Hazard Evaluation Index and Water Quality Index Assessment of Groundwater around Ikwe Ona Refinery and Surrounding Environment

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***Abstract*—This study was aimed at assessing the groundwater Water Quality Index (WQI) and Hazard Evaluation Index (HEI) around Ikwe Ona Refinery and its environs. Fourty-five water samples were collected from 15 water boreholes following strict sampling procedures and analyzed in the laboratory using the Atomic absorption spectrophotometer (AAS). Human Health risk was determined by calculating the average daily dosage (ADD), hazard quotient (HQ), and hazard index (HI) respectively. The HEI of toxic metals and the WQI were calculated. Arsenic had the least ADD value (0.114 µg/l) followed by aluminum (1.429 µg/l). However, iron (Fe) recorded the highest ADD value (6.80 µg/l) followed by copper (Cu) (5.114 µg/l) then lead (Pb)(5086 µg/l) respectively. The HQ for the selected toxic metals in the groundwater samples ranged from 9.71E-03 for Total Iron (Fe) to 5.37E+00 Cadmium (Cd). The HI was calculated to be 9.38E+00 while the mean values of HEI were calculated to be 55.77. The results of WQI from the different sampling stations varied from 38.53 (station 6) to 62.14 (station 13), with 14 out of 15 sampling points having a good water quality. The WQI result is in contrast to the HEI results indicating high contamination by toxic metals. This means that in terms of WQI, the 15 boreholes sampled had good water quality concerning WHO standards for agricultural and other household uses except for drinking and other critical industrial uses, except it is treated for the high HEI contamination by toxic metals such as Cadmium, Lead, Manganese, and Aluminum.**

***Keywords*—WQI, HEI, contamination, groundwater, toxic metals, Ikwe Ona**

I. INTRODUCTION

Groundwater and surface water in Nigeria has deteriorated in quality due to anthropogenic activities related to the release/discharge of biological and chemical contaminants among others ([1]-[8]) This increasing deplorable state of water quality is alarming, and this development portends serious environmental and health consequences to the host communities of industries 032+operating in Nigeria. The Niger Delta, for instance, has been host to oil and gas exploration, exploitation, refining, processing, and transportation since the 1950s. The activities of these oil and gas industries are said to be a major cause of pollution of both surface water and groundwater in the affected locations ([9]-[14]). Pollution of the environment (air, water, and land) by the oil and gas companies is usually through gas flaring, oil leaks, oil spills, wastewater disposal, oil and gas refining, etc. [11].

Heavy metals such as Cadmium, Arsenic, lead, mercury, etc. are minor constituents of hydrocarbons and are often part of the contaminants that reach the surface and groundwater when hydrocarbon products are released/discharged to the environment. Environmental contamination by metals can cause interference with plant metabolism and subsequently the food chain [15]. Industrial water supply and consumer waste, acidic rain, are some of the ways by which metals gain entry into environmental media such as streams, lakes, rivers, and groundwater ([16]-[18]). Heavy metal pollution have been found in regions that had been heavily involved in mining and mineral processing. Toxicity is dependent on the concentration of toxic metal in the body, and this can be the case even in minute amounts [19]. This is because

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heavy metals are naturally occurring elements in the Earth's crust, and they do not decompose very fast. Trace elements" such as selenium and zinc play an important role in the human body's metabolism. Water with high concentrations of iron and manganese has been shown to affect people's physical appearance as well as cognitive function and muscle tone [20], [21].

Studies have also shown that heavy metals are harmful to marine planktons and humans ([22]) resulting in tumors in the kidneys, impairment of proper functions of the kidneys, joints, reproductive organs, and nervous system, and are also found to be carcinogenic in humans ([15], [22],[23]). Mercury, lead, and arsenic are some of the most harmful pollutants among heavy metals [23]. Abdominal pain, nausea, vomiting, diarrhea, and muscle cramps are all possible side effects of acute exposure. Peripheral nerves in the body can be damaged over time by repeated exposures. Natural Cadmium is a highly toxic heavy metal. As a toxic industrial and environmental pollutant, is carcinogenic for humans. People who have been exposed to cadmium fumes for a short period may experience symptoms like fever, muscle pain, and issues with the respiratory tract and the kidneys. A micronutrient that plants, animals, and humans all require is the source of Cadmium's toxicity [22]. Wilson disease can result from cell damage caused by excessive copper exposure in humans ([20], [15]) Despite their importance to human survival, people who consume excessive amounts of Zn and Cu may not develop cancer.

Water-borne diseases such as typhoid, dysentery, cholera, and diarrhea are also on the rise in the Niger Delta, and according to the World Health Organization, diarrhea has killed an estimated 1.5 to 1.8 million children younger than the age of five every year ([24], [25]).

Ikwe-Ona which is the study area in the Niger Delta region has a lot of shallow aquifers that are prone to contamination but serves as water supply to inhabitants. The commercialization of safe-to-drink water has left this region with a scarcity problem and the presence of untreated borehole water which is the primary source of domestic water supply ([26],[25]). Information on the quality of groundwateter sources in Ikwe-Ona communities is seriously lacking hence the need for this study which is aimed at assessing the groundwater in the study area using the Water Quality Index and Hazard Evaluation Index. The water quality index (WQI) has been used as a means of deriving a single value from a collection of test results ([27]). The goal of the WQI is to make it simple to display a numerical expression that demonstrates thre water quality level ([28]-[32]). The health evaluation index assesses the health implications of parameters measured in an area.

II. MATERIALS AND METHODS

A. *Study area*

Ikwe Onna, in Ibeno Local Government Area, lies between latitude 4°30′00″-4°39′00″N and longitude 7°50′00″-8°02′00″E. Ibeno is surrounded by the Atlantic Ocean southward, Ona, Esit Eket, Eket Northward, and Obolo Local Government Area, Westward. Ibeno municipality covers more than 1,200 square kilometers of coastline in Akwa Ibom State. It stretches from Okposo in the east to the village of Atabrikang in the west, with the Atlantic Ocean in the south. Fishing is the main occupation of the inhabitants. It is a fishing and farming town because of its proximity to the Atlantic Ocean. Exxon Mobil and Total are among the companies that operate offshore drilling facilities near or in these communities. It is believed that the oil spill from the facilities of these companies responsible for the contamination of groundwate in the adjoining communities of the study area. The study area is in Nigeria's Niger Delta, which is one of the most industrialized regions in the Gulf of Guinea. Oil and gas activity in the region with its attendant pollution through gas flares, oil spills, and waste disposal are known to negatively affect local groundwater quality.

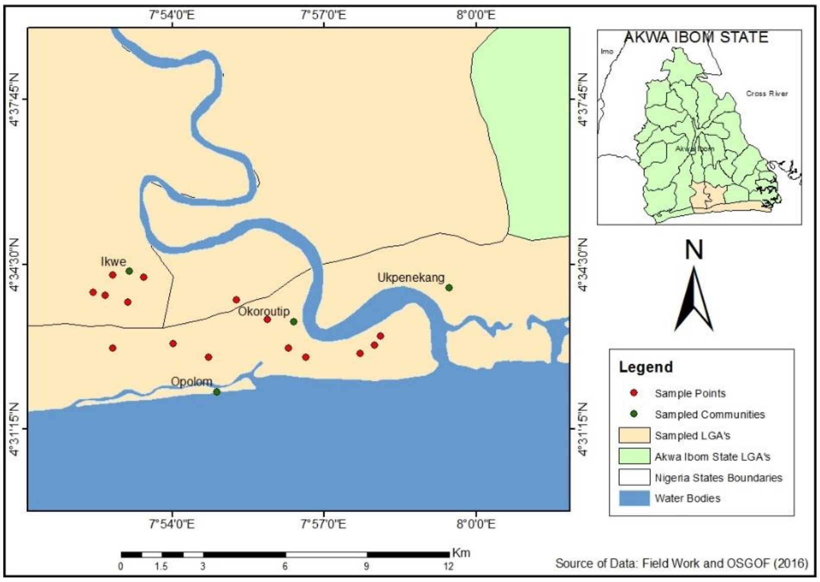

Fig. 1. Location of the study area and sampling map.

B. Sample Collection and Preservation

Sampling locations were decided as way points in Geographic Position System (GPS) and later plotted in a sampling map as represented in Fig. 1. A total of 15 boreholes (sampling points) were identified for sampling groundwater from three different communities in the local government under study using 1.5ltrs plastic and glass bottles for the water collection. The plastics and glasses bottles utilized were pre-treated by washing with dilute HCl (0.05m) and later rinsed with distilled water. The bottles were then air-dried in a dust-free environment At the sampling point, water sampling bottles were all rinsed twice using distilled water and then water from the boreholes. Triplicate (3samples each) water samples were collected from the 15 identified existing boreholes within the study area overoveronths from the wet season to the dry season (October to December 2020). All 45 water samples were labeled accordingly with date, time, location and name of collector respectively. The bottles containing water were then cocked tightly and transported from the site to Giolee Global Services Limited, Port Harcourt, for sample preparation and laboratory analysis.

C. Sample Treatment, Digestion, and Laboratory Analysis of Heavy Metals

Appropriate scaling of the required quantities of water needed for the test was transferred into laboratory test bottles and taken for laboratory analysis.

Water samples were acidified using HNO3 to pH < 2 and were well shaken to homogenize after which duplicate samples were prepared from it using the following standard procedures [33]. A 50 ± 1 mL sub-sample was then taken and dispensed into a 250ml beaker (digestion vessel) well fitted with a watch glass, 1.0 ± 0.1Ml of concentrated. HNO3 and 0.50 ± 0.05 mL concentrated HCl was added to each sample.

The solution was covered using the watch glass and digested for 2.0 – 2.5 hours at 95 ± 5°C in the fume hood. Samples were removed from the heat source and left to cool for at least 30 minutes to reduce any potentially harmful fumes from the sample.

The watch glass was then removed while samples were reconstituted back to 50 ± 1 mL with distilled water and shaken thoroughly to mix.

And the solution was transferred into a 100ml plastic can for Atomic absorption spectrophotometer (AAS) for metal concentration measurement. Atomic absorption spectrophotometric methodology was then used to determine the concentration of toxic metals in the samplegroundwaterer.

1) Human health risk assessment of heavy METALS

The number of metals in food crops, water, and soil can be determined using the average daily dose of metals. The estimated daily metal intake is the name given to this figure. For our list, we also took into consideration the average daily dose (ADD), hazard quotient (HQ), Hazard Index (HI), and Cancer Risk (Cr).

Average Daily Dose (ADD)

$$ADD = \frac{(CW \times IR \times EF \times ED)}{(BW \times AT)} \qquad (1)$$

where,

ADD = Average daily dose (μg/kg/day),
Cw = Average concentration of metals in water, (μg/L),
IR = Ingestion rate per day (l/day),
EF = Exhibition frequency per year (days/year),
ED = Exhibition duration in years,
BW = Body weight (kg) and
AT = Average time (days).

The exhibition frequency of 365 days and exhibition duration of 30 years for adults were used for this study.

This study used an average of 365 days to determine the non-carcinogenic risk and 70 x 365 days to determine the carcinogenic risk. 70 kg was used as the average value for Body weight and as reported in Akudo et al. ([34]), 2L/day of water consumption required for an adult was used

Hazard Quotient *(HQ)*

However, there may be health effects, but they are not always carcinogenic, except when the HQ value is more than 1

$$HQ = \frac{ADD}{RfD} \dots\dots\dots\dots\dots\dots\dots \qquad (2)$$

where RfD = Reference dose

Using risk-based counseling, the renal glomerular dysfunction of humans exposed to metals in drinking water i.e Oral Reference Dose (RfD) value can be calculated (Oller et al, 1997). Metals found in potable water samples can be assessed using this method.

Hazard Index *(HI)*

The hazard index was calculated by adding the values of different Hazard Quotients (HQ) of metals detected. The maximum acceptable value for Hazard Index is One (1) above which there is a potential health risk associated with exposure to such toxic metals.

The higher the Hazard Index value, the higher the risks associated with the exposures.

$$HI = \sum HQ \qquad (3)$$

where;

HQ= Hazard Quotient of each metal
HI=Hazard Index for all detected metals in all nth heavy metals

TABLE I. ORAL REFERENCE DOSE OF HEAVY METALS [35]

TOXIC METALS	**RfD**	
Arsenic As (μg/l)	0.3	WHO/NIS
Lead Pb (μg/l)	1.4	WHO/NIS
Aluminum Al (μg/l)	1000	WHO/NIS
Zinc Zn (μg/l)	300	WHO/NIS
Total Iron Fe(μg/l)	700	WHO/NIS
Copper Cu (μg/l)	40	WHO/NIS
Manganese Mn (mg/l)	140	WHO/NIS
Cadmium Cd (μg/l)	0.5	WHO/NIS

2) The heavy metal evaluation index

The heavy metal evaluation index is used to evaluate the overall quality of groundwater with heavy metals [36].

The HEI was calculated by using the relationship below:

$$HEI = \sum_{i=1}^{n} HC/HMAC \quad (4)$$

where:

HC represents the mean values of the heavy metals (*ith* Parameter),

HMAC is the maximum admissible concentration of the ***ith*** Parameter.

B. Water Quality Index

It was determined that seventeen water quality parameters could be used in this study to determine the quality of the water in the area. The World Health Organization ([37]) and Nigerian standard organizations for drinking [38] water quality were used to evaluate the WQI. The WQI was calculated utilizing the weighted arithmetic index method.

This expression was used by Oller et al. [35] to calculate the quality rating (Qn)

$$= 100\frac{[\mathrm{Vn} - \mathrm{Vio}]}{[Sn - Vio]} \quad (5)$$

where,

qn = Quality rating for the n^{th} Water quality parameter

Vn = Estimated value of the n^{th} parameter at a given water sampling station

Sn = Standard permissible value of the n^{th} parameter

Vio = Ideal value of n^{th} parameter in ground (7.0 and 14.6 mg/l respectively)

Weight for each unit was calculated using a value that was the opposite of Sn, which is the recommended standard value for that particular metric [39].

$$\mathrm{Wn} = \frac{K}{Sn} \quad (6)$$

where *Wn*= unit weight for nth water quality parameter

Sn= standard permissible value for nth parameter

k = proportionality constant.

The overall WQI is calculated by the following [40] equation.

$$\mathrm{WQI} = \sum qnWn/\sum Wn \quad (7)$$

TABLE II. WATER QUALITY INDEX RATING CHART

Water quality index level	Water quality Status
0-25	Excellent water quality
25-50	Good water quality
51-75	Poor water quality
76-100	Very poor water quality
>100	Unsuitable for drinking

III. PRESENTATION AND DISCUSSION OF RESULTS

The results of the toxic metals analysis (As, Pb, Al, Zn, Fe, Cu, Mn, and Cd) are shown in Table 3. From the results, the range for AS(0.00-0.01mg/l), Pb(0.02-0.65mg/l), Al(0.01-0.13), Zn(0.04-0.28mg/l), Fe(0.03-0.50mg/l, Cu(0.01-0.43mg/l), Mn(0.01-0.38mg/l), and Cd(0.01-0.17mg/l) shows that most of the values fall below the recommended standards except for Lead, Cadmium and Arsenic. The maximum value for Pband Cadmium are higher than the recommended value by Nigerian Standsrd for drinking water quality [38] and, therefore portends a high risk for users of the water. The maximum value for Arsenic is on the high threshold and also makes the water potential risk cconsumption. The human health risk (which includes ADD, HQ, and HEI), and the water quality index were computed using the toxic metal concentrations.

TABLE III. RANGE OF TOXIC METALS OF IKWE-ONNA GROUNDWATER

Paramet er (mg/l)	Minimu m	Maximu m	S.E	P-valu e	NSDWQ (2007) maximu m permitte d limit
Arsenic (As)	<0.00	0.01	0.0004 5	0.83 2	0.01
Lead (Pb)	0.02	0.65	0.0219	0.01 6	0.05
Aluminu m (Al)	0.01	0.13	0.0036	0.90 0	0.2
Zinc (Zn)	0.04	0.28	0.0103	0.00 0	3.00
Iron (Fe)	0.03	0.50	0.0183	0.03 8	0.1
Copper (Cu)	0.01	0.43	0.0183	0.00 0	1.00
Mangane se (Mn)	0.01	0.38	0.0136	0.25 9	0.2
Cadmium (Cd)	0.01	0.17	0.0075	0.84 8	0.003

A. Human Health Risk Assessment of heavy metals

1) The average daily dosage of toxic metals

The computed ADD form the results of the toxic metal concerntrations for the 15 sampling points are As= 0.114 µg/l, Pb=5.06 µg/l, Al=1.429 µg/l, Zn=4.429 µg/l, Fe=6.800 µg/l, Cu=5.114 µg/l, Mn=4.943 µg/l, and Cd=2.686 µg/l (Table 4) respectively . The average daily dosage of the toxic metals as calculated was in the following sequence Fe>Cu>Pb>Mn>Cd>Al>As.The average daily dosage of toxic metals from the study area indicates that Arsenic with ADD value of 0.114 µg/l, rcorded the least ADD followed by aluminum with ADD value of 1.429 µg/l. however, iron (Fe) with ADD value of 6.80 µg/l was the highest followed by copper (Cu) at 5.114 µg/l, then lead (Pb) at 5086 µg/l. The average daily dosage of lead from all the sampled locations reveals that this result was higher than the range of 1.823-3.426 µg/l reported by Belkhiri et al. ([41])and lower than 1.53E-02 which was reported by Adeyemi & Ojekunle, ([19]).

The variations in these studies could be a result of the difference in the methodologies for determining the average daily dose of exposure to Pb through ingestion. The researchers preferred to cluster their sampling area results, a situation we suggest must have been responsible for the slight difference in the results of the current study. The average daily dosage of aluminum from all the sampled locations was Al=1.429 µg/l. This result fell within the range of 1.163-1,949 µg/l as reported by Belkhiri et al. (2018). The average daily dosage of zinc from all the sampled locations was Zn=4.429 µg/l, this result falls within the range of 4.180- 5.029 µg/l as reported by Belkhiri et al. (2018). The average daily dosage of Iron from all the sampled location was Fe=6.800 µg/l, which is also within the range of 5.154-9.554 µg/l reported by Belkhiri et al. ([41]). However, their result recorded very high limit of the range in the cluster 2 and cluster 1 which might be due to the slight higher difference between the result of the current study and the reports of Belkhiri et al. ([41]). The average daily dosage of Copper from all the sampled stations were Cu=5.114 µg/l. This results are slightly in line with the results of Belkiri et al., ([41]) which reported a range of 2.294-6.380 µg/l. The average daily dosage of manganese from all the sampled location was Mn=4.943 µg/l, which was higher than 3.37E-03 reported by Adeyemi & Ojekunle, ([19]). These values are also higher than the range of daily dosage of manganese of 2.47E-3 – 2.36E-2 as reported by Nkpaa et al., ([42]). The average daily dosage of cadmium from all the sampled location was 2.68µg/l. This result is in line with that reported by Belkhiri et al. ([41]), who reported a range of 1.886-2.389 µg/l of Cadmium in groundwater. This result is higher than the report of Adeyemi & Ojekunle, (19), who reported an average daily dosage of cadmium in ground water as 2.01E-04. Also, the result were greater than the result of 5.48E-4 – 8.22E-4, as reported by Nkpaa et al. ([42])

TABLE IV. HUMAN HEALTH RISK OF TOXIC METALS

Toxic Metals	**Rfd**	**ADD**	**HQ**
Arsenic As (µg/l)	0.3	0.114	3.80E-01
Lead Pb (µg/l)	1.4	5.086	3.63E+00
Aluminum Al (µg/l)	1000	1.429	1.43E-03
Zinc Zn (µg/l)	300	4.429	1.48E-02
Total Iron Fe(µg/l)	700	6.8	9.71E-03
Copper Cu (µg/l)	40	5.114	1.28E-01
Manganese Mn (µg/l)	140	4.943	3.53E-02
Cadmium Cd (µg/l)	0.5	2.686	5.37E+00
HI		9.57E+00	

2) Hazard quotient and index of toxic metals

The calculated HQ are As (3.80E-01), Pb(3.63E+00), Al(1.43E-03), Zn(1.48E-02), Fe(9.71E-03), Cu(1.28E-01), Mn(3.53E-02), and Cd(5.37E+00) (Table 4) respectively. The Hazard Index (HI) was evaluated as 9.57E+00. The hazard quotient of the selected toxic metals in the groundwater samples of the study area ranged from 9.71E-03 for Total Iron(Fe) to 5.37E+00 for Cadmium(Cd) respectively. The HQ of the toxic metals of the groundwater from the study area is arranged in order of increasing HQ as follows; Total Iron (Fe)9.71E-03, Aluminum (Al)1.43E-03, Copper (Cu)1.28E-02, Zinc (Zn)1.48E-02, Manganese (Mn)3.53E-02, Arsenic (As)3.00E-01 Lead (Pb)3.63E+00 and Cadmium (Cd)5.37E+00. This result is higher than the report of Liu & Ma, ([43]), who reportean a HQ range of 1.478E-3 to 4.222E-4 in groundwater in the luan river catchment, North China Plain. The results indicated that Pb and cadmium Cd (HQ > 1) are the major contributors to the health risk posed to the inhabitants by drinking the water from the study area, relatively. On the other hand, Fe Al and Cu are the least contributors.

3) The Hazard Index (HI) of toxic Metals in groundwater samples

To assess the overall non-carcinogenic risk of ingesting groundwater contaminated with toxic metals, researchers calculate the study area's hazard index (HI). HI was calculated to be 9.38E+00. Cadmium with HQ (5.37E+00) and Lead with HQ of (3.63E+00) were the major contributors to the high HI value evaluated in this study. This result is similar to the finding of Belkhiri et al. ([41]), in their research. They reported the combined mean contribution of (5.26) from Cd and Pb to HI of the first cluster of their study. They concluded that lead and cadmium are toxic metals of serious health concern. Hence the result of the present study also shows that cadmium and lead are major contributors to chronic non-carcinogenic risks, hence the result of the two toxic metals HQ which is above one (1) means that there are significant non-cancer risks associated with human exposure to groundwater from the study area. This therefore, support the call that, special attention should be paid to Cd and Pb in Ikwe-ona to ensure that the level of cadmium and lead on groundwater from the study area is kept under close watch and monitoring to ensure that, non-carcinogenic risk such as cadmium and lead poisoning are prevented. Adeyemi and Ojekunle ([19]) also reported HI above 1 during their study on the health risk assessment of groundwater in Ogun state, Nigeria.

4) Hazard evaluation index

The HEI values obtained are As (0.40 µg/l), Pb (17.80µg/l), Al(1.91), Zn(0.05µg/l), Fe (0.79 µg/l), Cu(0.09µg/l), Mn(3.46µg/l), and Cd(31.27µg/l).The summation of the hazard evaluation index for all the toxic metals analysed is 55.77.

TABLE V. POLLUTION EVALUATION INDICES FOR TOXIC METALS (MG/L) IN GROUNDWATER SAMPLES.

Toxic Metal	MAC	Mean	HEI
Arsenic As (µg/l)	10	3.97	0.40
Lead Pb (µg/l)	10	178.00	17.80
Aluminum Al (µg/l)	30	57.24	1.91
Zinc Zn (µg/l)	3000	155.37	0.05
Total Iron Fe(µg/l)	300	237.70	0.79
Copper Cu (µg/l)	2000	179.44	0.09
Manganese Mn (mg/l)	50	172.82	3.46
Cadmium Cd (µg/l)	3	93.82	31.27
	ΣHEI		55.77

MAC: maximum admissible concentrations.

TABLE VI: WEIGHTED INDEX OF PARAMETERS (STATIONS 1-5)

Parameter	Sn	Wi*Qi (S1)	Wi*Qi (S2)	Wi*Qi (S3)	Wi*Qi (S4)	Wi*Qi (S5)
Colour (TCU)	15.00	5.24	5.62	7.04	6.04	5.28
pH @ 21.2^{O}c	8.50	3.89	5.21	6.77	0.78	4.91
Temp^{O} (^{O}c)	28.00	3.80	3.93	4.06	3.75	3.77
Turbidity NTU)	15.00	2.84	3.54	4.29	3.49	2.50
TSS (mg/l)	500.00	0.00	0.00	0.01	0.00	0.00
TDS (mg/l)	500.00	0.04	0.02	0.04	0.05	0.02
EC (µS/l)	1000.00	0.00	0.00	0.00	0.00	0.00
TH (mg/l)	150.00	0.13	0.21	0.26	0.21	0.15
BOD (mg/l)	10.00	2.39	2.15	3.42	2.12	2.40
DO(mg/l)	5.00	21.05	20.71	20.96	23.33	20.05
Zn (mg/l)	3.00	2.12	2.02	1.99	1.43	1.61
Ca	75.00	0.10	0.08	0.09	0.09	0.09
Mg	50.00	0.05	0.03	0.05	0.05	0.04
SO_4^{2-}	100.00	0.02	0.02	0.02	0.02	0.02
NO3-	50.00	0.06	0.06	0.09	0.07	0.09
Cl-	250.00	0.00	0.00	0.00	0.00	0.00

TA	120.00	0.11	0.12	0.09	0.12	0.13
	ΣWiQi	41.82	43.73	49.17	41.55	41.07
	Σwi	1.00	1.00	1.00	1.00	1.00
	WQI	41.82	43.73	49.17	41.55	41.07

TABLE VII: WEIGHTED INDEX OF PARAMETERS(STATIONS 6-10)

Parameter	Sn	Wi*Qi (S6)	Wi*Qi (S7)	Wi*Qi (S8)	Wi*Qi (S9)	Wi*Qi (S10)
Colour (TCU)	15.00	5.40	6.10	4.71	8.15	5.21
pH @ 21.2^{O}c	8.50	2.92	2.57	8.53	8.76	4.67
Temp^{O} (^{O}c)	28.00	3.76	3.93	3.74	4.33	3.79
Turbidity NTU)	15.00	3.03	3.75	3.41	4.87	3.50
TSS (mg/l)	500.00	0.00	0.00	0.00	0.01	0.01
TDS (mg/l)	500.00	0.01	0.03	0.02	0.02	0.01
EC (µS/l)	1000.00	0.00	0.00	0.00	0.00	0.00
TH (mg/l)	150.00	0.13	0.18	0.17	0.12	0.06
BOD (mg/l)	10.00	1.83	3.85	4.07	2.35	3.81
DO(mg/l)	5.00	19.26	20.05	18.66	20.05	19.79
Zn (mg/l)	3.00	1.86	2.44	1.70	1.44	2.13
Ca	75.00	0.09	0.10	0.10	0.09	0.09
Mg	50.00	0.06	0.07	0.05	0.07	0.07
SO_4^{2-}	100.00	0.02	0.02	0.02	0.02	0.02
NO3-	50.00	0.07	0.08	0.08	0.09	0.09
Cl-	250.00	0.00	0.00	0.00	0.00	0.00
TA	120.00	0.09	0.10	0.10	0.13	0.11
	ΣWiQi	38.53	43.27	45.35	50.48	43.35
	Σwi	1.00	1.00	1.00	1.00	1.00
	WQI	38.53	43.27	45.35	50.48	43.35

TABLE VIII: WEIGHTED INDEX OF PARAMETERS (STATIONS 11-15)

Parameter	Sn	Wi*Qi (S11)	Wi*Qi (S12)	Wi*Qi (S13)	Wi*Qi (S14)	Wi*Qi (S15)
Colour (TCU)	15.00	5.76	6.94	8.18	5.88	5.38
pH @ 21.2^{O}c	8.50	3.74	1.17	11.45	1.79	7.54
Temp^{O} (^{O}c)	28.00	3.71	4.02	4.41	3.92	3.71
Turbidity NTU)	15.00	3.75	4.13	4.85	3.74	3.87
TSS (mg/l)	500.00	0.01	0.01	0.01	0.00	0.00
TDS (mg/l)	500.00	0.02	0.01	0.02	0.02	0.01
EC (µS/l)	1000.00	0.00	0.00	0.00	0.00	0.00
TH (mg/l)	150.00	0.08	0.16	0.16	0.20	0.14
BOD (mg/l)	10.00	2.00	2.38	4.17	3.84	3.71
DO (mg/l)	5.00	21.26	19.62	25.45	20.85	17.63
Zn (mg/l)	3.00	2.02	1.96	3.09	2.08	2.24
Ca	75.00	0.09	0.10	0.10	0.08	0.09
Mg	50.00	0.06	0.04	0.05	0.03	0.03

SO_4^{2-}	100.00	0.02	0.02	0.02	0.02	0.02
NO3-	50.00	0.09	0.07	0.07	0.07	0.07
Cl-	250.00	0.00	0.00	0.00	0.00	0.00
TA	120.00	0.12	0.10	0.11	0.11	0.11
	ΣWiQi	42.72	40.73	62.14	42.63	44.56
	Σwi	1.00	1.00	1.00	1.00	1.00
	WQI	42.72	40.73	62.14	42.63	44.56

TABLE IX. WATER QUALITY INDEX OF THE SAMPLING STATIONS

Stations	Water quality index	Water quality rating
S1	41.82	Good water quality
S2	43.73	Good water quality
S3	49.17	Good water quality
S4	41.55	Good water quality
S5	41.07	Good water quality
S6	38.53	Good water quality
S7	43.27	Good water quality
S8	45.35	Good water quality
S9	50.48	Good water quality
S10	43.35	Good water quality
S11	42.72	Good water quality
S12	40.73	Good water quality
S13	62.14	**Poor water quality**
S14	42.63	Good water quality
S15	44.56	Good water quality

Based on the pollution evaluation indices, Table 5 shows how polluted the area is in terms of toxic metals concentrations. The mean values of HEI from the present study were calculated to be 55.77. This result is higher than the reports of Belkhiri et al. ([41]). They assessed Heavy Metals Contamination in Groundwater at the South of Setif Area, eastern Algeria, and reported an HEI value of 29.39 and 34 for three clusters of his study area. Based on their report, such value indicates that the water samples of the first cluster were contaminated with a low degree of pollution by heavy metals when compared to the second and third cluster respectively. Their report highlighted Al, ,Cd and Pb as major contributor to the pollution load of the groundwater. This assertion is same with the result of the present study except that magnesium is also a major pollution contributor in the present study.

B. Water Quality Index

The water quality Index of ground water from the study area ranges from 38.55-62.14. Sampling site 6, recorded the least value which shows that it is the least polluted while sampling 13 recorded the highest contamination. The weighted index of parameters are shown in Table 6 -to- Table 8.

The water quality index tells you how good a water's quality is for a specific use in terms of an index number (Etim et al., 2012). Water Quality Index (WQI) was calculated in this study by taking into account important physical and chemical factors such as the color and pH of the water. Trace elements such as calcium, magnesium, and zinc are also included. In order to determine the quality of the ground water, the water quality index assigns a numerical value to each factor that is examined. Except for dissolved oxygen, which had a mean value above the exposure level recommended by Nigerian industrial standards, the Nigerian standard organization, and the World Health Organization, samples of groundwater largely complied with the above standards.

Index values greater than 100 indicate that the water is not fit for human consumption. The range of index values for groundwater quality is 0-25, 26-50, 51-75, 76-100 and greater than 100. The water quality index (WQI) ranged from 38.53 at Station 6 to 62.14 at Station 13 for the 15 stations in the vicinity (Table 9). Borehole-sourced water is safe for human consumption, with the exception of station 13, which had a quality index of 62.14, which indicates that the water needs improvement. This result of elevated water quality index in sampling 13 could be as a result of the perceived oil and gas activities in the sampling location. This increased WQI could be because of a localized impact of oil and gas activities. The increased WQI could be as a result of increased levels of the parameters, such as Turbidity (11 mg/l) and Total suspended solids (15.80 mg/l), which was the maximum value in the entire sampling site. Biological oxygen demand(4.2 mg/l), was also the highest in sampling station 13 when compared with all sampling stations. This according to Asuquo & Etim, ([29]**)** is high**.** Surface and ground water contamination can be assessed using biochemical oxygen demand (BOD) values. Despite the fact that the BOD value from the sampling station are withing the acceptable limits, the fact that the highest value was recorded in station 13 contributes to the poor-quality index of the sampling station. Zinc (0.28mg/l) and Calcium (5.47 mg/l.) also recorded the highest in sampling station 13 when compared with all sampling stations investigated.

When Etim *et al.* (2013) examined well water in Nigeria's Niger delta, they discovered a WQI range of 38.52 to 48.67, which are in line with those of the previous ones. In this study, the range of WQI in Ikwe Ona was calculated to be 38.53 to 62.14. However Etim et al., [44] reported that all the samples from sampled borehole water in the Niger Delta region had good water quality (hence all data reported were below 50). The result of the present study reported results from sampling station 13 as 62.14. This values as stated above could be as result of localized impact of oil gas on the sampled station which led to the increased value of some important parameters such as BOD, Zinc etc**.** According to their estimates, the WQI ranges from 58.98 to 66.64 is higher than the findings of the current study. They conducted research on a tropical river, an open water body in an urban area, in order to gain more understanding of the WQI.

The study opined that the WQI levels were high because of the repeated release of waste effluents from many discharges that were dumped into the river by humans. Etim et al., ([45]), also reported high WQI values of 55.05 to 84. 94 for stream water and 34.76 to 36.26 for pipe born water all in the Niger Delta region. From the result of their study when comparing to the result of this study, it can be concluded that, open water bodies are more polluted than pipe borne water which is less polluted. However ground water still remains one of the best source of good water sources.

IV. CONCLUSION

This study evaluated the hazard index and water quality index of groundwater samples from Ikwo and envirions with a view to ascertain its status and suitability for different uses**.** From the results, the average daily dosage of groundwater from the study area indicates that, Arsenic with ADD value 0.114 µg/l, recorded the least ADD followed by aluminum with ADD value of 1,429 µg/l. however, iron (Fe) with ADD value of 6.80 µg/l was the highest followed by cupper (Cu) 5.114 µg/l.

Result of Hazard Quotient of the ground water from Ikwe-Ona indicated that, Lead (Pb) and cadmium (Cd) which recorded HQ > 1 are the major contributors to the human health risk of drinking groundwater to the inhabitants of the study area while Fe Al and Cu are the least contributors.

The hazard index (HI) exposure to toxic metals from drinking borehole water from the study area was calculated to be 9.38E+00. Cadmium with HQ of 5.37E+00 and Lead with HQ of 3.63E+00 were the major contributors to the high HI value evaluated from this study. The Hazard Evaluation Index of toxic metals in the study area was evaluated as 55.77. This result indicates high contamination of the groundwater in the study area by toxic metals

The WQI (water quality index) of 15 stations ranged from 38.53 (station 6) to 62.14 (station 13). According to Station 13 Results, all of the parameters analyzed from boreholes water samples have a quality index of 62.14, which indicates that the water is unfit for consumption by humans and other living organisms.

The hazard evaluation index indicates high health risk posed by human intake of water from the study areas a result of high pollution load of the groundwater by Al, Cd, Mg and Pb respectively. Water quality Index result which indicates the overall quality of the water from all physicochemical parameters and trace elements indicates that, apart from the WQI of station 13 (62.14) which revealed poor water quality, the ground water from the rest 14 stations were judged to be of good quality.It is therefore recommended that water from station 13 be treated before consumption and other critical uses.

CONFLICTS OF INTERESTS

No relevant financial or non-financial interests exist for the authors to disclose.

AUTHOR CONTRIBUTIONS

All authors contributed to the research. OHN conceived the research idea; all authors took part in the field work; VO,CDO and BBK coordinated the laboratory analysis;

while EOA edited and reviewd the report compiled by OHN.

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