by acidic rainwater.

Table 5 Comparative mean concentration of the physicochemical parameters of borehole water samples from Uyo and Etinan

S/No.	PARAMETERS	S1		S2		S3		S4		S5	
		U	E	U	E	U	E	U	E	U	E
1	pH	1.78	3.75	3.45	4.93	3.46	4.73	4.03	4.76	3.62	4.91
2	TDS(mg/L)	2856.67	86.10	38.7	19.86	181.17	19.53	57.2	9.16	11.9	18.3
3	EC(µs/cm)	4034.67	172.80	77.6	39.70	362	38.40	114.33	18.29	23.6	36.60
4	Ca(mg/L)	73.51	72.27	74.93	60.20	49.2	73.13	72.8	73.53	73.99	68.93
5	Cl^- (mg/L)	77.31	45.62	15.43	17.25	31.58	29.86	56.04	26.88	18.67	24.39
6	Mg(mg/L)	26.29	26.29	21.74	21.74	38.86	38.86	29.6	29.60	41.2	41.20
7	Alkalinity(mg/L)	84.33	41.80	28.6	49.86	39.6	33.00	24.93	46.93	52.07	22.00
8	Hardness (mg/L $CaCO_3$)	183.5	180.50	175.2	149.67	118.33	183.00	175.33	184.83	180.2	171.17
9	Pb (mg/L)	0.01	0.01	0.01	0.03	0.06	0.02	0.02	0.02	0.03	0.01
10	Cd (mg/L)	0	0.00	0	0.01	0.02	0.01	0	0.00	0.01	0.01
11	Fe (mg/L)	0.3	0.60	0.3	0.50	0.4	0.60	0.5	0.70	0.7	0.50
12	Cu (mg/L)	0	0.01	0	0.01	0	0.00	0	0.00	0.01	0.01

Where U = Uyo and E= Etinan. Source: Environmental study.

Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were below the recommended value of 1000 mg/L and 500 mg/L respectively by [23. 25] except in sample S1 in Uyo (4034.67 µs/cm and 2,856.67 mg/L respectively) (Table 5), indicating increased dissolved ions, possibly due to industrial effluents [26]. The concentrations of all the analysed parameters in the present study were below their respective recommended values by [23, 25]. As seen in Table 6 and 7, water quality index (WQI) in all the analysed samples was registered to be in the range 113.6163 – 263.0354 in the unsuitable for drinking category (WQI – above 100) (Figure 3). However, this water can be used for drinking purpose after purification treatment followed by disinfection before consumption and it should be protected from contaminants [27, 28]. The high WQI scores in all the above sites are contributed mainly by various anthropogenic activities like the inflow of direct sewerage from residential and commercial establishments, lack of proper sanitation system, agricultural run-off, direct disposal of untreated effluents from small scale industries and factories and unabated dumping of solid wastes by the communities residing in the catchment area, etc. Thus, high priority should be given to water quality monitoring and advanced technologies should be adopted to make water fit for, domestic and drinking use. The water quality index value of this study shows that the water body contains high organic matter and eutrophic conditions. The HPI calculated with mean concentration values of all metals analysed for in this study was in range 23.63706 – 646.58790 which some sites (S1, S2 and S4) were below the critical index value of 100 while S2 (in Etinan), S3 and S5 were higher than the critical index value of 100. This indicated that even after continuous environmental activities near the sites (S1, S2 and S4) for years, the water has not been contaminated by higher concentrations of heavy metals but S2 (in Etinan), S3 and S5 were contaminated. The heavy metal pollution index calculated for all the sampling locations is given in Tables 8 and 9.

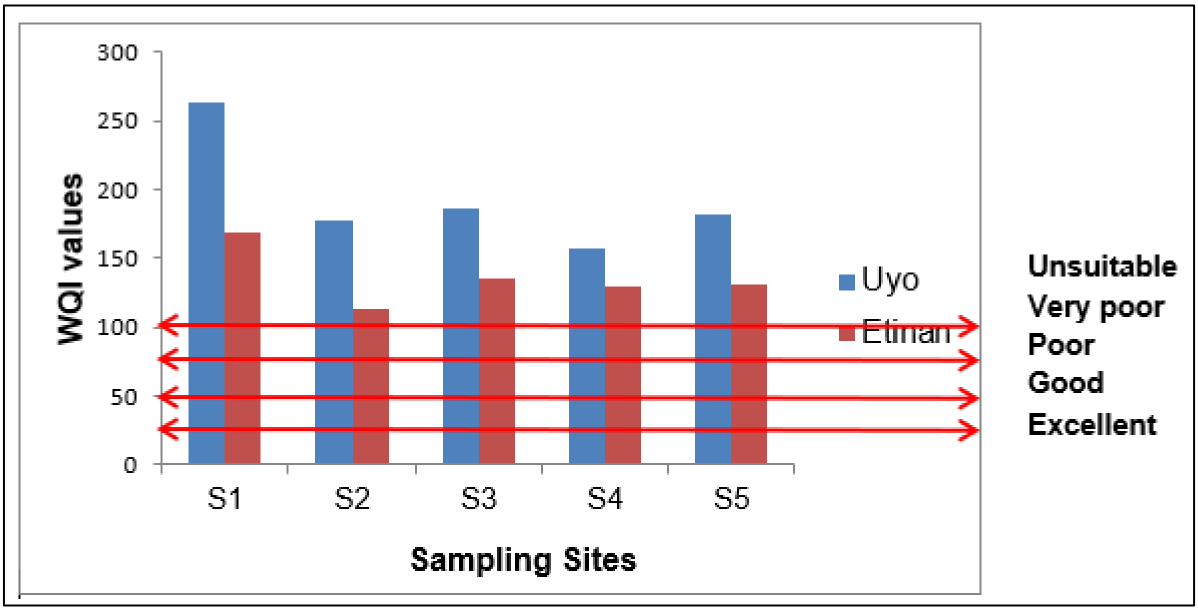

Figure 3 Water quality index (WQI) and status of water quality

Table 6 Water quality index calculation of samples in Uyo Study Area

S/N	Parameters	Observed values						Quality rating (q_i)					Weighted values W_iq_i				
		S1	S2	S3	S4	S5	W_i(Table 4)	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
1	pH	1.78	3.45	3.46	4.03	3.62	0.655	348	236.667	236	198	225.333	227.8978	154.988	154.5514	129.666	147.566
2	TDS(mg/L)	2856.67	38.7	181.17	57.2	11.9	0.011	571.334	7.74	36.234	11.44	2.38	6.360627	0.086169	0.403391	0.127361	0.026496
3	EC(µs/cm)	4034.67	77.6	362	114.33	23.6	0.006	403.467	7.76	36.2	11.433	2.36	2.245887	0.043196	0.201506	0.063641	0.013137
4	Ca(mg/L)	73.51	74.93	49.2	72.8	73.99	0.074	98.01333	99.90667	65.6	97.06667	98.65333	7.274511	7.415033	4.868806	7.204249	7.322011
5	Cl^- (mg/L)	77.31	15.43	31.58	56.04	18.67	0.022	30.924	6.172	12.632	22.416	7.468	0.68855	0.137425	0.281263	0.499112	0.166282
6	Mg(mg/L)	26.29	21.74	38.86	29.6	41.2	0.186	87.63333	72.46667	129.5333	98.66667	137.3333	16.26028	13.44612	24.03478	18.3075	25.48206
7	Alkalinity(mg/L)	84.33	28.6	39.6	24.93	52.07	0.028	42.165	14.3	19.8	12.465	26.035	1.173551	0.398003	0.551081	0.34693	0.724615
8	Hardness (mg/L $CaCO_3$)	183.5	175.2	118.33	175.33	180.2	0.019	61.16667	58.4	39.44333	58.44333	60.06667	1.134941	1.083606	0.731867	1.08441	1.114531
							$\sum W_i$ = 1.000					$\sum W_iq_i$	263.0354	177.5972	185.6236	157.2988	182.4142
												$\frac{\sum W_iq_i}{\sum W_i}$	263.0354	177.5972	185.6236	157.2988	182.4142

Table 7 Water quality index calculation of samples in Etinan Study Area

S/N	Parameters	Observed values						Quality rating (q_i)					Weighted values W_iq_i				
		S1	**S2**	**S3**	**S4**	**S5**	**W_i (Table 4)**	**S1**	**S2**	**S3**	**S4**	**S5**	**S1**	**S2**	**S3**	**S4**	**S5**
1	pH	3.75	4.93	4.73	4.76	4.91	0.021135	216.667	138	151.333	149.333	139.333	141.8904	90.37328	99.105	97.79524	91.24645
2	TDS(mg/L)	86.1	19.86	19.53	9.16	18.3	0.000359	17.22	3.972	3.906	1.832	3.66	0.191709	0.04422	0.043485	0.020396	0.040747
3	EC(µs/cm)	172.8	39.7	38.4	18.29	36.6	0.00018	17.28	3.97	3.84	1.829	3.66	0.096189	0.022099	0.021375	0.010181	0.020373
4	Ca(mg/L)	72.27	60.2	73.13	73.53	68.93	0.002395	96.36	80.26667	97.50667	98.04	91.90667	7.151801	5.95736	7.236906	7.27649	6.821276
5	Cl^- (mg/L)	45.62	17.25	29.86	26.88	24.39	0.000719	18.248	6.9	11.944	10.752	9.756	0.406308	0.153635	0.265944	0.239403	0.217226
6	Mg(mg/L)	26.29	21.74	38.86	29.6	41.2	0.005988	87.63333	72.46667	129.5333	98.66667	137.3333	16.26028	13.44612	24.03478	18.3075	25.48206
7	Alkalinity(mg/L)	41.8	49.86	33	46.93	22	0.000898	20.9	24.93	16.5	23.465	11	0.581696	0.693861	0.459234	0.653086	0.306156
8	Hardness (mg/L $CaCO_3$)	180.5	149.67	183	184.83	171.17	0.000599	60.16667	49.89	61	61.61	57.05667	1.116387	0.925704	1.131849	1.143167	1.058681
							$\sum W_i$ = 1.000					$\sum W_iq_i$	168.6948	113.6163	135.2986	129.4455	130.193
												$\frac{\sum W_iq_i}{\sum W_i}$	168.6948	113.6163	135.2986	129.4455	130.193

Table 8 Heavy metal pollution index calculation of samples in Uyo Study Area

S/No	Parameters	Observed values						Quality rating (Q_i)					Weighted values W_iQ_i				
		S1	**S2**	**S3**	**S4**	**S5**	**W_i(Table 4)**	**S1**	**S2**	**S3**	**S4**	**S5**	**S1**	**S2**	**S3**	**S4**	**S5**
1	Pb (mg/L)	0.01	0.01	0.06	0.02	0.03	0.229	100	100	600	200	300	22.875	22.875	137.247	45.749	68.624
2	Cd (mg/L)	0	0	0.02	0	0.01	0.762	0	0	666.667	0	333.3333	0.000	0.000	508.324	0.000	254.162
3	Fe (mg/L)	0.3	0.3	0.4	0.5	0.7	0.008	100	100	133.333	166.667	233.3333	0.762	0.762	1.017	1.271	1.779
4	Cu (mg/L)	0	0	0	0	0.01	0.001	0	0	0	0	0.5	0.000	0.000	0.000	0.000	0.001
							$\sum W_i$ = 1.000					$\sum W_iQ_i$	23.63706	23.63706	646.5879	47.01995	324.5653
												$\frac{\sum W_iQ_i}{\sum W_i}$	23.63706	23.63706	646.5879	47.01995	324.5653

Table 9 Heavy metal pollution index calculation of samples in Etinan Study Area

S/No	Parameters	Observed values						Quality rating (Q_i)					Weighted values W_iQ_i				
		S1	**S2**	**S3**	**S4**	**S5**	**W_i(Table 4)**	**S1**	**S2**	**S3**	**S4**	**S5**	**S1**	**S2**	**S3**	**S4**	**S5**
1	Pb (mg/L)	0.01	0.03	0.02	0.02	0.01	0.229	100	300	200	200	100	22.875	68.624	45.749	45.749	22.875
2	Cd (mg/L)	0	0.01	0.01	0	0.01	0.762	0	333.333	333.333	0	333.3333	0.000	254.162	254.162	0.000	254.162
3	Fe (mg/L)	0.6	0.5	0.6	0.7	0.5	0.008	200	166.666	200	233.333	166.6667	1.525	1.271	1.525	1.779	1.271
4	Cu (mg/L)	0.01	0.01	0	0	0.01	0.001	0.5	0.5	0	0	0.5	0.001	0.001	0.000	0.000	0.001
							$\sum W_i$ = 1.000					$\sum W_iQ_i$	24.400	324.057	301.436	47.528	278.308
												$\frac{\sum W_iQ_i}{\sum W_i}$	24.400	324.057	301.436	47.528	278.308

4. Conclusion

By comparing borehole water quality between Etinan and Uyo LGAs, the study reveals that water quality of Etinan was better than that of Uyo samples. On the basis of the above discussions, it may be concluded that the WQI for all samples were found in the range of 111.6157 - 263.0354 in the unsuitable for drinking category (WQI – above 100). The comparatively low pH indicates the water is not suitable for domestic use without giving treatment. The HPI calculated was in range 0.228771 - 6.435704 which is far below the critical index value of 100. This indicates that despite the environmental activities the ground water of the sampling locations was not polluted with respect to heavy metals. Water quality assessment is an important and significant technique for complete assessment of water body. Hence highest priority should be given to water quality monitoring and indigenous technologies should be adopted to make water fit for domestic and drinking purpose after treatment

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflicts of interest related to this study.

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