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Evaluating the Effects of Pollutants on Groundwater Quality in Okrika Nigeria

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Abstract:- The environmental quality of groundwater is very important to determine its suitability for drinking and agricultural purposes. The current status of groundwater in Okrika Local Government Area, Rivers State, Nigeria and host to the Port Harcourt Refinery Company was evaluated. A total of 20 samples from boreholes, were taken from Okrika island, Ogoloma, OganAma, Kalio, George, Okari, Ekerekana, Abam, Orupabo and Isaka Communities. The water samples were collected during the dry and wet seasons (February, July and November, 2020) and analyzed using standard methods. The samples were analyzed for the following parameters: pH, Temperature (T), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Salinity, Turbidity, Chlorine, Bromine, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Nitrate, Phosphate, Cadmium (Cd) Lead (Pb) and Zinc(Zn). Results obtained showed significant deviation of some components from WHO standards. Water samples showed that (80%) had pH concentration lower than the WHO and NSDWQ Directive limit of 6.5 - 8.5 for potable water; DO and BOD values were below and above recommended limits of 6mgIL and 0.002 mg/L respectively. Four samples exceeded the WHO limit of 0.5mgIL phosphate in drinking water. The results of Water Quality Index (WQI) rating in study area in the two seasons are above the standard rate which is an indication that the water is unfit for drinking.

***Keywords**:- Groundwater, Water Quality, Pollutants Public Health, Okrika.*

I. INTRODUCTION

Groundwater in Okrika Local Government Area, Rivers State, Nigeria is polluted with discharges from the Refinery, Fertilizer Company, other industrial activities, crude oil bunkering, solid waste and sewage disposal. Generally, petroleum refining has generated gaseous, liquid and solid wastes into the environment which include draining fluid, petroleum waste water, petroleum effluent treatment plant sludge and bottom tank sludge (Johnson, 2018). These activities according to various studies have exposed pollutants into the drinking water system in the area which is sourced through groundwater in form of boreholes and hand-dug wells. The quality of water is the degree of its safety and hygienic conditions. Drinking water is said to be potable when such conditions are attained and it is determined by the amount and level of physico-chemical, microbial and heavy metals (which included suspended and dissolved substances in the water, the degree of alkalinity (pH), temperature, appearance in terms of colour, taste, odour and the presence of non- desirable microorganisms). Water for domestic purposes should therefore be free from these substances in order to prevent waterborne diseases. The understanding and monitoring of sources of water used for water supply remains social, economic and conservational importance. This is necessary, since per capita water demand is increasing, while accessibility to freshwater availability has continued to decline. Studies observed that potable water of communities in Okrika showed serious pollution from effect of refinery effluents. Also, water in Okrika is not suitable for drinking as well as other domestic purposes as a result of artisanal refining activities (Nwankwoala *et al.*, 2017).

It has also been documented that drinking contaminated or polluted water can cause serious health effects to humans and animals. Residents through long term accumulation of these pollutants in form of heavy metals, hydrocarbons, inorganic and organic acid will likely to cause cancer, kidney, liver diseases, etc. If the water resource system is not treated, the current situation in the area demands regular monitoring/surveillance of the water resources system. This study will help update and increase the database on the environmental quality of water in the area. The aim of this paper is to document the current status of the water system in Okrika Local Government Area. Towards this goal, relevant authorities can use the data to remediate heavily polluted areas, enforce strict regulations and laws concerning potable water, thereafter relevant authorities can establish and maintain sustainable ecosystems in the area for future generations by appropriate remediation criteria.

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II. STUDY AREA, GEOLOGY AND HYDROGEOLOGY OF THE AREA

❖ Study Area

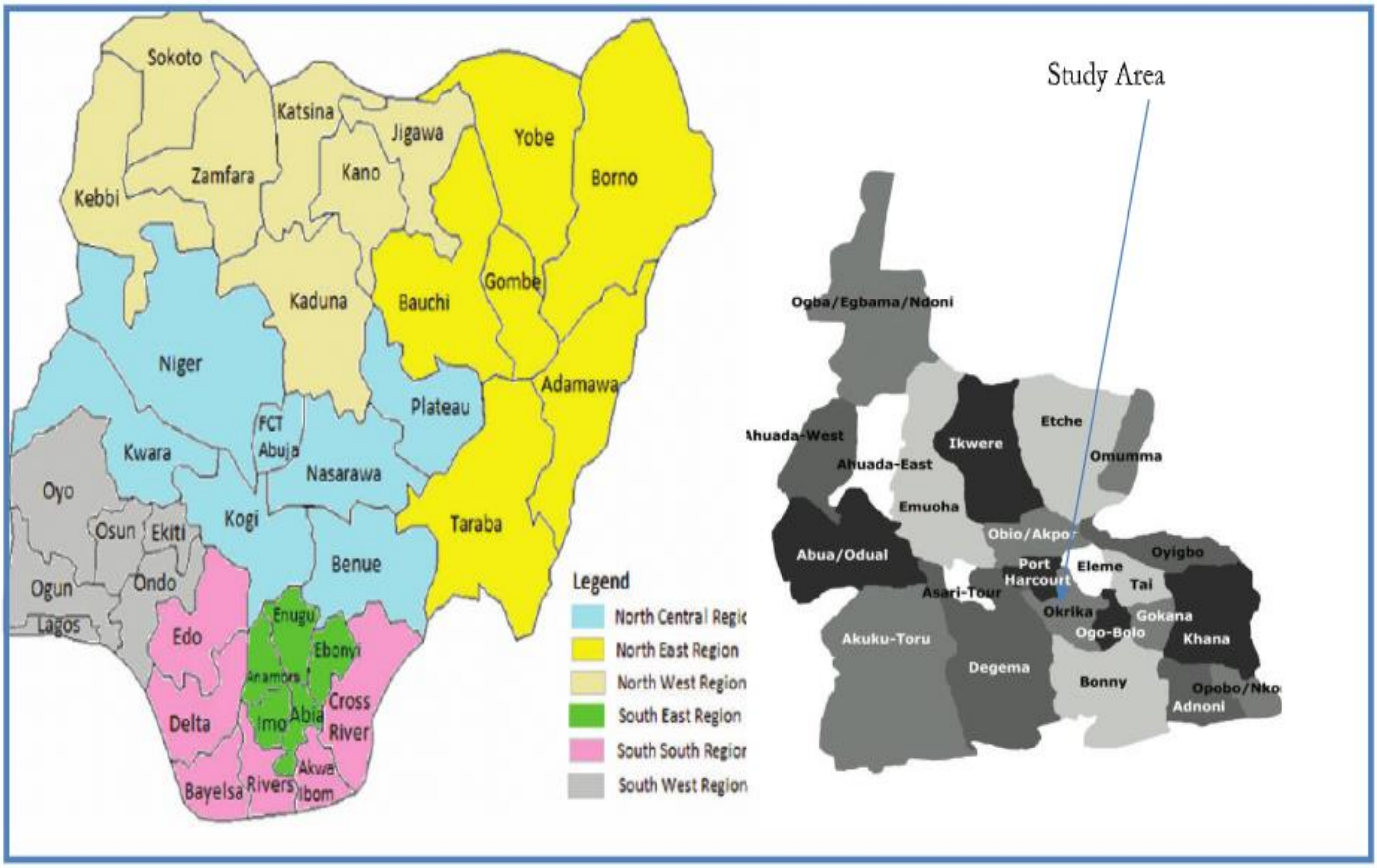

Fig. 1– Map of Nigeria and Rivers State showing study area

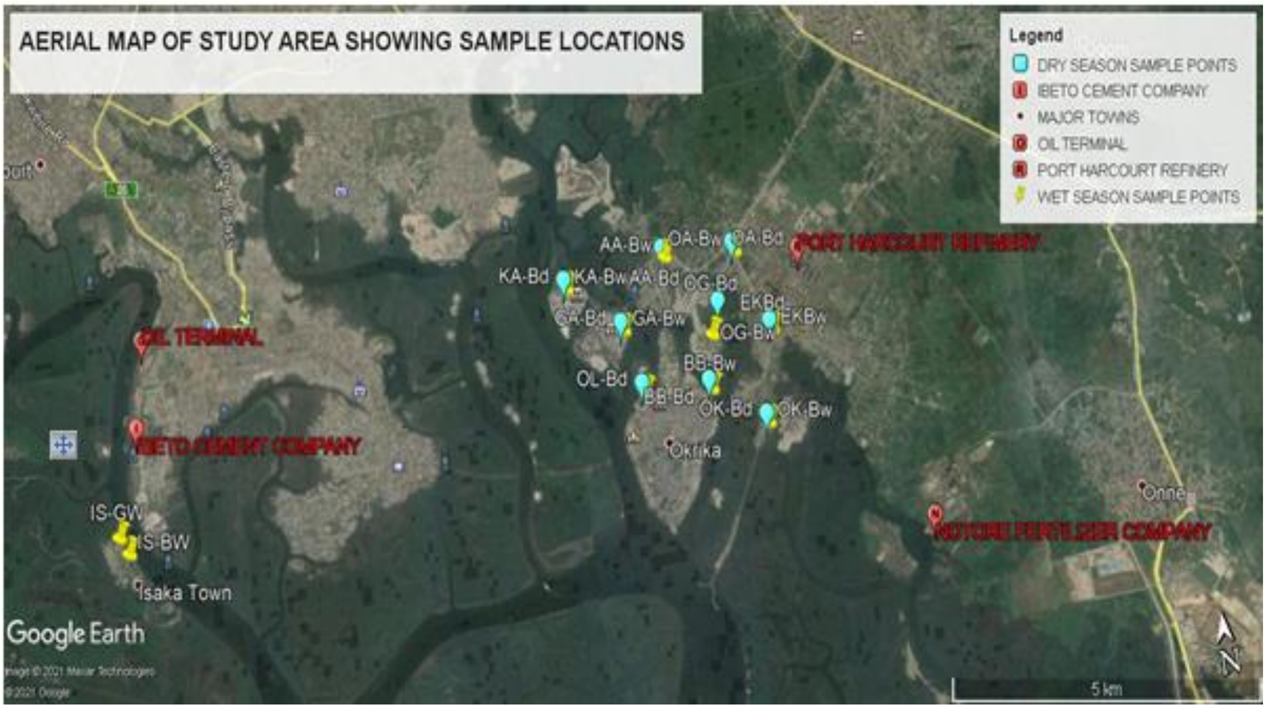

Fig. 2 – Map of Okrika Local Government Area showing Sampling Locations

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Table 1: Coordinates of the Study Area (Okrika Local Government)

(a) Boreholes (Dry Season)

S/No.	LOCATION CODES	OWNERSHIP	LATITUDE	LONGITUDE	TOWN
1.	OG-Bd	RSG	4°45'13.52"N	7° 5'33.37"E	Ogan-Ama
2.	OA-Bd	Private	4°45'38.98"N	7° 5'45.28"E	Orupabo-Ama
3.	KA-Bd	Private	4°45'35.74"N	7° 4'11.86"E	Kalio-Ama
4.	GA-Bd	Private	4°45'11.93"N	7° 4'39.81"E	Geoge-Ama
5.	AA-Bd	Private	4°45'42.17"N	7° 5'6.93"E	Abam- Ama
6.	BB-Bd	Community	4°44'38.95"N	7° 5'22.83"E	Bulome-biri
7.	OL-Bd	Private	4°44'42.93"N	7° 4'46.83"E	Ogoloma
8.	OK-Bd	Private	4°44'19.18"N	7° 5'51.01"E	Okari -Ama
9.	EKBd	Private	4°45'0.53"N	7° 5'59.64"E	Ekerekana

(b) Boreholes (Wet Season)

S/No.	LOCATION CODES	OWNERSHIP	LATITUDE	LONGITUDE	TOWN
1.	OG-Bw	PHRC	4°45'3.10"N	7° 5'27.00"E	Ogan-Ama
2.	OA-Bw	Private	4°45'38.98"N	7° 5'45.28"E	Orupabo-Ama
3.	KA-Bw	Private	4°45'35.74"N	7° 4'11.86"E	Kalio-Ama
4.	GA-Bw	Private	4°45'11.93"N	7° 4'39.81"E	Geoge-Ama
5.	AA-Bw	Private	4°45'42.17"N	7° 5'6.93"E	Abam- Ama
6.	BB-Bw	Community	4°44'38.95"N	7° 5'22.83"E	Bulome-biri
7.	OL-Bw	Private	4°44'42.93"N	7° 4'46.83"E	Ogoloma
8.	OK-Bw	Private	4°44'19.18"N	7° 5'51.01."E	Okari- Ama
9.	EKBw	Private	4°45'0.53"N	7° 5'59.64"E	Ekerekana
10.	IS-BW	Private	4°44'14.60"N	7° 0'4.43"E	Isaka Town
11.	IS-GW	FGN	4°44'22.42"N	6°59'59.86"E	Isaka Town

Okrika Local Government Area is located in Rivers State in the Niger Delta region in the coastal part of the South -South Nigeria (fig.1). The area lies between latitude 4°44^{1}31. 74^{11} N and longitude 7°051^{11}125^{11}E South of Rivers State (Nigeria Federal Surveys, 2500/364/668). The area is within the sub equatorial region of Nigeria. It is characterized by its beautiful beaches, mangroves, swamps and barrier bars. The climate in Okrika is characterized majorly by two seasons, the dry season begins in November and ends in February, while the wet season begins in March and ends in October, with a peak period in June and July,. Annual rainfall in the area is over 3000mm.

It is also characterized by high temperature and humidity as is common with humid tropical climate. Average annual temperature in the area is about 27°C, with maximum values in the months of March and April and the lowest in July and August. The climate conditions have an intimate relationship with vegetation type in the area. The high rainfall and humidity promote thick vegetation termed tropical Rain forest. Topographic height rarely exceeds 80m in the area. Okrika is entirely within the tidal salt water Zone of the Eastern Niger Delta, and a maze of rivers and winding creeks intersect it. There are within it stretches of marshy land roots as the vegetation (Abam,, 2019). There is also a mainland forest area within which the people have been carrying on with some farming from time to time. Thus, though Okrika is primarily a riverine area, it also has maintained settlements. Okrika area is drained by many rivers and creeks, the major river, which is Bonny River.

Okrika is bounded to the North by Eleme Local Government Area, to the East by Ogu/Bolo Local Government Area, to the South by Bonny Local Government Area. To the South-west by Degema Local Government Area and to North-West by Port Harcourt city.

The area plays host to Port Harcourt Refinery Company (PHRC) the Pipeline Product Marketing Company (PPMC), all subsidiaries of the Nigerian Petroleum Corporation (NNPC) . The area is also host of the Okrika jetty and Terminal used for loading and unloading of oil and gas related activities. These had led to the continuous influx of associated companies and people into the area thereby resulting to increase in anthropogenic activities and corresponding discharge of pollutants into the environment and the constant erosion of shorelines of the communities due to waves caused by ocean vessels. Okrika creeks are used for effluent/waste drainage outlets from Port Harcourt Refinery and Former NAFCON, now Notore Fertilizer Company. Previous studies in these areas have indicated a big pollution problem with these discharges and other effluents.

❖ Geology

The general geology of Okrika, which is also of Niger Delta consists of various types of Quaternary deposits overlying the three major lithostratigraphic units. These are from bottom to top, the Akata, Agbada and Benin Formations. The Akata formation forms the basal unit of Niger Delta and consists of an open marine facial unit dominated by high- pressured carbonaceous shale, the range in thickness could exceed 1000 meters. It is overlain by the Agbada Formation consisting of the alternating Deltaic sands and shales. It is Eocene to Oligocene in age and exceeds 3000 meters in thickness. This Formation is oil reservoir of the Niger Delta Basin. The overlying Benin Formation is Oligocene to Pleistocene in age and consists predominantly of freshwater continual friable sands and gravel that are of excellent aquifer properties with occasional intercalation of shales. The thickness of the formation is variable but generally exceeds 2000 meters (Avwenagha, *et al*., 2014).

❖ Hydrogeology

Fresh water from the Benin Formation have been identified as unconsolidated, highly porous sands. All aquifers in the Niger Delta are located within this lithostratigraphic unit. Also, in the Niger Delta, the regional groundwater occurs in four major aquifers delineated from lithologic and geophysical log within a depth bracket of 0 - 300 meters. The first aquifer occurs between 0 -45m under phreatic conditions and is the most extensively exploited. The second (50 -130m) and the third (136 - 212m) are semi confined, while the fourth (219 - 300) is perfectly confined and is the thickest. The aquifers are predominantly very fine to coarse grained sand beds with minor clays and conglomerate intercalations (Tse and Eshiemomo, 2016).

III. METHODOLOGY

3.1 Sample Collection and Determination of physico-chemical parameters

Borehole and hand-dug well samples were obtained from different communities in Okrika Local Government Area, Rivers State, Nigeria during the dry (February) and wet (July and November) seasons, 2020. All samples were collected in properly rinsed bottles. The collected samples were transported to the laboratory in ice-packed coolers for analysis according to APHA, 1998. The physico-chemical properties of the borehole water samples were determined with the standard methods as highlighted in Table 4.
Fourteen parameters were analysed and the results obtained are shown in Table 4.

3.2 Determination of Water Quality Index (WQI)

Water Quality Index Model

Water Quality Index (WQI) is a very useful and efficient method for assessing the suitability of water quality. It is also a very useful tool for communicating the information on overall quality of water (Jaji et al., 2007) to the concerned citizens and policy makers. It, thus, becomes an important parameter for the assessment and management of water quality (both surface and groundwater). WQI reflects the composite influence of different water quality parameters and is calculated from the point of view of the suitability of (both surface and groundwater) for human consumption. In general, water quality indices incorporate data from multiple water quality parameters into a mathematical equation that rates the health of waterbody with number (Akoteyon, et al 2011 https://www.researchgate.net/publication/279900384). The study assessed groundwater water quality for domestic use based on computed water quality index values as shown in equation (1).

$$Q_p = \sum_{p=1}^{n} \left(\frac{A_p - I_p}{S - I_p} \right) \times 100 \qquad (1)$$

Where Q_p= quality of parameters
A_p= average values of parameters determined under laboratory conditions
S = standard permissible values obtained from recognized bodies
I_p= ideal values for the parameters.
All ideal values (I_p) are taken to be zero, except that of pH=7; DO =14.6; Fluorides = 1 (Dakhad, et al, 2008).
The water quality index is determined by aggregating the products of the parameter qualities and the unit weights dividing by the aggregate of the unit weights as in equation (2).

$$WQI = \frac{\sum_{p=1}^{n} Q_p W_p}{\sum_{p=1}^{n} W_p} \qquad (2)$$

The water quality ratings assigned to assigned to water quality index values are shown in table 1

TABLE 2: WATER QUALITY INDEX AND WATER STATUS

Water Quality Index	Water Quality Status
0-25	Excellent
26-50	Good
51-75	Bad
76-100	Very bad
>100	Unfit for drinking

Source: Chatterji and Razuiddin(2002)

IV. RESULTS AND DISCUSSIONS

Unit	Parameters	Unit	SAMPLE ID									Mean	Std.	Min	Max	WHO	NSDWQ
			AA-Bd	OL-Bd	BB-Bd	OG-Bd	GA-Bd	OK-Bd	EK-Bd	KA-Bd	OA-Bd						
1	pH		6.9	6.0	5.6	8.0	5.8	5.7	6.0	5.9	6.7	6.3	0.78	5.6	8.0	6.5 – 8.5	6.5 – 8.5
2	Temperature	˚C	31	30	30	31	31	30	30	30	31	30.44	0.53	30	31		
3	Electrical Conductivity	us/cm	504	38	103	44	45	44	103	145	17	115.9	151.25	17	504	-	1500
4	Total Dissolved Solids(TDS)	mg/l	475	23	73	77	30	25	18	89	15	91.67	148.53	15	475	600	1000
5	Salinity	mg/l	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.79	1.0	1.09	0.26	1	1.79	200	
6	Turbidity	NTU	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	5	5(10)
7	Chlorine	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	5	0.1 – 0.2
8	Bromine	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.05	
9	Dissolved Oxygen (DO)	mg/l	0.9	0.7	0.5	0.7	1.6	1.5	0.5	0.8	1.3	0.94	0.42	0.5	1.6	6	
10	Biochemical Oxygen Demand (BOD)	mg/l	0.7	1.1	1.0	0.7	0.7	1.1	1.3	0.9	0.2	0.85	0.32	0.2	1.3	0.002	
11	Nitrate	mg/l	0.294	0.181	0.222	0.159	0.638	1.635	0.269	0.116	0.193	0.41	0.48	0.12	1.64	50	50
12	Phosphate	mg/l	0.098	0.075	0.058	0.081	0.132	0.109	0.058	0.017	0.092	0.08	0.03	0.02	0.13	0.5	

Table 4: Physicochemical Parameters of Borehole Water Samples (Dry Season)

Unit	Parameters	Unit	SAMPLE ID									Mean	Std.	Min	Max	WHO	NSDWQ
			AA-Bd	OL-Bd	BB-Bd	OG-Bd	GA-Bd	OK-Bd	EK-Bd	KA-Bd	OA-Bd						
1	pH		6.9	6.0	5.6	8.0	5.8	5.7	6.0	5.9	6.7	6.3	0.78	5.6	8.0	6.5 – 8.5	6.5 – 8.5
2	Temperature	˚C	31	30	30	31	31	30	30	30	31	30.44	0.53	30	31		
3	Electrical Conductivity	us/cm	504	38	103	44	45	44	103	145	17	115.9	151.25	17	504	-	1500
4	Total Dissolved Solids(TDS)	mg/l	475	23	73	77	30	25	18	89	15	91.67	148.53	15	475	600	1000
5	Salinity	mg/l	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.79	1.0	1.09	0.26	1	1.79	200	
6	Turbidity	NTU	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	5	5(10)
7	Chlorine	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	5	0.1 – 0.2
8	Bromine	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.05	
9	Dissolved Oxygen (DO)	mg/l	0.9	0.7	0.5	0.7	1.6	1.5	0.5	0.8	1.3	0.94	0.42	0.5	1.6	6	
10	Biochemical Oxygen Demand (BOD)	mg/l	0.7	1.1	1.0	0.7	0.7	1.1	1.3	0.9	0.2	0.85	0.32	0.2	1.3	0.002	
11	Nitrate	mg/	0.29	0.18	0.22	0.15	0.63	1.63	0.26	0.11	0.19	0.4	0.48	0.	1.6	50	50

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		l	4	1	2	9	8	5	9	6	3	1		12	4		
12	Phosphate	mg/l	0.098	0.075	0.058	0.081	0.132	0.109	0.058	0.017	0.092	0.08	0.03	0.02	0.13	0.5	

Table 5: Physicochemical Parameters of Borehole Water Samples (Wet Season)

S/N	PARAMETERS	UNITS	SAMPLE ID											Mean	Std.	Min	Max	WHO	NSDWQ
			AA-B	OL-B	BB-B	OG-B	GA-B	OK-B	EK-B	KA-B	OA B	IS-B	IS-GB						
1	pH		5.64	5.39	5.17	5.48	5.92	5.08	5.86	5.62	5.27	6.44	5.57	5.59	0.39	5.08	6.44	6.5 – 8.5	6.5 – 8.5
2	Temperature	˚C	26.9	26.6	26.6	26.4	26.4	27.3	26.8	26.4	26.4	28.3	28.4	26.95	0.74	26.4	28.4	12 - 24	
3	Electrical Conductivity	us/cm	1500	1700	1500	1600	1600	1400	1600	1700	1300	175	311	1307	540.65	175	1700	-	1500
4	Total Dissolved Solids (TDS)	mg/l	825	935	825	880	880	770	880	935	715	96.25	171.1	8118	297.35	96.3	935	600	1000
5	Salinity	mg/l	0.1	0.114	0.10	0.107	0.107	0.094	0.107	0.114	0.087	66	96	14.8	33.40	0.09	96	200	
6	Turbidity	NTU	0.329	0.334	0.279	0.198	0.326	0.281	0.370	0.216	0.272	1	2	0.51	0.54	0.20	2	5	5(10)
7	Chlorine	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	20	29	8.92	20.22	0.01	29	5	0.1 – 0.2
8	Bromine	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-	-	0.01	0.00	0.01	0.01	0.05	
9	Dissolved Oxygen (DO)	mg/l	1.0	0.6	0.6	0.8	0.8	0.6	1.0	0.5	0.5	7.9	9.2	2.14	3.20	0.5	9.2	6	
10	Biochemical Oxygen Demand (BOD)	mg/l	0.8	0.4	0.4	0.5	0.6	0.4	0.8	0.3	0.3	0.54	0.29	0.48	0.19	0.29	0.8	0.002	
11	Nitrate	mg/l	1.358	1.318	1.247	0.513	0.790	0.592	0.624	0.734	0.987	0.5	1.5	0.92	0.37	0.50	1.50	50	50
12	Phosphate	mg/l	0.278	0.453	0.283	0.361	0.387	0.408	0.521	0.597	0.413	0.23	1.2	0.47	0.27	0.23	1.20	0.5	

Table 6: Heavy Metals for Borehole Samples (Dry Season)

S/N	PARAMETERS	EK – B	OG – B	OK – B	GA – B	KA – B	AA – B	OA – B	BB – B	OL - B	Mean	Std.	Min	Max	WHO	NSDWQ
1	Cadmium (mg/l)	0.001	0.001	0.001	0.016	0.052	0.001	0.001	0.001	0.071	0.02	0.00	0.001	0.071	0.003	0.01
2	Lead (mg/l)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.00	0.002	0.002	0.003	0.01
3	Zinc (mg/l)	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.00	0.005	0.005		3.0

Table 7: Heavy Metals for Borehole Samples (Wet Season)

S/N	Parameters	EK – B	OG – B	GA – B	KA – B	AA – B	OA – B	BB – B	OL – B	OK – B	IS – B	IS - GB	Mean	Std.	Min	Max	WHO	NSDWQ
1	Cadmium (mg/l)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.00	0.001	0.001	0.003	0.01
2	Lead (mg/l)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.00	0.001	0.001	0.003	0.01
3	Zinc (mg/l)	0.001	0.001	0.001	0.039	0.001	0.001	0.001	0.001	0.052	0.001	0.001	0.008	0.00	0.001	0.052		3.0

❖ RESULTS

pH

pH values for borehole sample during the dry season ranged from 5.6 to 8.0 with a mean value of 6.3. The highest recorded occurred in O.G-B (8.0) while the lowest occurred in Bulome-biri borehole (BB-B) at 5.6.

For wet season, the borehole samples ranged from 5.08 to 6.44. The highest recorded pH occurred in IS-B (6.44) and the lowest in OK-B (5.08) the results show that none of the boreholes had acceptable pH values of 6.5 - 8.5.

Temperature

Water temperature values for the borehole samples in dry season ranged from 30°C to 31°C. For wet season, water temperature values for the borehole samples ranged from 26.4°C to 28.4°C with the mean value of 26.9°C.

Electrical Conductivity

Electrical conductivity values in dry season for borehole ranged from 17µs/cm to 504µs/cm with mean value of 115.8 µS/cm for wet season, Electrical Conductivity values ranged from 311 µS/cm to 1700 µS/cm with a mean value of 1307 s/cm.

Total Dissolved Solids

The values of Total Dissolved Solids (TDS) value in borehole water samples during the dry season ranged from 15 - 475mg/l with the mean valve of 91.7mg/l. The /highest value was recorded in AA - B with value of 475mg/l while the lowest value was recorded in OA- B as 15mg/l.

For wet season, Total Dissolved Solids (TDS) value ranged from 96.25mg/l - 935 mg/l with a mean value of 719.30mg/l.

Salinity

Salinity values for boreholes in dry season ranged from 1.0 mg/l to 1.79mg/l. For wet season, Salinity values ranged from 0.087 mg/l to 96mg/l with a mean value of 14.83mg/l.

Turbidity

Turbidity values for borehole water samples in the dry season recorded 0.01 NTU in all water samples. For wet season, Turbidity values ranged from 0.198 NTU to 2 NTU with mean value of 0.509 NTU.

Chlorine

Chlorine values for borehole water samples in dry season recorded 0.01mg/l in all the water samples. For wet season, Chlorine values ranged from 0.1 to 58mg/l with mean value of 8.91mg/l.

Bromine

Bromine values for borehole water samples in dry season recorded 0.01mg/l in all the boreholes. For wet season, the same bromine values of 0.01mg/l were recorded for all borehole water samples.

Dissolved Oxygen

Dissolved oxygen values for borehole water samples in dry season ranged from 0.5 mg/l to 1.6mg/l with a mean value of 0.94mg/l.

For wet season, dissolved oxygen values ranged from 0.5mg/l to 9.2mg/l with a mean value of 2.14mg/l. The highest concentration value of 9.2mg/l was recorded in IS - GB while the lowest value of 0.5mg/l was recorded in KA-B and OA - BB respectively.

Biochemical Oxygen Demand

Biochemical Oxygen Demand (BOD) values for borehole water samples in dry season from 0.2mg/l to 1.6mg/l with a mean value of 9.77mg/l.

For wet season, Biochemical Oxygen Demand values ranged from 0.29mg/l to 0.8mg/l with a mean value of 0.48mg/l.

Nitrate

Nitrate values in dry season ranged from 0.116mg/l to 1.635mg/l with a mean value of 0.411mg/l. For wet season, Nitrate values ranged from 0.5mg/l to 1.5mg/l with a mean value of 0.92mg/l.

Phosphate

Phosphate values in dry season ranged from 0.017mg/l to 0.132mg/l with a mean value of 0.72mg/l. For wet season, Phosphate values ranged from 0.23mg/l to 1.20mg/l with a mean value of 0.466mg/l.

Heavy Metals

Cadmium

Cadmium values in dry season ranged from 0.001mg/l to 0.071mg/l with a mean value of 0.020mg/l. The Highest value of 0.071mgIL in OL-B (Ogoloma) while the lowest values of 0.001mg/I was recorded in AA-B (Abam-Ama), BB-B (Bulome-biri), OG-B (Ogan), OK-B (Okari-Ama), EK-B (Ekerekana) and OA-B (Orupabo-Ama) respectively.
In wet season, Cadmium values of 0.001mg/l was recorded in all the boreholes.

Lead

Lead values in dry season for borehole water samples recorded 0.002 mg/l in all the boreholes.

Zinc

Zinc value in dry season was recorded 0.0005 mg/l for all boreholes.
For wet season, Zinc value ranged from 0.001mg/l to 0.052mg/l with a mean value of 0.008; the highest 0.052mg/l was recorded in OK-B (Okari-Ama).

❖ DISCUSSION

Temperature

Temperature values were between 30°c to 31°c for borehole during the dry season while temperature value for boreholes were between 26.4°c - 28.5°c during the wet season. Temperature changes in physical, chemical and microbial processes in the sub surface environmental leading to groundwater quality changes (Bonte et al.,2011, Hahnlein et al.,2013).

Cool water is generally more palatable than warm water. High temperature most times may increase problems related to taste, odour, colour and corrosion and also enhance the growth of microorganism. (WHO,2017). The temperature of 31°c is into within the permissible limit of World Health Organization (WHO) Ezeribe et al.,(2012) reported result of 29°c of well water. However, the aesthetic objective for water temperature in the guidelines for Canadian Drinking Water Quality is 15°c.

Electrical Conductivity

Electrical Conductivity values for borehole for dry and wet seasons ranged from 17us/cm - 1700us/cm.

According to National Drinking Water Quality Standards (NDWQS),all boreholes during wet season were above allowable limits of 1500 us/cm except Isaka borehole and Government borehole (175 and 311 us/cm). Using Jordania Standards and Guideline for drinking water, with the allowable limit of 400us/cm, one borehole (Abam Ama) during the dry season was above the limit, all boreholes during wet season except Isaka Town, during the wet season were above the guideline. During raining season, Inam and Offiong, 2017 recorded 65.75us/cm. Electrical Conductivity is a measure of water capacity to convey electric current. Dissolved salts and other inorganic chemicals conduct electrical current, conductivity increases as salinity increases. Subsequently, Conductivity is also affected by temperature. The warmer the water, the higher the conductivity. Conductivity is an early indication of change in a water system. This can be used to determine saltwater intrusion in groundwater (Atkins,2020). Pure water is not a good conductor of electricity (Alley, 2007; APHA,2005).

Total Dissolved Solids (TDS)

The palatability of water with a Total Dissolved Solids (TDS) level of loss than about 600mg/I is considered to be good. Drinking water becomes unpalatable as TDA levels is greater than 100mg/I (WHO,2017). TDS values for boreholes during the dry season were all below the allowable limit of 600mg/I while during the wet season, only boreholes at Isaka Town were within allowable limit, all the other boreholes were above 600mg/I. However, allowable limit for US Environmental Protection Agency is 500mg/I.

TDS is non - ionized matter. Where TDS is high, the water may be saline. High TDS in drinking water can cause organoleptic implications (EPA,2001).

This may be attributed to the presence of natural solute or from industrial treatment plants or groundwaters pollution. TDS values of groundwater samples 559.2589.7,319.5 and 247.5mg/I were obtained in Lagos Metropolis (Popoola, et al.,2019).

Salinity

Drinking water salinity has been linked to risk of preeclampisa and gestational hypertension. Over extraction of groundwater may cause salinity in water.

The salinity values for boreholes and were all very low expect the boreholes at Isaka Town, which were recorded 66mg/l and 96mg/l respectively. This values although not up to the WHO. Guideline value of 200mg/I are lower compared to the value of 170mg/I reported by Chakraborty et al., (2019). Increased water salinity may lead to infant mortality, cholera outbreaks, skin and diarrheal diseases.

Turbidity

In drinking water, the higher the turbidity level the higher the risk that people may develop gastrointestinal diseases. This is worse for people with low immunity. Turbidity is a measure of the light refractiveness of water. It is a very important parameter for water quality. Some problematc particles in turbid water can include metals or other types of sediment that can negatively, affect human health. These particles can harbour microorganisms, protecting them from disinfection, also trap heavy metals(Government of Canada,2020). Turbidity values from all boreholes for dry and wet seasons recorded were below the allowable limits of 5 NTU for WHO and NSDWQ. WHO established that the turbidity for drinking water should not be more than 5NTU and should be ideally below 1NTU. The levels in the two boreholes (IS-B and IS-GB) which are 1NTU and 2NTU are therefor above the ideal allowable limit. However, the European Standards for turbidity states that it must be no more than 4NTU. Canadian guideline is between 0.1 to 1.0 NTU. Inam and Offiong (2017) during dry season recorded 13.08 NTU which is higher.

Chlorine

High Chlorine in drinking water may not hurt at first but may have long term health effects. Increased risk of cancer, hazardous for children's health, cell damage and increase the risk of Asthma and some of the effects. Cancer risk among people drinking chlorinated water is 93 percent higher than those who drink water without chlorine (Wiant,2019).

The chlorine values for all the boreholes were below 0.01mg/I except the boreholes at Isaka Town which recorded 20mg/I and 29mg/I.

The allowable limit for chlorine is 5mg/I (WHO,2017) while it is 4mg/I (USEPA,2018). Chlorine in Isaka Town maybe as a result of industrial activities around the area.

Bromine

Bromine in drinking water can cause different effects depending on the compound. This could in a short period of time cause symptoms such as nausea and vomiting (gastrointestinal symptoms). It is also corrosive to human tissue in liquid state, malfunctioning of the nervous system, disturbances in genetic materials and damage to the thyroid gland.

Bromine values for all boreholes during the dry and wet seasons were at 0.01mg/I. The values recorded were within the guideline value of 0.05mg/l(WHO).

Dissolved Oxygen

Dissolved Oxygen (DO) is a measurement of how much Oxygen is dissolved in water. DO can tell a lot about water.

The DO values for boreholes during dry season as 0.9, 0.7, 0.5, 0.7, 1.6, 1.5, 0.5, 0.8, 1.3, 1.3mg/1 respectively while for the wet season, it was recorded as 1.0, 0.6, 0.6, 0.8, 0.8, 0.6, 1.0, 0.5, 0.5, 7.9, 9.2mg/1 respectively.

However, the boreholes at Isaka Town had higher values of 7.9 and 9.2mg/1. With the guideline limit of 7.5mg/1 (EQS Japan, 2015), the values recorded in Isaka Town were above the limit. WHO value is 6mgil.

Biochemical Oxygen Demand (BOD)

BOD gives a measure of Oxygen requirement for biodegradation of Carbonaceous matter in a simple. The BOD values for all boreholes were all below 1mg/1 except - Ogoloma (1.1), Bulomebiri (1), Okari Borehole (1.1), Ekerekana (1.3) during the dry season. With the guideline limit of 1mg/1 (Environmental Quality Standard (EQS, Japan), four of the boreholes are above the allowable limit. WHO (2017) limit for BOD is 0.002mg/l. Adesuyi etal.,(2015) also had almost similar value of 1.0-2.0mgil.

Nitrate

Consuming much nitrate can affect how blood carries Oxygen and cause methemoglobinemia (also known as blue baby-Hazard to infants above 11mg/1(EPA, 2001). Presence of nitrate in ground waters is a risk to babies of less than six months and unborn foetus of pregnant women. Adults with specific rare metabolic disorders may also be at risk.

Nitrate levels for all boreholes were within the allowable limit of 50mgil. 11mg/1 for babies (infants) and 50mg/ 1 for adults. Inam and Offiong (2017) in their study also recorded nitrate value (mg/1) 0.910 in dry season and 0.002 in wet season. Similar findings of 0.002 to 0.054mgil, (Musa et al., 2014).

Phosphates

Phosphate levels in all the boreholes during the dry and wet seasons were below 1mg/1. This is compared to United Kingdom drinking water standard. Phosphate concentrations of (1mg/l). However, too much phosphate can cause health problems such as kidney damage and osteoporosis. Phosphate shortages can occur due to extensive use of medicine. Also, too little can cause problems.

Heavy Metals

Cadmium (Cd)

Heavy metals are toxic to humans and to fish. They easily accumulate in fish and other tissue, therefore liable to enter food chain. Cadmium (Cd) in water is due to industrial discharges and leachates. Cadmium is highly toxic, therefore severe restrictions on its concentration in water has been formulated. It is released into the environment in wastewater and pollution by contamination from fertilizers, fossil fuels, coal, lead and copper ores. The physiological effects of Cadmium are bone damage, chronic kidney disease, cancer and hypertension. Cadmium values in borehole water sample during the dry season recorded 0.001mg/1 except boreholes in Ogoloma (0.071mg/1), George-Ama (0.016mg/1) and Kalio-Ama (0.052mg/1). During the wet season, all boreholes recorded 0.001mg/1.

WHO Guideline values for Cadmium is 0.003mg/1. Also, NSDWQ guideline value is 0.003mg/1.

Lead

Lead originated from effluent discharges which attack water pipes. Lead has toxic cumulative poison. It is one of the most commonly determined heavy metals. Exposure to lead include neurodevelopmental effects, mortality (due to cardiovascular disease), impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes. Damage to nervous system and red blood cells.

Lead values of 0.002mg/1 was recorded during the dry season in all the boreholes and 0.001mg/1 during the wet season all samples were within the limit of 0.01mg/l. The guideline limit for lead is 0.01mg/1 for WHO and NSDWQ. USEPA Action is 0.015mg/l while for Maximum Contaminant Goal Limit is 0.00mg/l

Zinc (Zn)

This occurs from wastes and natural geological occurrences. It is essential to man but if ingested in large amounts, it has a bad effect, like stomach cramps, nausea and vomiting. Water with a Zinc concentration of more than 5mg/1 may become chalky in appearance with a delectable deterioration in taste. Zinc in water through wastewater releases, industrial methods involving metals and atmospheric outcomes. Zinc inhalation can cause neurological toxicity, dizziness, pain, headache and tiredness (Sankhla et al., 2019)

Zinc values for all boreholes during the dry season recorded 0.005mg/1 while during the wet season, all boreholes recorded 0.001mg/1 except Okari-Ama (0.052mg/1) and Kalio-Ama (0.039).

WHO and NSDWQ guidelines limit for Zinc is 3mg/1. Jordian guideline for Zinc is at 0.01mg/1. Therefore, traces of Zinc metal were eminent in these boreholes. Zinc values in this study can be compared to values reported by Ubong et al. (2016), which ranged from 0.76mg/l to 0.185mg/l.

RESULTS OF WQI OF GROUNDWATER FROM OKRIKA AND ITS ENVIRONS

TABLE 8: WET SEASON

Parameter	**Observed Value**	**Standard Value (WHO)**	**Unit Weight (W_p)**	**Quality Rating (Q_p)**	**WQI (W_pQ_p)**
pH	5.59	6.5-8.5	0.011	282	3.102
Electrical Conductivity	1307	1000	0.0050	130.7	0.654
TDS	8118	600	0.052	1353	**70.356**
Salinity	14.8	200	0.0002822	7.4	0.0021
Turbidity	0.51	5	0.0004004	10.5	0.004204
Chlorine	8.92	5	0.006788	178	1.208
Bromine	0.01	0.05	0.0007627	20	0.015
DO	2.14	6	0.005525	144.884	0.80
BOD	0.48	0.002	0.915	24000	**21960**
Nitrate	0.92	50	0.0000702	1.84	0.0001292
Phosphate	0.47	0.5	0.003585	94	0.337
TOTAL			$\sum W_p = 1$	**26222**	**26240**

TABLE 9: DRY SEASON

Parameter	**Observed Value**	**Standard Value (WHO)**	**Unit Weight (W_p)**	**Quality Rating (Q_p)**	**WQI (W_pQ_p)**
pH	6.3	7.5	0.003266	140	0.457
Electrical Conductivity	115.9	1000	0.0002706	11.6	0.00314
TDS	91.67	600	0.000357	15.3	0.005462
Salinity	1.09	200	0.00001272	0.545	0.0000070
Turbidity	0.01	5	0.0000047	0.2	0.00000094
Chlorine	0.01	5	0.0000047	0.2	0.00000094
Bromine	0.01	0.05	0.0000047	20	0.0094
DO	0.94	6	0.00371	158.84	0.590
BOD	0.85	0.002	0.992	42500	42160
Nitrate	0.41	50	0.00001913	0.82	0.0000157
Phosphate	0.08	0.5	0.0003733	16.0	0.005973
TOTAL			$\sum W_p = 1$	**42860**	

The analysis has shown that the water status for wet and dry season is unfit for drinking.

V. CONCLUSION

The evaluation of the parameters that determine the level of contaminants to groundwater has been carried out. The methodology adopted is the standard one. The Biochemical Oxygen Demand (BOD) values obtained which reflect the Water Quality Index status is a key parameter that should be investigated further. The inference drawn for the study shows that the effluents from the process industries have impact on the groundwater resource.

The results from the area under study (Okrika Local Government Area) showed that water within the study area is not suitable for drinking. It is therefore imperative for relevant Agencies of Government; Local Government, State and Federal Government to monitor and regulate the activities of the process industries around Okrika Local Government. Besides, activities of illegal and unsafe refining of crude oil in the area should be brought under control.

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