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CHARACTERIZATION OF WATER QUALITY INDEX OF WELL-WATER AT AREAS OF HISTORIC ARTISANAL REFINING ACTIVITIES

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Abstract
This study assessed the quality of water in the area and possible sources of water contaminants using some physicochemical properties of groundwater from hand-dug wells impacted by artisanal refining activities in some settlements in Ahoada West and Ahoada East Local Government Areas of Rivers State. Three sampling sites and a control site (Igbu Ulagbe - Idu-Ekpeye, Igbu Odiabidhi -Opkorowo, Igbu Okpudhor - Ubeta) were studied. Oil spills resulting from the artisanal crude oil refining activities have led to the contamination of groundwater in Ahoada-East and Ahoada-West Local Government Areas. Results of the physiochemical analysis showed that values of turbidity, pH, Temperature, total hydrocarbon content and dissolved oxygen at three sites; Igbu Ulagbe -Idu Ekpeye (20.95±0.82 NTU, 5.00±0.15, 29.3±0.71ºC, 24.72±2.80mg/l & 4.10±0.47mg/l), Igbu Odiabidhi- Okporowo (27.40±0.59 NTU,5.24±0.27, 27.6±0.34ºC, 25.15±1.02mg/l & 4.59±0.78mg/l), and Igbu Okpudhor - Ubeta (30.53±1.38 NTU, 4.29±0.09, 29.5±0.29ºC, 23.88±0.54mg/l & 4.47±0.64mg/l) were above NSDWQ standard. Values of THC at Igbu Ulagbe Idu Ekpeye (24.72 mg/l), Igbu Odiabidhi -Okporowo (25.15mg/l) and Igbu Okpudhor -Ubeta (23.88 mg/l) were above NSDWQ, (2007) standard (0.3mg/l). Values of cadmium, chromium and lead were above NSDWQ, (2007) standards. The result of the total heterotrophic bacteria count (THBC) was above the maximum contamination Levels (MCLs) of 500cfu/100ml in drinking water. The result obtained at the control station (Igbu Ogbor -Ahoada) is relatively within the permissible limit except for nutrients, THBC, temperature and turbidity. The quality of water is anchored on the result of the groundwater physico-chemical characteristics through which the water quality can be determined with ease. The result of the analysis of the studied parameters was applied to compute the WQI of well water from the area. The WQI of the three stations and control were found to be 194.71, 258.30, 293.30 and 52.91 respectively indicating that the water in the respective stations was of unsuitable water quality- UWQ (category 5 for the study area and category 3 for the control station-PWQ) thus suggesting that the well water sample studied is unsafe for consumption. The study therefore suggested that measures of controlling the heinous act be activated as quickly as possible by the government and IOCs operating in the area to mitigate the toxicological health hazards on the ecosystem and residents of the area who relied on the well water for consumption and other domestic purposes.

Keywords: Water Quality Index, Characterization, Well-water, Groundwater, Artisanal Refineries

Introduction
Water is a vital gift of nature designed to sustain life on the planet Earth which continually revolves between the biosphere and atmosphere (Rumman et al., 2012). It is therefore noteworthy that water as a natural asset which is used for agricultural purposes is also jointly used with human consumption and the aquatic and terrestrial ecosystem (Otene & Alfred-Ockiya, 2019). It is a fact that freshwater plays a vital role in man's daily survival and welfare, which is why its degradation has been captured as a top environmental challenge and hence studied by scholars from different disciplines like chemists, biochemists, civil engineers, geomorphologists and other environmentalist (Kumar & Dua, 2009). Groundwater is principally the major source of water globally for domestic, agricultural and industrial applications therefore its degradation has been acknowledged as one of the most worrisome challenges in recent times due to anthropogenic activities of man that release high levels of toxic substances to the environment (Belkhiri et al., 2010). Groundwater quality evaluation is a complicated procedure undertaking a wide array of parameters capable of impacting stresses on the general groundwater quality. Different scholars globally have designed and formulated water quality indices which can ease explain the total water quality of a particular

geographic location efficiently and effectively with provable results (Nwankwoala & Udom, 2011). Water Quality Index (WQI) is an approach of rating that avails the compound impact of single water quality characteristics on the total quality of water for use by man for drinking purposes (WHO, 1993). To assess the state of water quality, we need a full understanding of the working procedures and basic concepts of water and other related matters (Nikbakht, 2004). It is therefore a key tool for the evaluation and proper management of water resources (Edet, 2010). Recently, artisanal refining has become one of the worrisome anthropogenic activities that contribute greatly to the downgrading of the quality of water in this area of study as their operation has remained unabated. Anthropogenic activities can influence water quality adversely by releasing pollutants like toxic metals, PAHs and other hazardous compounds that alter water parameters. The degradation of groundwater quality may give rise to serious restrictions on the use of water especially when it pertains to domestic uses. The reason is that contaminated water can pose health challenges to humans and other animals. A holistic approach to evaluating the groundwater of the study area to establish its suitability for consumption is required due to the widespread illegal crude oil refining activities. This study is therefore intended to evaluate the quality of groundwater in the area impacted by crude oil using the water quality index by computing the results of the physicochemical properties studied.

The study area description

The study area is a crude oil bearing and pipeline delivery community within Ahoada -East and Ahoada -West Local Government Areas in Rivers State, Nigeria. The geographical coordinates (GPS) of Ahoada -West Local Government Area are 5°09' and 5°59' North, 6° 28' and 6°47' East respectively and Ahoada –East Local Government Area are 5°07' and 5°41' North, 6° 38' and 6°64' East respectively. Ahoada -West and Ahoada -East Local Government Areas are situated within latitudes 5°09' and 5°59' N and between longitudes 6°28' and 6°47'E and5°07' and 5°41' N, 6° 38' and 6°64' E respectively. It is recorded that the climate of a place determines the vegetation type of that area. In summary, the vegetation of the study area can best be described as having two major geographic classifications, namely the marshy rainforest region (riverine) and the semi-arid rainforest region (upland).

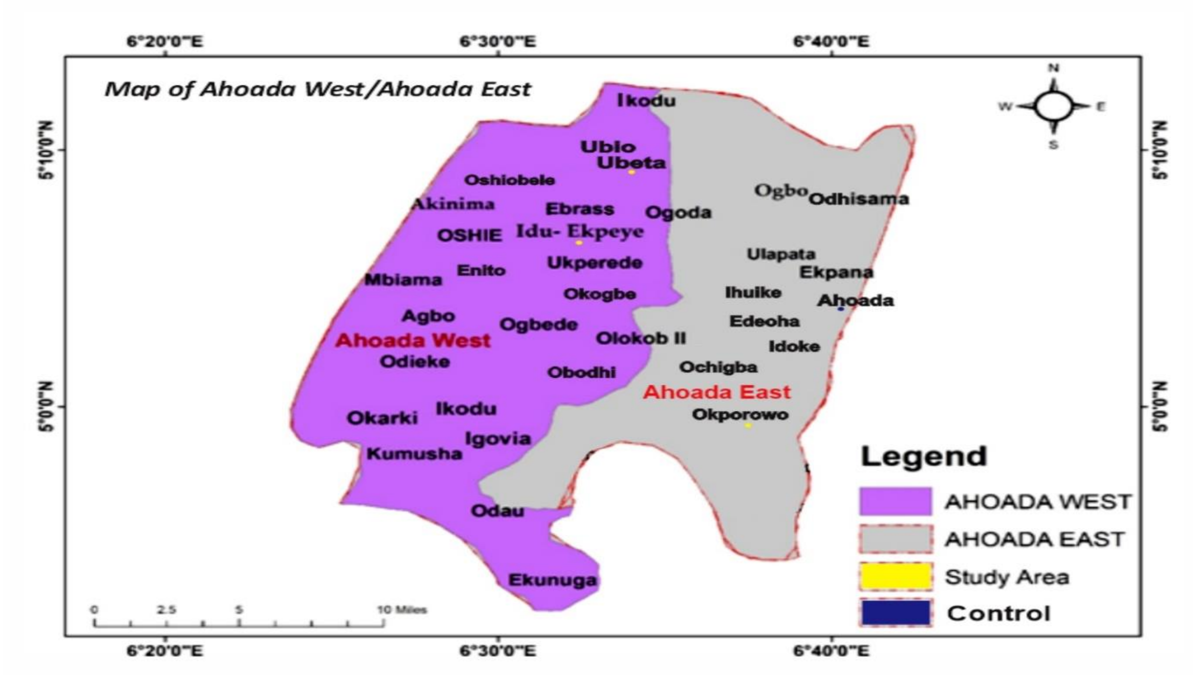

Fig. 1: Map of the study area displaying study sites

Material and Methods

A composite sampling approach was adopted in groundwater sampling from four wells from each of the three sampling stations in the study area in Ahoada-West and Ahoada-East Local Government Areas of Rivers State, Nigeria. At each well where water samples were collected, the sterilized sample bottles were properly washed with distilled water and rinsed with the water to be sampled before sample collection. Sampling was done in duplicates for analyses of physicochemical parameters, heavy metals and total hydrocarbon content. Samples were collected in plastic bottles labelled appropriately stating the location, date and time of sampling. The stabilization of water samples for heavy metal analysis was done by adding a few drops of nitric acid to each of the samples collected before capping the container. Parameters such as pH, electrical conductivity (EC), dissolved oxygen (DO) and temperature were analyzed in situ to avoid alteration of reading due to environmental influence on the water samples. All properly labelled samples were stored in an ice chest and conveyed to the laboratory for analysis. The physicochemical parameters and the presence of some heavy metals in the samples were analyzed using the procedures of the American Public Health Association (APHA, 2012) and WHO guidelines for physical and chemical analysis of water quality parameters in the laboratory (WHO, 2011). The parameters studied were determined as follows:

Hydrogen ion potential (pH) of test water samples

Before the analysis of the pH of the various water samples collected, the hand- held electronic pH meter was calibrated. The probe of the pH meter was inserted into 50 ml of the water samples in a 100 ml capacity beaker and the reading was taken recorded when the reading became stable.

Temperature (°C) of test water samples

The temperature was analyzed in-situ using a mercury-in-glass thermometer. The thermometer was dipped into 50ml of water sample and allowed to stand for 2 minutes to obtain a stable reading and the temperature reading was read and recorded in ºC (degree Celsius).

Electrical conductivity of test water samples

The conductivity probe was calibrated using distilled water and was inserted into 50 mL of the water samples in a 100 ml capacity beaker and the reading was read and recorded in µs/cm.

Total Alkalinity of test water samples

Total alkalinity was determined titrimetrically. 100ml of water sample was pipetted into a 250ml capacity conical flask to which 2 to 3 drops of methyl orange indicator was added which turns the colour of the solution orange. The burette was rinsed with distilled water and filled with the 0.01M sulfuric acid (H_2SO_4) solution up to zero mark. The titrant was then titrated against the water sample until a pinkish colouration appeared and the volume of titrant used was recorded (Jibrin, 2019). Total alkalinity was thereafter calculated using the expression below:

$$\text{Total alkalinity (mg/L as CaCO3)} = \frac{A \times M \times 50 \times 1000}{B\ (mL)} \quad (1)$$

A = titre value; M= Molarity of sulfuric acid (0.01M); 50 = equivalent weight of $CaCO_3$; B = volume of sample used. The 1000 was to convert the result to L.

Total hardness of test water samples

The total hardness of water was determined titrimetrically. 50 ml of water sample was measured into a 250 ml conical flask. 2 – 3 drops of Eriochrome black T (EBT) were added and shaken to thoroughly mix the solution. 0.01M EDTA solution was titrated against 50 ml of the sample until the colour changed from wine red to sky blue (Kugali et al. (2013).

$$\text{Total hardness} = \frac{A \times M \times CaCO_3(\text{eq wt}) \times 1000}{\text{The volume of sample used}} \quad (2)$$

M = molarity of EDTA (0.01M); the equivalent weight of $CaCO_3$=50; A= volume of sample. To convert the value obtained to mg/L, the value obtained was multiplied by 1000.

Total dissolved solids of test water samples

Total dissolved solids were determined gravimetrically. An empty evaporating dish was weighed and recorded as (W1). The water sample was filtered using a filter paper. The filter paper and the residue were transferred into the dish and heated in an oven until a constant mass at 103ºC was achieved and weighed and recorded as W2. The increase in the weight implies that there was the presence of dissolved solids. The total dissolved solids was then calculated as the change in weight =W2 - W1 (Muhammad et al ., 2020).

$$TDS= \frac{W2 - W1 \times 1000}{\text{mL of water sample}} \quad (3)$$

To convert the result to mg/L, the value obtained was multiplied by 1000.

Dissolved oxygen (DO) of test water samples

Dissolved oxygen (DO) in the test water sample was analyzed using a dissolved oxygen meter. 50ml of water sample was diluted to 300ml with distilled water and poured into two labelled 100ml capacity DO bottles and capped. Bottle A test samples were used to determine the DO instantly using a dissolved oxygen meter (MW 600 model). The probe of the dissolved oxygen meter was calibrated with distilled water later inserted into the test water sample and the dissolved oxygen reading was allowed to stable and reading was recorded as D1 being the reading on day 1 of the test. The second test bottle B was properly wrapped with black polythene and kept in a dark place for five days for determination of BOD.

Biochemical Oxygen Demand (BOD_5 mg/l) of test water samples

The second test sample bottle B that was wrapped with black polythene and stored in a dark place for 5 days was unwrapped on the fifth day. The same procedure was followed as explained above for D1 and was recorded as D5. (Chris & Oghenetekevwe, 2023).

$$BOD_5\ (mg/L) = \frac{D_1 - D_5}{V_S/V_d} \quad (4)$$

Where:

D1 = Dissolved oxygen reading on the first day

D5 = Dissolved oxygen reading on the fifth day

Vs/Vd = Dilution factor of sample volume and bottle volume

Chemical Oxygen Demand of test water samples

Chemical oxygen demand (COD) in the test water sample was analyzed titrimetrically. This was done using the $KMnO_4$ method, 10 ml test sample and blank were set up simultaneously for 4 hrs observations. 1ml of 20% sulphuric acid was added to the test sample and 1ml 0.0125m of $KMnO_4$ was added to both samples these were left to stand for 4hrs within this period $KMnO_4$ was added to the test sample because the colour was fading away and the volume of $KMnO_4$ added within this period was recorded. 1ml 10% potassium iodide was added at the end of 4hrs. Two to three drops of starch indicator were added to the solution and were thereafter titrated against 0.025M sodium bisulphate ($NaHSO_4$) solution. COD was calculated using the formula below:

Because more $KMnO_4$ was used, the titre of the sample was divided by the total volume of $KMnO_4$ used up before subtracting from the blank titre volume. All the samples were repeated in triplicates and the values were recorded (Chris & Oghenetekevwe, 2023).

$$COD(mg/l = \frac{\text{Blank titre - test titre} \times 8 \times 1000}{\text{mL of sample used}} \quad (5)$$

Phosphate ion of test water sample

The phosphate ion level in the test water sample was measured spectrophotometrically. 25mL of test water sample was measured into a 250mL conical flak, 2mL of ammonium molybdate tetrahydrate solution $(NH_4)_6Mo_7O_{24}\cdot 4H_2O)$ and 2mL of ascorbic acid ($C_6H_8O_6$) were added. The mixture was swirled for 5 minutes and was subsequently diluted to the mark with distilled water and allowed to stand for an hour for maximum development of colour. The absorbance of the solution was then measured in a UV/visible spectrophotometer at 660nm wavelength. The same procedure was followed for the blank. This procedure was applied to the remaining samples and a calibration curve was prepared for solutions from 0.1ppm – 1.0ppm (Sai'd & Mahmud, 2013).

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Nitrate ion of test water samples

Nitrate ion concentration in the test water sample was measured spectrophotometrically. The calibration curve was constructed using potassium nitrate salt of concentration ranging from 1.0 ppm – 10 ppm. 5mL of test water sample was measured into a 50mL conical flask, to which 14.4M sulfuric acid and dopamine-MBTH indicator mixed solution (dissolution of 0.5g of dopamine and 0.5g MBTH indicator in distilled water) was added. The mixture was vigorously swirled and was allowed to stand for 20 minutes for full-colour development. The mixture was thereafter diluted to the mark with distilled water and the absorbance was measured at 530nm wavelength. The same procedure was repeated in the blank without the test samples (Amoo et al., 2021).

Total hydrocarbon content (THC) of test water samples

Liquid-liquid extraction was used to determine total hydrocarbon content as employed in APHA (2012). 50ml of the test water samples was measured and transferred into a separatory funnel. 20ml of toluene was thereafter added and agitated and allowed to stand for 20 minutes to allow for complete extraction. The absorbance of the extract was then read using a UV/visible spectrophotometer at 420 nm wavelength. A calibration curve was prepared using the known concentration of the crude oil which was then used to convert the result to parts per million (ppm)

Total heterotrophic bacterial count (THBC) of test water samples

Spread plate method was used in determining the total bacteria count in the test water sample. Aliquots from a **serial dilution (dilution factor 10^{-1} – 10^{-9})** of the test water sample were spread on plates. 1.0 mL of test water sample containing an unknown number of bacteria was spread over the surface of an already prepared agar plate, to create a **spread plate.** The spread plates were subsequently incubated for 24 - 48 hours. During the period of incubation, the individual viable bacterial cell rapidly multiplies producing a readily visible colony. The number of colonies was counted which equals the number of viable bacterial cells in the initial volume of the test water sample that was spread on the plate. Plates containing **30-300 colonies per plate were counted.** (Ewelike et al., 2022).

$$\text{CFU/mL} = \text{Mean number of colonies identified} \times DF^{-1} \times \text{plated volume}^{-1} \quad (6)$$

Where DF is the dilution factor.

Heavy metals analysis of test water samples

Heavy metals were analyzed spectrophotometrically using AAS. 20 ml of each test water sample was measured and transferred into a 100 ml conical flask. 18 ml aqua regia was added to each flask (15 ml HCl + $5HNO_3$) and placed on a hot plate in a fume cupboard. The solution was allowed to be heated to dryness and subsequently cooled for 10 minutes. 50ml distilled water was added and filtered into a 100ml laboratory test bottle and was diluted to mark with distilled water. Reading for various metals using an atomic absorption spectrophotometer (AAS - BUCK 200 model) was read recorded.

Determination of water quality index (WQI)

Twelve key parameters were used in the computation of the water quality index (WQI). The weighted arithmetic Index Method as described by Otene and Alfred-Ockiya (2019) was employed for the computation of WQI whereas the quality rating (qn) of water was computed using the expression:

$$q_i = 100\frac{(V_i - V_{id}}{S_i - V_{id}} \quad (7)$$

Where:

q_i = water quality rating of each parameter

V_i = result of each parameter

S_i = standard value of water parameters by local and international regulatory bodies

V_{id} = ideal value of the nth water quality parameter in pure water (i.e id for all other parameters except pH and Dissolved Oxygen (7.0 and 14.6mg/1 respectively).

The overall WQI was therefore computed by adding the quality rating with the unit weight correspondingly as follows:

$$WQI = \frac{\sum q_i * W_i}{\sum W_i} \quad (8)$$

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Where :
W_i = unit weight that was calculated by a value that is the reciprocal of the permissible standard of each parameter considered in the calculation of WQI, $W_i = K/S_i$ (9)

$$K = \frac{1}{\sum 1/S_i} \quad (10)$$

Results

Table 1: Statistical description of groundwater physicochemical properties in Igbu Ogbor -Ahoada and Igbu Ulagbe -Idu-Ekpeye

Parameters	Min	Max	Mean	Standard Deviation	Variance	NSDWQ 2007	WHO (2011)
		Igbu Ogbor	**Ahoada (control)**				
Chloride	6.05	6.40	6.30	0.06	0.004	200-250	250
Nitrate	1.71	5.17	2.87	1.98	3.90	5.0	4.0-5.0
Phosphate	0.301	0.311	0.305	0.26	0.07	0.1	0.5-1.0
DO	4.80	5.16	4.96	0.29	0.08	5	5
BOD	3.74	3.98	3.85	0.13	0.02	<5	10
COD	7.40	7.51	7.35	0.09	0.007	10	10
TH	180.7	192.5	185.8	5.75	33.06	<300	200-300
TA	20.68	24.70	22.71	0.58	0.34	100-200	200-600
THBC	7.32E5	7.81E5	7.54E5	1.5E4	2.2E8	-	500
THC	ND	ND	ND	-	-	0.3	0.05
Cd	0.0012	0.0016	0.0014	0.002	4.4E-6	0.003	0.003
Cr	0.0116	0.0135	0.0125	0.006	0.00004	0.05	0.05
Pb	0.00022	0.00025	0.00023	0.001	1.0E-6	0.01	0.01
Temp	24.7	25.4	25.05	0.39	0.15	20	20
EC	283	331	308	23.8	564.06	<1000	1250
TDS	213.50	260.52	237.55	19.10	364.81	500	500-1000
Turbidity	11.20	11.34	11.35	0.038	0.0014	<10	5
pH	6.05	6.40	6.30	0.16	0.026	6.5-8.5	6.5-8.5
		Igbu	**Ulagbe**	**Idu Ekpeye**			
Chloride	38.50	39.87	39.34	0.11	0.013	200-250	250
Nitrate	0.979	0.984	0.981	0.027	0.0007	5.0	4.0-5.0
Phosphate	0.200	0.210	0.206	0.03	0.0009	0.1	0.5-1.00
DO	3.50	4.52	4.10	0.47	0.23	5	5
BOD	4.62	4.79	4.65	0.075	0.0056	<5	10
COD	10.47	10.73	10.55	0.35	0.123	10	10
TH	62.20	68.45	65.28	2.80	7.84	<300	200-300
TA	27.80	29.75	28.82	0.98	0.95	100-200	200-600
THBC	1.61E5	1.74E5	1.72E5	4.5E4	2.0E9	-	500
THC	22.84	27.17	24.72	2.80	7.84	0.3	0.05
Cd	0.0028	0.0039	0.0035	0.076	0.0058	0.003	0.003
Pb	0.003	0.0035	0.0032	0.0002	4E-8	0.01	0.01
Cr	0.060	0.078	0.077	0.0092	8.4E-5	0.05	0.05
Temp	28.7	30.1	29.3	0.71	0.51	20	20
EC	343	376	364	17.95	322.20	<1000	1250
TDS	265.8	284.7	273.6	9.05	81.90	500	500-1000
Turbidity	20.50	21.60	20.95	0.82	0.67	<10	5
pH	4.78	5.14	5.00	0.15	0.023	6.5-8.5	6.5-8.5

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Table 2: Statistical description of groundwater physicochemical properties in Igbu Odiabidhi – Okporowo and Igbu Okpudhor Ubeta

Parameters	Min	Max	Mean	Standard Deviation	Variance	NSDWQ 2007	WHO (2011)
		Igbu Odiabidhi Okporowo					
Chloride	10.76	24.63	24.13	0.464	0.215	200-250	250
Nitrate	0.316	0.324	0.319	0.03	0.0009	5.0	4.0-5.0
Phosphate	0.204	0.207	0.201	0.023	0.0005	0.1	0.5-1.0
DO	4.53	5.62	4.59	0.78	0.608	5	5
BOD	4.18	4.67	4.38	0.235	0.055	<5	10
COD	10.45	10.46	10.87	0.505	0.255	10	10
TH	48.82	57.87	53.80	4.47	19.98	<300	200-300
TA	18.88	20.29	19.80	0.582	0.339	100-200	200-600
THBC	6.83E5	6.93E5	6.73E5	1.8E4	3.2E8	-	500
THC	23.93	25.99	25.15	1.02	1.044	0.3	0.05
Cd	0.0045	0.0070	0.0058	0.009	8.1E-7	0.003	0.003
Pb	0.0259	0.0289	0.0269	0.018	0.00032	0.01	0.01
Cr	0.0051	0.0095	0.0069	0.0025	6.3E-6	0.05	0.05
Temp	27.2	27.9	27.6	0.336	0.112	20	20
EC	233	348	293	9.62	92.48	<1000	1250
TDS	234.92	287.50	257.45	27.08	733.33	500	500-1000
Turbidity	26.54	27.98	27.40	0.59	0.348	<10	5
pH	5.03	5.48	5.24	0.27	0.072	6.5-8.5	6.5-8.5
		Igbu	**Okpudhor**	**Ubeta**			
Chloride	22.40	23.66	23.08	0.566	0.320	200-300	250
Nitrate	0.820	0.840	0.830	0.003	0.0009	5.0	4.0-5.0
Phosphate	0.205	0.217	0.196	0.02	0.0004	0.1	0.5-1.0
DO	4.06	5.33	4.47	0.635	0.403	5	5
BOD	3.22	4.50	4.05	0.70	0.490	<5	10
COD	8.83	9.37	9.16	0.231	0.053	10	10
TH	59.27	68.80	61.82	5.90	34.81	<300	200-300
TA	17.88	19.45	18.89	0.58	0.339	100-200	200-600
THBC	5.63E5	5.33E5	2.03E5	2E5	4.0E10	-	500
THC	22.65	24.67	23.88	0.54	0.292	0.3	0.05
Cd	0.0058	0.0087	0.0071	0.003	9.0E-6	0.003	0.003
Pb	0.028	0.031	0.029	0.075	0.0056	0.01	0.01
Cr	0.0063	0.0085	0.0076	0.026	0.00068	0.01	0.01
Temp	29.2	29.8	29.5	0.29	0.088	20	20
EC	339	426	380	6.67	44.49	<1000	1250
TDS	273.42	313.63	294.55	19.65	386.12	500	500-1000
Turbidity	28.50	33.38	30.53	1.38	1.904	<10	5
pH	4.17	4.36	4.29	0.09	0.0081	6.5-8.5	6.5-8.5

Table 3: Water quality index and rating

Classification	WQI range	WQI grading
1	0 – 25	Excellent water quality (EWQ)
2	26 – 50	Good water quality (GWQ)
3	51 – 75	Poor water quality (PWQ)
4	76 – 100	Very poor water quality (VPWQ)
5	Above 100	Unsuitable water quality (UWQ)

Table 4: Water quality index (WQI) computation for Igbu Ogbor -Ahoada

Water Parameter	Experimental value	Permissible value (S_i)	Unit weight (W_i)	Quality rating (q_i)	W_iq_i
pH	6.30	6.5 – 8.5	0.00033	146	0.048
EC	308	1000	0.0000028	30.80	0.000086
TA	22.71	100	0.000028	22.71	0.00064
DO	4.96	5	0.00056	100.42	0.056
BOD	3.85	5	0.00056	77	0.043
COD	7.35	10	0.00028	73.5	0.0206
Turb	11.35	5	0.00056	227	0.127
PO_4^{3-}	0.305	0.1	0.028	305	8.54
NO_3^-	2.87	50	0.000056	5.75	0.00032
THC	ND	-	-	-	-
Cd	0.0014	0.003	0.933	46.67	43.54
Cr	0.0125	0.05	0.056	25	1.40
Total			**1.019**	**1059.84**	**53.78**

$$\mathbf{WQI = \frac{\sum q_i * W_i}{\sum W_i}}$$

= 52.91 (PWQ)

Table 5: Water quality index (WQI) computation for Igbu Ulagbe- Idu Ekpeye

Water Parameter	Experimental value	Permissible value (S_i)	Unit weight W_i	Quality rating (q_i)	W_iq_i
pH	5.00	6.5 – 8.85	0.00033	133.33	0.044
EC	364	1000	0.0000028	36.4	0.000102
TA	28.82	100	0.000028	28.82	0.000807
DO	4.10	5	0.00056	109.38	0.061
BOD	4.65	5	0.00056	93.00	0.0521
COD	10.55	10	0.00028	105.50	0.0295
PO43-	0.206	0.1	0.028	206	5.768
NO3-	0.981	50	0.000056	1.962	0.00011
Turb	20.95	5	0.00056	419	0.235
Cd	0.0035	0.003	0.933	116.67	108.85
Cr	0.077	0.05	0.056	154	8.624
THC	24.72	0.3	0.0093	8240	76.632
Total			**1.0287**	**9644.062**	**200.30**

$$\mathbf{WQI = \frac{\sum q_i * W_i}{\sum W_i}}$$

= 194.71(UWQ)

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Table 6: Water Quality Index (WQI) computation for Igbu Odiabiadhi- Okporowo

Water Parameter	Experimental value	Permissible value (S_i)	Unit weight W_i	Quality rating (q_i)	W_iq_i
pH	5.00	6.5 – 8.85	0.00033	117.33	0.0387
EC	364	1000	0.0000028	100.30	0.000281
TA	28.82	100	0.000028	19.80	0.00055
DO	4.10	5	0.00056	104.27	0.0584
BOD	4.65	5	0.00056	87.60	0.0491
COD	10.55	10	0.00028	108.70	0.0304
PO43-	0.206	0.1	0.028	201	5.628
NO3-	0.981	50	0.000056	0.638	0.0000357
Turb	20.95	5	0.00056	548	0.307
Cd	0.0035	0.003	0.933	193.33	180.38
Cr	0.077	0.05	0.056	13.80	0.778
THC	24.72	0.3	0.0093	8383.33	77.965
Total			**1.0287**	**9878.10**	**265.23**

$$\mathbf{WQI = \frac{\sum q_i * W_i}{\sum W_i}}$$

= 258.30 (UWQ)

Table 7: Water quality index (WQI) computation for Igbo Okpudhor- Ubeta

Water Parameter	Experimental value	Permissible value (S_i)	Unit weight W_i	Quality rating (q_i)	W_iq_i
pH	5.00	6.5 – 8.85	0.00033	180.67	0.0596
EC	364	1000	0.0000028	38	0.000106
TA	28.82	100	0.000028	18.89	0.000529
DO	4.10	5	0.00056	105.52	0.0591
BOD	4.65	5	0.00056	81	0.0454
COD	10.55	10	0.00028	91.6	0.0256
PO43-	0.206	0.1	0.028	196	5.488
NO3-	0.981	50	0.000056	1.66	0.0000930
Turb	20.95	5	0.00056	610.6	0.342
Cd	0.0035	0.003	0.933	236.67	220.81
Cr	0.077	0.05	0.056	15.2	0.851
THC	24.72	0.3	0.0093	7960.00	74.03
Total			**1.0287**	**9535.81**	**301.71**

$$\mathbf{WQI = \frac{\sum q_i * W_i}{\sum W_i}}$$

= 293.30(UWQ)

Discussion

Physicochemical characteristics of water samples

The mean values of the physicochemical properties of the samples are displayed in Tables 1 and 2 above. The mean value of the pH levels of the samples were 5.00± 0.15, 5.24± 0.27 and 4.36± 0.09 at Igbu Ulagbe Idu Ekpeye, Igbu Odiabidhi and Igbu Okpudhor- Ubeta respectively. The control station (Igbu Ogbor Ahoada) had a pH mean value of 6.30± 0.16. Following WHO (2011) and NSDWQ (2007) standards for pH concentration in groundwater (pH = 6.5 - 8.5), the average pH values observed in this study indicated that groundwater in the area is not safe for human consumption. The average result showed that samples across the study area and control station were slightly acidic. The acidic condition is typical of groundwater from the Niger Delta which can be attributed to high precipitation that resulted in loss of basic cations in the soil due to leaching. This result is similar to the findings of Nwankwoala & Amachree (2020) but disagrees with the study conducted by Ekpete (2002) who found the water samples to be more alkaline compared to the findings of this research. The conductivity of crude oil-impacted soil was discovered to have increased in comparison to the result of the control water sample. The study area recorded a mean electrical conductivity of 345.67 µS/cm whereas the control water sample recorded a mean electrical conductivity of

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308μS/cm. The increase in the electrical conductivity of the hydrocarbons impacted water may have been influenced by the corresponding increase in the presence of charged cations and anions in the water (Adeyemo & Aliu, 2021). Turbidity which is the measure of how cloudy water is influenced by the presence of many particles is one of the monitoring parameters in water analysis. The turbidity level of the samples had mean values of 20.95± 0.82, 27.40± 0.59 and 30.53± 1.38) at Igbu Ulagbe - Idu Ekpeye, Igbu Odiabidhi- Okporowo and Igbu Okpudhor-Ubeta respectively. The control station (Igbu Ogbor-Ahoada) turbidity had a mean value of 11.35± 0.038). These values were above the <10NTU & 5.0NTU WHO and NSDWQ permissible ranges of turbidity in normal drinking water. If the level of turbidity of water is high, it makes the water facially undesirable and can even induce gastrointestinal illnesses (Muhammed et al., 2020). TDS ranged from 213.50 – 260.52 mg/L for the control site whereas the average TDS in groundwater from the study area were 273.60 ± 9.05 mg/L, 257.45± 27.08 mg/L, and 294.55± 0.16 mg/L for Igbu Ulagbe Idu Ekpeye, Igbu Odiabidhi-Okporowo and Igbo Okpudhor- Ubeta respectively. The TDS of all the study stations had TDS values within the permissible limit of 500 - 1000mg/L set by WHO (2011). The total alkalinity of the water samples recorded in the study area was observed to be below the 200 maximum limits set by NSDQW (2007) and WHO (2011) making the water not safe for human consumption.

The total alkalinity of the study sites ranged from 17.88 and 29.75 mg/L which agrees with the position of the findings of the study (Jibrin, 2019). According to WHO, if the alkalinity of water is found to be low, it is generally confirmed to be a corrosive irritative to the eyes. Alkalinity less than 75mg/L has the potential to dissolve toxic metals thus making the water to be corrosive because of the dissolved toxic metals (WHO, 2010). The total alkalinity of the samples from all the locations had a level of alkalinity below 75mg/L which may have a dangerous effect on the water and humans who depended on the water for drinking. The concentration of total hardness of the samples obtained from Igbu Ulagbe Idu Ekpeye, Igbu Odiabidhi – Okporowo and Igbu Okpudhor- Ubeta ranged from 48.82 mg/L to 68.80mg/L respectively. The concentration of total hardness of all the water samples did not meet the specification set by WHO (2011) thus making it unsafe for consumption. The findings disagreed with that of Kugali et al. (2013) who observed that the total hardness of groundwater in Sudan was above the permissible limit. Water may contain significant levels of hardness but its consumption may not constitute any health effect instead it will be undesirable for consumption because of the strong dry taste (WHO,2011). Minerals and metals found in water may be associated to the presence of metals coming from the parent rocks and anthropogenic activities in the area because the hardness of water is mostly linked to minerals leached from rocks and soil. Changes in the temperature of any environment can alter life processes either positively or negatively. It is a major factor that influences the solubility of gases and salts in water (Hart & Zabbey, 2005). This research found that the groundwater temperature fluctuated and the range was between 28.7°C and 30.1°C at Igbu Ulagbe – Idu Ekpeye, 78.2°C and 27.9°C at Igbu Odiabidhi – Okporowo and 29.2°C and 29.8°C at Igbu Okpudhor- Ubeta. The values were not significantly different for the study area but significantly different with the control station with values ranging from 24.7ºC to 25.4ºC. The values exceeded the WHO (2010) and NSDWQ limits of 20°C for drinking water.

A similar range of results was also reported by Hart and Zabbey (2005). Ogbonna (2014) recorded a similar result and posited the difference in temperatures in the study area was a result of enormous activities going on in the locality as well as its morphometric characteristics. An increase in temperatures has been reported by Ayoade and Olusegun (2012) to be caused by a huge volume of suspended particles from anthropogenic activities. Dissolved oxygen (DO) in the study area had mean values of 4.10±0.47 mg/l, 4.59 ±0.78mg/l and 4.47±0.64mg/ for Igbu Ulagbe - Idu Ekpeye, Igbu Odiabidhi - Okporowo and Igbu Okpudhor - Ubeta respectively which is below WHO standard of 6.0 - 10.0 mg/l, while that of the control area (Igbu Ogbor -Ahoada) had an average value of 4.96±0.29 mg/l which is less than 6mg/l, the lower limit value recommended by WHO(2011) and NSDWQ(2007). The low levels of DO in the study area indicated that the groundwater is contaminated with organic matter whose decomposition is gradually eating up the available oxygen in the water. The biochemical oxygen demand (BOD) in the study area had average values of 9.65±9.08 mg/l, 9.38±0.24mg/l and 9.05±0.70mg/l for Igbu Ulagbe - Ekpeye, Igbu Odiabidhi - Okporowo and Igbu Okpudhor -Ubeta respectively which exceeded the recommended NSDWQ(2007) and WHO (2011) permissible limit of 4.0 mg/l, whereas that of the control area ranged from 3.74 mg/l to 3.98 mg/l with a mean value of 3.85±0.13 mg/l which is less than the recommended WHO (2011) and NSDWQ (2007) standard. This implied that the groundwater of the study area is polluted with organic matter and heterotrophic bacteria in the media and therefore not good for consumption since the BOD exceeded 4mg/l recommended by both local and international regulatory guidelines.

The total hydrocarbon content (THC) of test water samples from the study locations had mean values of 24.72±2.80mg/l, 25.15±1.02mg/l and 23.88±0.54 mg/l for Igbu Ulagbe- Idu Ekpeye, Igbu Odiabidhi -Okporowo and Igbu Okpudhor - Ubeta respectively. This concentration observed is above the WHO (2011) and NSDWQ(2007) standards of 0.05 and 0.3 mg/l, respectively. The level of THC in the control site was below the detection limit. This is an indication of hydrocarbon pollution of groundwater in the study area and thus amounted to the high BOD level and low DO detected in the study area. Contaminated groundwater with crude oil is linked to low levels of DO, elevated BOD, high water temperature, and increased amount of organic impurities thus resulting in acidic groundwater (Ojiegbe, 2006; Nwachukwu & Osuagwu, 2013). A decrease in dissolved oxygen levels may indicate a polluted environment where bacteria thrive and use up the oxygen (Liu et al., 2021). This agrees with Akankali et al. (2022) who stated that the decrease in dissolved oxygen levels may be due to the microorganisms using oxygen to decompose large plants. Boyd et al. (2019) also stated that a large number of aquatic plants in the water also reduces dissolved oxygen levels. In addition, the presence of decaying organic materials can also cause low oxygen levels, resulting in the emission of toxic gases such as hydrogen sulphide and methane (Hamoda & Alshalahi, 2021). The total heterotrophic bacterial counts of the well water samples varied from 161000 – 694000 CFU/mL while the control station result ranged from 7.32×10^5 to 7.81×10^5 CFU/ml. The bacteria count across the sites exceeded the World Health Organization permissive limit of <500 CFU/mL (WHO, 2008; Ewelike et al., 2022) indicating the well water to be unsafe for drinking. For the anions, the average concentration of PO_4^{3-}, NO_3^-, Cl are 0.206± 0.03 mg/l, 0.201 ± 0.02 mg/l and 0.196 ± 0.02 mg/l for phosphate, 0.981± 0.03mg/L, 0.319± 0.03 mg/L and 0.830± 0.003mg/L for nitrate and 39.34± 0.11mg/L, 24.13+0.46mg/l and 23.08 ± 0.56 mg/L for chloride at the three study stations respective. These values are not within WHO (2011) and NSDWQ (2007) permissible limits for drinking water (PO_4^{3-} = 0.1mg/l; Cl^- =250 mg/l). The nitrate level in the water samples is within the regulatory limit of 5.0 mg/L in all stations. Hence, the water is not considered safe for consumption following the level of phosphate but may be safe for consumption based on the observed level of nitrate. The result obtained is similar to the findings of Nnaji and Egwu, 2020 but at variance with the values reported by Sai'd and Mahmud (2013).

The analysis of heavy metals showed that Cd varied from 0.0028 mg/l to 0.0039 mg/l with a mean value of 0.0035 ± 0.076 mg/L in Igbu Ulagbe-Idu Ekpeye, 0.0045 - 0.007 mg/L with a mean value of 0.0058 ± 0.01 mg/L for Igbu Odiabidhi - Okporowo and 0.0055 - 0.0087mg/l with a mean value of 0.0071+0.003mg/l for Igbu Okpudhor -Ubeta. The concentration of cadmium exceeded WHO (2011) and NSDWQ (2007) standards of 0.003 mg/L in the study area but was lower than the value obtained by Edori et al. (2019). The results indicated that cadmium level in the test water samples from the study area is considerably high suggesting that the water is not safe for drinking. Chromium level had mean values of 0.077 ± 0.009mg/L in Igbu Ulagbe-Idu Ekpeye, 0.0069 ± 0.0025mg/L in Igbu Odiabidhi - Okporowo and 0.0076±0.026mg/l in Igbu Okpudhor -Ubeta. The overall result of chromium in the area is below WHO (2011) standard for Cr (0.05mg/l) in drinking water except in Igbu Ulagbe-Idu Ekpeye where the level of Cr exceeded the permissible limit. The concentration of Pb registered mean values of 0.032±0.0002mg/l, 0.029±0.018mg/l and 0.029±0.075mg/l at Igbu Ulagbe -Idu Ekpeye, Igbu Odiabidhi -Okporowo and Igbu Okpudhor -Ubeta respectively. The concentration of Pb is below the value obtained by Ekpete et al. (2019), though despite the low value observed, it exceeded the stipulated guidelines of WHO (2011) and NSDWQ (2007) regulatory limit of 0.01mg/l except for the Igbu Ulagbe- Idu Ekpeye that is below the permissible limit. This result renders the well water unsuitable for drinking because of the toxic effect of pb on human health. The result of the heavy metal analysis of this study aligns with the findings of Nwankwoala and Amachree, (2020) and Yusuf et al. (2018).

Water Quality Index (WQI)

The water quality index is a model applied to recast arrays of data from water parameters to a unit value that explains the total water quality of a geographical area under study of different physicochemical parameters that transformed compound water quality dataset into an explainable and interpretable information at the public disposal (Rumman et al., 2012). The various water quality indices of the control and study stations (52.91, 194.71, 258.30 and 293.30) computed indicated poor water quality to unsuitable water quality for humans. The WQI computation showed that the well water of Ahoada East and Ahoada West LGAs lies between poor water quality to unsuitable water quality for human consumption. This is an indication that the well water in the study area is heavily impacted by crude oil refining activities and natural disasters like flooding and thereby unsafe for drinking. The result of this study aligns with the findings of Nwankwoala and Amachree (2020) but disagrees with the position of Otene and Alfred-Ockiya (2019).

Conclusion

Conclusively, the quality of water in the study area was assessed for its suitability for human consumption as well as for identifying possible contaminants negatively impacting the water quality of the area. The study revealed that the pH, total alkalinity (TA), total hardness (TH), temperature, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), total heterotrophic bacteria count (THBC), phosphate (PO_4^{3-}) and total hydrocarbon content (THC) of the test water samples analyzed had concentrations that exceeded both local and international permissible limit except for electrical conductivity (EC), chloride (Cl^-), total dissolved solid (TDS) and nitrate (NO_3^- that were within the permissible limit. Therefore, the groundwater in the study area is unsuitable for consumption following the alterations in the concentration of the aforementioned parameters that were impacted by the level of crude oil in the test water samples owing to the operations of illegal refineries in Ahoada-East and Ahoada-West local Government Areas and other human and natural influence. The WQI of the studied sites and control were found to be 194.71, 258.30, 293.30 and 52.91 respectively thus implying that the well water in the various stations was of unsuitable water quality- UWQ (category 5 for the study area and category 3 for control station-PWQ) thus suggesting that the well water is unsafe for drinking. It is therefore recommended that authorities that are saddled with the responsibilities of monitoring and controlling government critical infrastructure like pipelines should intensify their efforts towards reducing the operations of the illicit act to the barest minimum level while working out modalities of remediating the polluted ecosystem of the affected communities to mitigate the persistent impact on the environment.

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