Chapter

Toxicants in Water: Hydrochemical Appraisal of Toxic Metals Concentration and Seasonal Variation in Drinking Water Quality in Oil and Gas Field Area of Rivers State, Nigeria

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Abstract

Groundwater pollution is a major issue in many tropical countries. Governments at all levels are doing little or nothing to supply inhabitants with clean and accessible water, particularly in Nigeria's Niger Delta region. This study compares differences in water quality parameters in the study area (determine the level of pollutions in the different sites). The investigation made use of standard analytical methodologies. All sampling, conservation, transportation as well as analysis followed the usual APHA procedures (2012). To prevent degradation of the organic substances, all obtained samples were transferred to the laboratory, while keeping in an icebox. Result shows that during wet season, the mean values obtained for water quality parameters were significantly lower in site 9 compared with that obtained in other sites ($p < 0.05$) with the exemptions of temperature, DO, BOD, COD, acidity, TH, TDS, K, Mg, Zn, Mn, Cd, Pb, Cu, Cr, NH_3, NO_2, NO_3, Ni though slightly lower in most cases in site 9 were not significantly different ($p > 0.05$) and both alkalinity and SO_4 which were significantly higher in site **9** than site 1 ($p < 0.05$). Result obtained during dry season reveals that there is no remarkable difference in pH, acidity, Pb and Ni between the nine sites ($p > 0.05$) while other water quality parameters were significantly lower in site 9 than other sites excluding Cl and Mg which were both significantly higher in site 9 than site 8 ($p < 0.05$). Extra efforts must be made to completely understand the hydrogeochemical properties and appropriateness of groundwater in Nigeria's core Niger Delta region in order to ensure quality groundwater supply for varied applications. As a result, this research will contribute to the establishment of a quantitative understanding of the effects of many causes on groundwater level changes in every aquifer worldwide. This analysis also reinforces a useful resource for scholars, activists, and public officials looking to improve community awareness, planning, and performance. The verdicts will serve as a valuable guideline for policymakers, the Ministry of Water Resources, and development practitioners, as they highlight the need for appropriate approaches to mitigating toxic elements of water resource contamination in the core Niger Delta in order to protect public health from carcinogenic and non-carcinogenic risks.

Keywords: reproductive health, human health risk, toxicants, community awareness, extractive industry, Core Niger Delta, Nigeria

1. Introduction

Approximately 80% of houses in Niger Delta rely on this domestic water supply. Concern about safety of groundwater supplies have centered on pollution induced by human activities, with natural contamination receiving less attention [1–4]. This is linked to a lack of safe water, which exacerbates health issues and reduces productivity. According to the UNDP [5] only about a quarter (24%) of the indigenous people and half of the urban population in the Niger Delta have access to safe drinking water. This is consistent with the findings of a Bayelsa State Micro Credit Administration Agency poverty baseline survey, which revealed that only a small percentage of the indigenous populace has access to safe drinkable water [6]. However, several studies (e.g., [6-11]) have shown and document (scientifically) that the increasing presence of geogenic contaminants in the Niger Delta can have serious health effects as well as wellbeing on the indigenous population, thus leading to both environmental and community concerns, resulting in the prohibition of oil and gas companies in some locations. Access to safe drinking-water is a key health as well as development concern at the local, regional and national levels [6–11]. As groundwater becomes an important source of freshwater for residential use in the Niger Delta and most Nigerian cities, it is necessary to analyze its quality, particularly in terms of geogenic contaminants. This is due to the fact that people rely on groundwater from shallow aquifers, putting a significant number of people at risk of contamination. While, trace elements are among the few compounds that have been shown to cause severe health concerns in humans as a result of excessive drinking-water exposure [6, 12–15]. The study aims to compare water quality parameters in the study region (determine the level of pollutions in the different sites) in the vicinity of "Gas Flaring Area of Ebocha-Obrikom of Rivers State, Nigeria". This research will provide valuable information and add to our understanding on the physico-chemical examination of drinking water associated with the contamination of the ground waters by petroleum products. Hence, the study will help in integrating the health needs of the populace into the state health scheme, in recognition of the fact that health is required for national development. The study will also bring to the awareness of the local people the type of water that is good for them as drinking water according to recommended standards. It will provide a structural framework for effective management of groundwater and provide an available reference source and base line data for researchers involved in water resources assessment.

2. Material and methods

2.1 The study area

Ebocha-Obrikom is located among latitude 5°20 N–5°27 N as well as longitude 6°40 E–6°4 6E (**Figure 1**). It includes the towns of Obor, Obie, Obrikom, Agip New

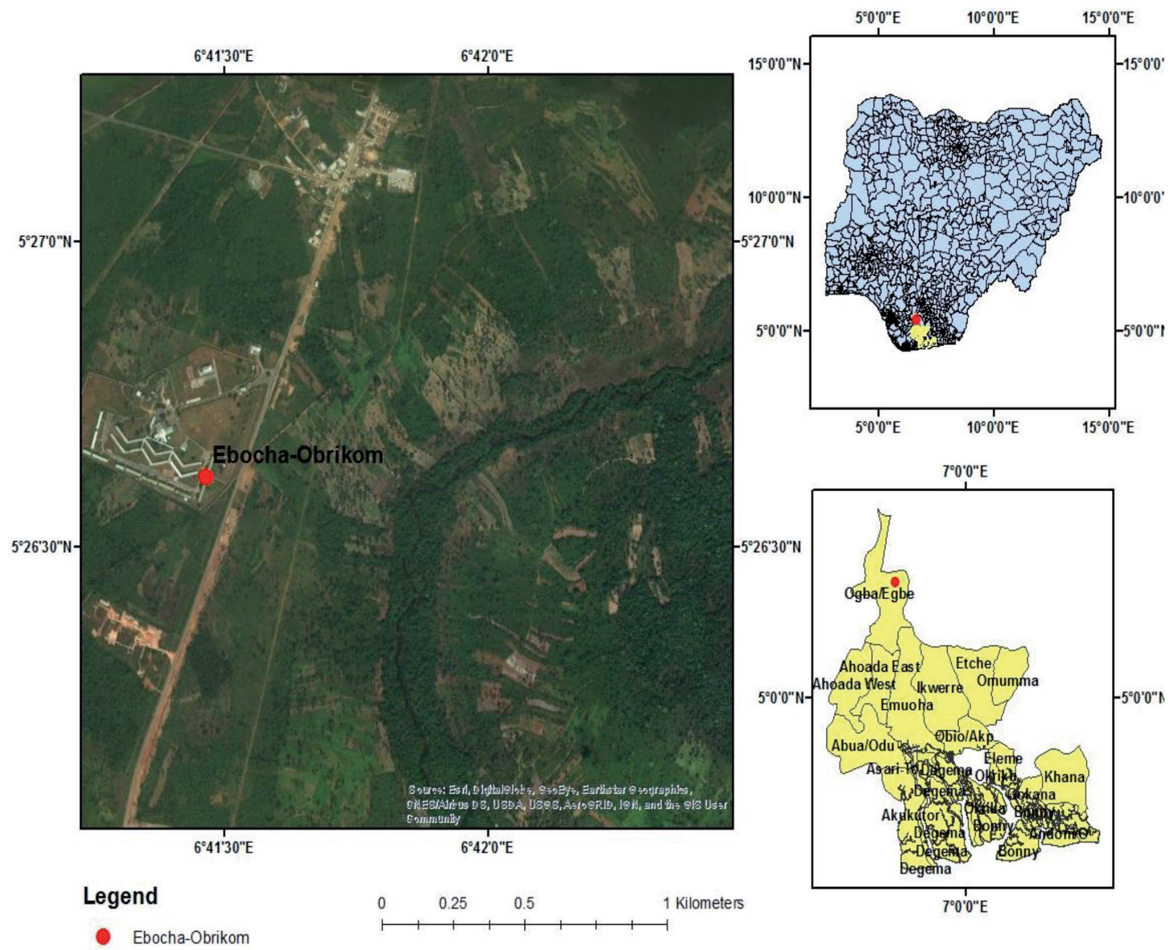

Figure 1.
Map showing the study area with Nigeria and River State insert. Sources: Adapted from Olalekan et al. [14].

Base and Ebocha, all of which are positioned in Ogba/Egbema/Ndoni Area (**Figure 1**) of Rivers State. The research study area is bordered to the North by the Nkissa River, to the West by the Orashi River, to the East by the Sombrero River, and to the South by Omoku town [1, 2].

2.2 Sample collection

The current research inquiry used a sample method similar to that used by Morufu and Clinton [13], Raimi and Sabinus [12], and Olalekan et al. [14], in which sampling was targeted in selected vulnerable quarters in a highly populated environment. These areas are prone to pollution not just due to their physical location, but also due to the existence of crude petroleum exploration and exploitation. Water samples were taken from groundwater sources near the sampling location (see **Table 1** below) and used mostly for drinking and domestic purposes. Only groundwater from dug wells or shallow pumping wells built specifically for residential use was sampled. The wells range in depth from 10 to 28 meters, indicating that they are in a phreatic aquifer. Portable GPS devices were used to record the sampling locations. Ground water sources in the neighborhood of the depot were chosen at random but at varying distances from one another for the purposes of this experiment. Furthermore, samples were manually collected from nine (9) strategic locations in the study area for ground water (boreholes and wells) into previously washed clean plastic sampling bottles after approximately 20 min of continuous water flow to ensure adequate aquifer that can remain suitably represented.

S/N	Locations	Altitude (m)	Latitude	Longitude
Site—1	(Borehole) (opposite Ijeoma Quarters. 750 m away from Agip Gas Flaring Center Ebocha)	10	Lat N05°27′068″	Long E006°41′480″
Site—2	(Borehole) (200 m opposite Agip Gas Flaring Centre Ebocha and 50 m from Agip Waste Pit)	—	Lat N05°27′28.7″	Long E006°41′58.1″
Site—3	(Well) (The Apple Hotel 500 m from Waste Pit and 150 m away from Mgbede Field Oil Well 7 Ebocha)	16	Lat N05°27′37.5″	Long E006°42′05.3″
Site—4	(Well) (1000 m away from the Agip Flare Stack Ebocha)	22	Lat N05°26′51.5″	Long E006°41′38.8″
Site—5	(Borehole) (Abacha Road Obrikom, 800 m away from Agip Gas Plant)	—	Lat N05°23′48.6″	Long E006°40′36.8″
Site—6	(Borehole) (Eagle Base Obor. 2500 m away from Agip Gas Plant)	28	Lat N05°23′00.9″	Long E006°41′07.4″
Sites—7	(Well) (Obor Road Obie. 2000 m away from Agip Gas Plant)	24	Lat N05°23′22.5″	Long E006°40′ 49.1″
Sites—8	(Borehole) (Green River Plant Propagation Centre Naoc 3000 m away from Agip Gas Plant)	17	Lat N05°24′18.9″	Long E006°40′55.0″
Sites—9	(Control) (35,000 m from Ebocha)	—	Lat N5°4′58.1412″	Long E6°39′30.4806″

Table 1.
Geographical coordinates of the nine (9) sampling sites (samples).

All samples were collected during the day, from 9:00 am to 4:00 pm. As a result of flooding, insecurity as well as lockdown from COVID-19. Night samples were not taken, and the sampling took place between the month of September 2019 and August 2020.

2.3 Sampling, preservation and analysis

Water sampling, conservation, transportation, and analysis have all been carried out in accordance with the standard methods specified in APHA [16]; Morufu and Clinton [13]; Raimi and Sabinus [12]; Olalekan et al. [14]; Morufu et al. [2].

2.4 Ground water collection

Ground water samples were obtained in pre-rinsed 1litre plastic containers for analyses of physico-chemical characteristics. Prior to storage, pre-rinsed ground water samples for trace metal analyses remained obtained in 1litre containers with nitric acid and treated with 2 ml nitric acid (assaying 100%, Fisher Scientific, Trace Metal Grade). These steps were taken to keep the metals oxidation settings stable. For Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) assays, groundwater samples remained obtained in two groups of 250 ml glass-stoppered-reagent bottles per sampling site. The BOD samples were carefully filled without air trapping and the bottles were wrapped in black polythene bags. This was done to exclude the presence of light in the samples, which was capable of creating DO by autotrophes (algae). The BOD samples were cultured for 5 days before being added to 2 ml of each sample. Winkler solutions I and II apply various dropping pipettes to each sample to slow

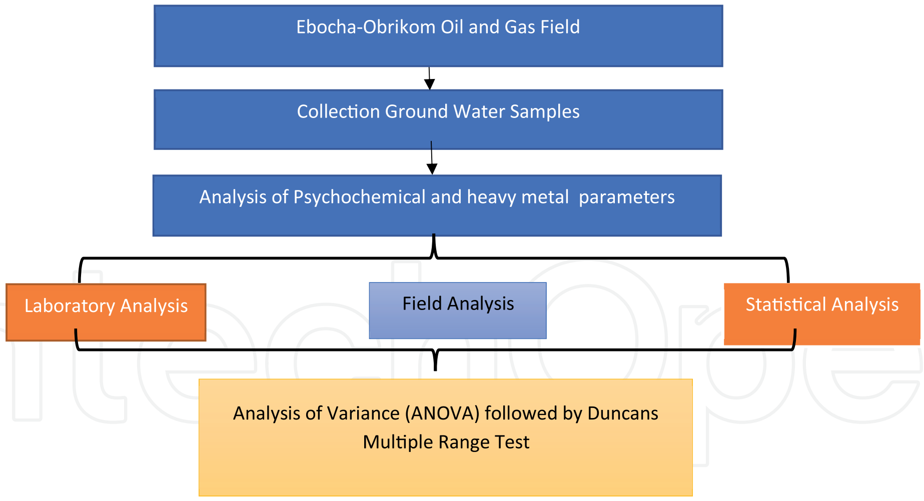

Figure 2.
A schematic illustration of quantification methodology adopted for the current study.

down additional biological activity. To precipitate the floc that was at the bottom of the bottles, the bottles were thoroughly shaken. Furthermore, Winkler solution I is a manganese sulphate solution, whereas solution II is a mixture of sodium or potassium iodide, sodium azide (sodium nitride), sodium or potassium hydroxide as well as sodium hydroxide. The samples of DO were collected in transparent bottles with tight-fitting stoppers. With dissolved oxygen samples kept on the spot using Winkler I and II solutions identical to those used for BOD samples [16]. For simple identification, all samples had remained carefully identified and kept at 4°C. On-site measurements were taken to determine the unstable concentrations and sensitive water quality indicators such as pH, electrical conductivity (EC), total dissolved solids (TDS), alkalinity (Alka.) as well as temperature (Temp). As a result, **Figure 2** depicts the key methodologies for researching groundwater composition.

2.5 Quality assurance and quality control (QA/QC)

Furthermore, using high purity analytical reagents and solvents, all analytical methods remained closely monitored using quality assurance and control methodologies. The instruments were calibrated using calibration standards. The analytical technique validation included the use of triplicate analysis, procedure blanks and the examination of certified reference materials (CRM). The limit of detection (LoD), precision, reproducibility, repeatability and accuracy of each organic pollutant from the groundwater samples were determined.

3. Results and discussion

3.1 Compare differences in water quality parameters in the study area (determine the level of pollutions in the different sites)

Trace elements exist in a variety of forms, including oxides, salts, organometallic complexes, sulphides, and dissolved ions in groundwater and soil. Chemical processes are driven by the partitioning of water, air as well as soil through particles adsorption or pH-dependent water dissolution [1–3, 6, 13, 17]. Thus, **Tables 2** and **3** provide the statistical analysis findings for the physicochemical parameters. The Ebocha-Obrikom area of Rivers State is significant for irrigation, drinking, as well as industrial uses [1–3, 6, 12–14]. Over the previous three decades it has been significantly altered by population expansion and increased agricultural productivity. A detailed analysis of groundwater geochemistry as well as associated estimation of community's health risk that are visible to the groundwater, remain yet to be carried out. A clear understanding of the utmost significant aspects regulating the health risks is vital toward taking effective management measures for the residents regarding drinking water. Thirty-four (34) water quality parameters were analyzed during rainy and dry season respectively. Eighteen (18) parameters such as temperature, pH, conductivity, turbidity, DO, BOD, Acidity, TSS, Salinity, Fluoride, Aluminum, Potassium, Magnesium, Iron, Zinc, Manganese, Cadmium and TPH were lowest at location nine (9) during the rainy season. For dry season, twenty-two (22) parameters, which include: turbidity, BOD, Acidity, TH, TDS, TSS, Salinity, Fluoride, Aluminum, Potassium, Calcium, Iron, Zinc, Manganese, Cadmium, Copper, Chromium, Sulphate, Ammonia, Phosphate, Nickel and TPH recorded minimum values below limits of detection in sampling locations nine (9). Thus, the results showed a significant disparity between the various sampling locations. As it is evident that samples from location 1 to location 9 must remain adequately observed since, there may be a remarkable increase in these heavy metal level in the future, which could eventually cause health-related threats for indigenous residents. While, there is high temperature variation in this region. Temperature was found to be highest with an average value of (28.77–32.46)°C at location 4 and 2 during the rainy and dry seasons. While it was lowest (26.01–29.00)°C at location 9 and 6 during the rainy and dry season. The maximum permissible limit for temperature has not been stated but ambient in nature. Groundwater temperature tend to be influenced more by dry season than rainy season. Thus, Morufu and Clinton [13]; Raimi and Sabinus, [12] and Olalekan et al. [14] indicated that temperature of groundwater in areas prone to pollution and gas flaring typically is higher than that of the surrounding environment, a study has shown. Unarguably, an increase in air temperature at a gas flare site must have led to a rise in groundwater temperature. Hence, rising temperature may adversely impact agriculture, thereby increasing the vulnerability of marginalized agriculture-dependent rural populations. This is particularly true for communities in Ogba/Egbema/Ndoni Local Government Area of Rivers State, which is home to Agip's Ebocha, Obrikom oil and gas facilities. The people of Ogba are predominantly fishermen and farmers who rely on groundwater and small streams for their water supply. Ogba is abundant in natural gas as well as is home to the state-owned gas turbine facility. There are several large and functioning gas stacks in the community. Water pH represents hydrogen ion concentration as well as is affected by the interaction of several compounds dissolved in water. The pH range in which aquatic creatures thrive varies [6, 14]. It is in itself poisonous at a certain level and can influence the toxicity of heavy metals and cyanides. The pH of water is determined by the carbonate cycle, which is composed of CO_2, H_2CO_3, HCO_3^- and CO_3^{-2}. The pH has no direct impact on human health but can change water taste as well as exhibit linked to other water quality characteristics [1–3, 6, 14, 18]. The alkalinity remarkability lies in its role for carbon dioxide chemistry, trace metal speciation and buffer capacity of the groundwater. Hydrogen-ion-concentration (pH) is a master control measure in the environment that demonstrates the chemical as well as biological features of water. pH ranges from 5.82 to 7.98, depending on the environment, with values

	Location								
Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Temperature (°C)	28.63 ± 2.46^{a}	28.24 ± 2.06^{a}	27.83 ± 2.62^{a}	28.77 ± 1.73^{a}	27.96 ± 1.50^{a}	28.01 ± 1.18^{a}	28.27 ± 1.61^{a}	26.79 ± 1.80^{a}	26.01 ± 2.10^{a}
Hydrogen potential (pH)	7.20 ± 1.37^{c}	7.98 ± 0.73^{c}	7.06 ± 1.05^{c}	6.27 ± 0.59^{b}	6.49 ± 0.95^{b}	5.92 ± 0.27^{a}	6.44 ± 1.74^{b}	6.13 ± 0.52^{b}	5.82 ± 0.28^{a}
Conductivity (ЧSCM^{-1})	48.09 ± 24.23^{d}	52.29 ± 28.76^{d}	30.99 ± 18.42^{c}	18.57 ± 9.24^{a}	20.96 ± 9.27^{a}	36.88 ± 25.03^{c}	27.48 ± 14.18^{b}	26.93 ± 11.24^{b}	24.22 ± 7.61^{a}
Turbidity (NTU)	7.41 ± 2.97^{a}	7.36 ± 6.50^{a}	42.43 ± 14.40^{d}	31.43 ± 11.72^{c}	11.14 ± 5.05^{b}	3.35 ± 1.18^{a}	48.24 ± 20.57^{d}	4.99 ± 1.56^{a}	1.78 ± 0.66^{a}
Dissolved oxygen (DO) (mg/l)	17.27 ± 0.81^{a}	17.21 ± 1.38^{a}	17.84 ± 1.29^{a}	16.91 ± 1.19^{a}	16.37 ± 0.43^{a}	16.42 ± 0.45^{a}	17.01 ± 0.89^{a}	16.99 ± 0.73^{a}	16.29 ± 0.37^{a}
(BOD) (mg/l)	5.35 ± 0.29^{a}	5.31 ± 0.44^{a}	5.05 ± 0.10^{a}	5.48 ± 0.37^{a}	5.21 ± 0.40^{a}	5.42 ± 0.44^{a}	5.26 ± 0.21^{a}	5.47 ± 0.39^{a}	4.98 ± 0.10^{a}
(COD) (mg/l)	40.06 ± 12.15^{a}	37.27 ± 8.79^{a}	39.61 ± 11.84^{a}	41.78 ± 13.07^{a}	39.72 ± 6.80^{a}	32.03 ± 9.65^{a}	33.50 ± 7.15^{a}	32.75 ± 6.61^{a}	32.64 ± 6.57^{a}
Acidity (mg/l)	90.11 ± 48.55^{a}	90.96 ± 45.54^{a}	101.18 ± 46.68^{a}	90.01 ± 42.52^{a}	87.11 ± 42.97^{a}	89.92 ± 42.26^{a}	99.56 ± 46.44^{a}	86.18 ± 35.99^{a}	85.53 ± 45.14^{a}
Alkalinity (mg/l)	103.73 ± 60.46^{b}	119.56 ± 58.6^{b}	18.17 ± 7.42^{a}	134.96 ± 50.03^{b}	119.23 ± 65.28^{b}	119.15 ± 65.15^{b}	130.93 ± 43.65^{b}	134.76 ± 47.90^{b}	117.73 ± 63.97^{b}
(TH) (mg/l)	41.06 ± 2.27^{a}	41.49 ± 4.18^{a}	42.22 ± 2.26^{a}	37.71 ± 9.49^{a}	35.02 ± 7.45^{a}	37.64 ± 9.47^{a}	39.48 ± 3.08^{a}	40.30 ± 2.58^{a}	37.64 ± 4.64^{a}
TDS (mg/l)	11.12 ± 3.77^{a}	11.50 ± 3.89 ^{a}	8.24 ± 3.98 ^{a}	9.31 ± 4.62 ^{a}	9.27 ± 4.71 ^{a}	10.11 ± 5.14 ^{a}	8.06 ± 4.50 ^{a}	7.88 ± 4.27 ^{a}	10.61 ± 2.06 ^{a}
TSS (mg(l)	39.80 ± 3.66^{b}	34.72 ± 2.65 ^{a}	35.96 ± 1.95^{a}	37.49 ± 2.30 ^{b}	37.28 ± 1.85^{b}	37.11 ± 1.91 ^{b}	38.40 ± 3.05^{b}	38.73 ± 3.12^{b}	34.00 ± 2.47^{a}
Salinity (mg/l)	0.12 ± 0.08^{a}	0.14 ± 0.10^{a}	11.50 ± 10.60^{c}	15.74 ± 11.29 ^{c}	0.07 ± 0.01^{a}	1.71 ± 0.76^{b}	25.71 ± 5.35^{c}	0.09 ± 0.08 ^{a}	0.01 ± 0.02^{a}
Chloride (mg/l)	30.61 ± 2.11^{b}	31.43 ± 1.50 ^{b}	32.16 ± 1.81 ^{b}	32.10 ± 0.51 ^{b}	31.66 ± 0.24 ^{b}	31.13 ± 0.70 ^{b}	28.33 ± 1.96^{a}	29.05 ± 2.34^{a}	28.97 ± 2.31^{a}

Parameters	Location								
	1	2	3	4	5	6	7	8	9
Fluoride (mg/l)	0.00 ± 0.00 ^{a}	0.00 ± 0.00 ^{a}	0.00 ± 0.00^{a}	0.29 ± 0.27^{b}	0.53 ± 0.43 ^{b}	0.82 ± 0.25 ^{c}	0.85 ± 0.34^{c}	0.79 ± 0.31^{s}	0.00 ± 0.00 ^{a}
Aluminum (mg/l)	0.00 ± 0.00 ^{a}	0.00 ± 0.00^{a}	0.01 ± 0.01^{a}	0.01 ± 0.01^{a}	0.02 ± 0.00 ^{b}	0.02 ± 0.01^{b}	0.03 ± 0.01^{b}	0.02 ± 0.01^{b}	0.00 ± 0.00^{a}
Sodium (mg/l)	12.32 ± 2.38^{a}	16.06 ± 1.99	12.22 ± 2.72 ^{a}	14.54 ± 0.80^{b}	14.45 ± 1.07^{b}	14.65 ± 0.90^{b}	16.39 ± 0.20^{b}	15.48 ± 2.40^{b}	12.85 ± 2.63 ^{a}
Potassium (K) (mg/l)	2.65 ± 0.76 ^{a}	2.49 ± 0.61 ^{a}	3.14 ± 0.03 ^{a}	3.23 ± 0.56 ^{a}	2.97 ± 0.64 ^{a}	3.07 ± 0.52 ^{a}	3.10 ± 0.04 ^{a}	3.29 ± 0.17 ^{a}	2.42 ± 0.59 ^{a}
Calcium (Ca) (mg/l)	52.22 ± 7.67 ^{a}	52.58 ± 8.57 ^{a}	56.20 ± 8.18 ^{b}	59.76 ± 6.15^{b}	59.72 ± 6.47^{b}	50.31 ± 6.60^{a}	59.98 ± 6.29^{a}	51.99 ± 7.61^{a}	50.47 ± 6.77^{a}
Magnesium (mg/l)	137.23 ± 11.45 ^{a}	136.11 ± 12.02 ^{a}	132.71 ± 48.02 ^{a}	129.99 ± 37.38 ^{a}	129.26 ± 37.07 ^{a}	129.66 ± 37.10 ^{a}	146.67 ± 21.78 ^{a}	145.74 ± 19.58 ^{a}	129.26 ± 37.07 ^{a}
Iron (mg/l)	2.23 ± 0.42 ^{a}	2.29 ± 0.73 ^{a}	3.27 ± 0.98 ^{b}	2.96 ± 2.18^{b}	4.01 ± 0.12^{c}	2.06 ± 0.02 ^{a}	5.16 ± 1.74 ^{c}	3.37 ± 1.60 ^{b}	1.21 ± 0.20 ^{a}
Zinc (mg/l)	0.67 ± 0.16 ^{a}	0.72 ± 0.15 ^{a}	0.77 ± 0.09 ^{a}	0.66 ± 0.24 ^{a}	0.67 ± 0.23 ^{a}	0.64 ± 0.17 ^{a}	0.67 ± 0.23 ^{a}	0.57 ± 0.04 ^{a}	0.56 ± 0.04 ^{a}
Manganese (mg/l)	0.02 ± 0.01 ^{a}	0.03 ± 0.02 ^{a}	0.02 ± 0.02 ^{a}	0.03 ± 0.02 ^{a}	0.04 ± 0.02 ^{a}	0.03 ± 0.02 ^{a}	0.02 ± 0.02 ^{a}	0.03 ± 0.03 ^{a}	0.00 ± 0.00 ^{a}
Cadmium (mg/l)	0.01 ± 0.02 ^{a}	0.02 ± 0.02 ^{a}	0.00 ± 0.00 ^{a}	0.01 ± 0.03 ^{a}	0.00 ± 0.00 ^{a}	0.00 ± 0.00 ^{a}	0.02 ± 0.03 ^{a}	0.02 ± 0.03 ^{a}	0.00 ± 0.00 ^{a}
Lead (mg/l)	0.12 ± 0.04 ^{a}	0.11 ± 0.07 ^{a}	0.09 ± 0.08 ^{a}	0.11 ± 0.05 ^{a}	0.09 ± 0.06 ^{a}	0.13 ± 0.07 ^{a}	0.14 ± 0.06 ^{a}	0.12 ± 0.08 ^{a}	0.11 ± 0.04 ^{a}
Copper (mg/l)	0.03 ± 0.03 ^{a}	0.04 ± 0.03 ^{a}	0.03 ± 0.03 ^{a}	0.04 ± 0.04 ^{a}	0.03 ± 0.04 ^{a}	0.05 ± 0.04 ^{a}	0.03 ± 0.04 ^{a}	0.03 ± 0.04 ^{a}	0.03 ± 0.03 ^{a}
Chromium (mg/l)	0.76 ± 1.21 ^{a}	0.60 ± 0.28 ^{a}	0.60 ± 0.28 ^{a}	0.56 ± 0.32 ^{a}	1.29 ± 1.05 ^{a}	1.17 ± 0.86 ^{a}	0.81 ± 1.06 ^{a}	1.27 ± 0.99 ^{a}	0.82 ± 1.30 ^{a}
Sulphate (mg/l)	0.87 ± 0.20 ^{a}	0.86 ± 0.17 ^{a}	0.86 ± 0.17 ^{a}	0.99 ± 0.22 ^{b}	0.92 ± 0.02 ^{b}	0.85 ± 0.04 ^{a}	0.84 ± 0.05 ^{a}	0.85 ± 0.11 ^{a}	0.94 ± 0.12 ^{b}

	Location								
Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Ammonia (mg/l)	2.63 ± 1.01 ^{a}	2.79 ± 1.11 ^{a}	2.79 ± 1.11 ^{a}	2.79 ± 1.20 ^{a}	2.76 ± 1.08 ^{a}	2.80 ± 1.10 ^{a}	2.75 ± 1.06 ^{a}	2.22 ± 1.00 ^{a}	2.38 ± 1.03 ^{a}
Phosphate (mg/l)	0.15 ± 0.16 ^{a}	0.38 ± 0.02 ^{a}	0.38 ± 0.02 ^{a}	0.18 ± 0.15 ^{a}	0.24 ± 0.14 ^{a}	0.21 ± 0.14 ^{a}	0.20 ± 0.13 ^{a}	0.23 ± 0.20 ^{a}	0.24 ± 0.23 ^{a}
Nitrite (mg/l)	1.90 ± 1.12 ^{a}	1.70 ± 1.06 ^{a}	1.70 ± 1.06 ^{a}	2.33 ± 1.60 ^{a}	2.10 ± 1.62 ^{a}	1.66 ± 1.08 ^{a}	1.90 ± 1.09 ^{a}	1.95 ± 1.15 ^{a}	1.61 ± 0.48 ^{a}
Nitrate (mg/l)	2.87 ± 1.28 ^{a}	2.34 ± 0.80 ^{a}	2.34 ± 0.80 ^{a}	3.23 ± 0.71 ^{b}	3.36 ± 1.11 ^{b}	2.33 ± 0.76 ^{a}	1.90 ± 0.17 ^{a}	2.23 ± 0.67 ^{a}	2.01 ± 0.16 ^{a}
Nickel (mg/l)	0.97 ± 0.61 ^{a}	0.91 ± 0.26 ^{a}	0.91 ± 0.26 ^{a}	1.00 ± 0.42 ^{a}	0.90 ± 0.25 ^{a}	0.84 ± 0.22 ^{a}	0.94 ± 0.15 ^{a}	0.94 ± 0.17 ^{a}	0.95 ± 0.15 ^{a}
TPH (mg/l)	14.86 ± 0.38 ^{d}	10.41 ± 4.55 ^{c}	13.861 ± 1.21 ^{d}	13.00 ± 1.52 ^{d}	2.81 ± 1.58 ^{b}	11.57 ± 1.62 ^{c}	4.07 ± 0.94 ^{b}	3.84 ± 0.45 ^{b}	0.001 ± 0.00 ^{a}

Similar superscript means not significantly different ($p > 0.05$) while different superscripts indicates significantly difference in means ($p < 0.05$).

Table 2.
Comparison of the parameters in the different locations during rainy season.

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	Location								
Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Temperature (°C)	32.38 ± 0.58^{b}	32.46 ± 1.33^{b}	30.98 ± 0.92^{b}	29.62 ± 1.23^{a}	30.50 ± 0.96^{b}	29.00 ± 1.05^{a}	29.70 ± 0.64^{a}	29.74 ± 1.17^{a}	29.52 ± 1.17^{a}
pH	7.23 ± 0.90^{a}	5.99 ± 0.48^{a}	6.43 ± 0.70^{a}	6.99 ± 1.03^{a}	6.54 ± 0.57^{a}	7.22 ± 1.17^{a}	6.16 ± 1.01^{a}	6.56 ± 0.60^{a}	6.02 ± 0.19^{a}
Conductivity (ЧSCM^{-1})	35.66 ± 8.36^{c}	11.93 ± 1.27^{a}	32.26 ± 0.21^{c}	46.76 ± 15.34^{d}	39.35 ± 17.98^{c}	14.44 ± 2.08^{a}	24.58 ± 6.55^{b}	18.97 ± 0.3^{a}	17.34 ± 6.80^{a}
Turbidity (NTU)	5.27 ± 1.36^{a}	4.39 ± 4.26^{a}	11.40 ± 12.64^{b}	11.56 ± 8.23^{b}	2.84 ± 1.55^{a}	3.09 ± 1.19^{a}	16.75 ± 2.54^{c}	1.89 ± 0.19^{a}	1.82 ± 0.15^{a}
DO (mg/l)	18.69 ± 0.04^{b}	18.46 ± 1.17^{b}	19.10 ± 0.9^{b}	18.48 ± 0.54^{b}	17.09 ± 0.04^{a}	17.03 ± 0.14^{a}	17.90 ± 0.03^{a}	17.86 ± 0.28^{a}	17.09 ± 0.05^{a}
BOD) (mg/l)	5.60 ± 0.09^{b}	5.33 ± 0.44^{b}	4.95 ± 0.16^{a}	5.75 ± 0.11^{b}	6.03 ± 0.02^{c}	6.09 ± 0.05^{c}	5.54 ± 0.04^{b}	5.98 ± 0.11^{c}	4.86 ± 0.08^{a}
COD (mg/l)	21.87 ± 0.61^{a}	24.58 ± 0.26^{a}	22.64 ± 0.27^{a}	32.49 ± 12.21^{b}	24.53 ± 0.27^{a}	24.20 ± 0.06^{a}	23.19 ± 0.28^{a}	23.79 ± 0.19^{a}	22.53 ± 0.34^{a}
Acidity (mg/l)	156.72 ± 4.79^{a}	158.18 ± 11.08^{a}	168.82 ± 1.22^{a}	151.82 ± 0.44^{a}	152.18 ± 2.90^{a}	150.53 ± 0.88^{a}	167.09 ± 0.46^{a}	167.51 ± 0.49^{a}	138.08 ± 49.31^{a}
Alkalinity (mg/l)	53.52 ± 41.47^{b}	52.43 ± +46.56^{b}	30.57 ± 8.94^{a}	62.47 ± 0.47^{b}	23.66 ± 0.09^{a}	23.88 ± 0.26^{a}	64.25 ± 0.14^{b}	64.58 ± 0.47^{b}	24.22 ± 0.66^{a}
TH (mg/l)	44.79 ± 1.18^{b}	36.44 ± 1.52^{a}	37.35 ± +1.27^{a}	50.95 ± 0.68^{c}	51.66 ± 0.11^{c}	51.37 ± +0.30^{c}	43.38 ± 0.60^{b}	44.42 ± 0.52^{b}	35.78 ± 3.07^{a}
TDS (mg/l)	6.37 ± 1.11^{a}	7.56 ± 3.32^{a}	14.84 ± 0.17^{b}	16.25 ± 0.39^{c}	16.15 ± 0.12^{c}	15.72 ± 0.18^{c}	14.15 ± 0.42^{b}	14.01 ± 0.14^{b}	6.03 ± 0.07^{a}
TSS (mg(l)	34.66 ± 0.44^{d}	31.30 ± 0.76^{b}	32.20 ± 1.04^{c}	34.52 ± 0.27^{d}	34.54 ± 0.23^{d}	34.14 ± 0.20^{d}	33.77 ± 0.11^{d}	34.76 ± 0.43^{d}	29.56 ± 0.99^{a}
Salinity (mg/l)	0.11 ± 0.08^{a}	0.09 ± 0.04^{a}	16.00 ± 8.94^{b}	12.02 ± 13.02^{b}	0.11 ± 0.11^{a}	0.71 ± 0.39^{a}	8.00 ± 8.37^{b}	0.18 ± 0.06^{a}	0.04 ± 0.03^{a}
Chloride (mg/l)	27.10 ± 1.62^{b}	27.62 ± 0.88^{b}	29.22 ± 0.37^{d}	31.16 ± 0.03^{e}	31.27 ± 0.19^{e}	30.36 ± 0.35^{e}	25.26 ± 0.39^{a}	25.49 ± 0.54^{a}	26.44 ± 0.51^{b}
Fluoride (mg/l)	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.02 ± 0.04^{a}	0.68 ± 0.41^{b}	0.45 ± 0.00^{b}	1.02 ± 0.22^{c}	0.32 ± 0.29^{b}	0.00 ± 0.00^{a}
Aluminum (mg/l)	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.01 ± 0.00^{a}	0.01 ± 0.01^{b}	0.00 ± 0.01^{a}	0.02 ± 0.01^{b}	0.01 ± 0.00^{b}	0.00 ± 0.00^{a}

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	Location								
Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Sodium (mg/l)	9.47 ± +2.00^{a}	11.77 ± 0.12^{b}	9.22 ± 1.95^{a}	13.33 ± 0.16^{c}	12.66 ± 0.12^{b}	13.11 ± 0.21^{c}	11.70 ± 0.15^{b}	11.81 ± 0.19^{b}	9.41 ± 1.19^{a}
Potassium (K) (mg/l)	1.52 ± 0.05^{a}	1.57 ± 0.38^{a}	3.03 ± 0.03^{b}	4.11 ± 0.03^{c}	3.79 ± 0.13^{b}	3.81 ± 0.12^{b}	3.04 ± 0.02^{b}	3.11 ± 0.04^{b}	1.37 ± 0.36^{a}
Calcium (Ca) (mg/l)	44.38 ± 2.21^{b}	46.32 ± 6.36^{b}	44.33 ± 0.41^{b}	50.73 ± 0.11^{c}	50.58 ± 0.09^{c}	40.56 ± 0.29^{a}	50.44 ± 0.30^{c}	40.59 ± 0.21^{a}	40.37 ± 0.47^{a}
Magnesium (mg/l)	149.44 ± 10.30^{a}	151.87 ± 1.82^{a}	178.57 ± 0.25^{c}	184.68 ± 0.25^{d}	184.35 ± 0.57^{d}	184.28 ± 0.89^{d}	178.13 ± 0.71^{c}	175.85 ± 4.68^{c}	184.35 ± 0.57^{d}
Iron (mg/l)	1.74 ± 0.45^{a}	2.47 ± 1.27^{b}	3.82 ± 1.00^{c}	1.07 ± 0.52^{a}	2.71 ± 1.62^{b}	1.85 ± 0.45^{a}	4.42 ± 1.56^{c}	2.88 ± 1.64^{b}	0.95 ± 0.02^{a}
Zinc (mg/l)	0.86 ± 0.10^{b}	0.83 ± 0.12^{b}	0.91 ± 0.04^{c}	1.01 ± 0.00^{c}	1.00 ± 0.00^{c}	0.85 ± 0.04^{b}	0.80 ± 0.45^{b}	0.63 ± 0.02^{a}	0.61 ± 0.00 ^{a}
Manganese (mg/l)	0.04 ± 0.02^{a}	0.04 ± 0.01^{a}	0.07 ± 0.01^{c}	0.08 ± 0.00^{c}	0.08 ± 0.00^{c}	0.06 ± 0.01^{b}	0.06 ± 0.00^{b}	0.07 ± 0.00^{c}	0.03 ± 0.01^{a}
Cadmium (mg/l)	0.04 ± 0.00^{b}	0.05 ± 0.01^{c}	0.01 ± 0.00 ^{a}	0.06 ± 0.00^{d}	0.01 ± 0.00^{a}	0.01 ± 0.00^{a}	0.06 ± 0.00^{d}	0.05 ± 0.00^{c}	0.01 ± 0.00^{a}
Lead (mg/l)	0.01 ± 0.02^{a}	0.01 ± 0.00^{a}	0.03 ± 0.06^{b}	0.01 ± 0.00^{a}	0.01 ± 0.00^{a}	0.01 ± 0.01^{a}	0.01 ± 0.00^{a}	0.00 ± 0.00^{a}	0.01 ± 0.00^{a}
Copper (mg/l)	0.07 ± 0.00^{a}	0.08 ± 0.01^{b}	0.07 ± 0.01^{a}	0.09 ± 0.01^{c}	0.08 ± 0.00^{b}	0.08 ± 0.00^{b}	0.08 ± 0.01^{a}	0.09 ± 0.01^{c}	0.07 ± 0.01^{a}
Chromium (mg/l)	2.59 ± 0.03^{c}	1.01 ± 0.00^{b}	0.81 ± 0.28^{b}	2.81 ± 0.04^{c}	2.76 ± 0.06^{c}	2.38 ± 0.30^{c}	2.63 ± 0.08^{c}	2.76 ± 0.06^{c}	0.49 ± 0.49^{a}
Sulphate (mg/l)	1.08 ± 0.18^{b}	1.21 ± 0.01^{a}	1.17 ± 0.12^{b}	0.96 ± 0.01^{a}	0.93 ± 0.02^{a}	0.88 ± 0.05^{a}	0.99 ± 0.02^{a}	1.01 ± 0.01^{b}	0.88 ± 0.05^{a}
Ammonia (mg/l)	3.79 ± 0.86^{b}	4.30 ± 0.13^{c}	4.39 ± 0.26^{c}	3.97 ± 0.98^{c}	4.35 ± 0.12^{c}	4.35 ± 0.05^{c}	3.61 ± 0.05^{b}	3.67 ± 0.41^{b}	1.00 ± 0.00^{a}
Phosphate (mg/l)	0.50 ± 0.01^{c}	0.41 ± 0.01^{b}	0.37 ± 0.01^{a}	0.44 ± 0.00^{b}	0.43 ± 0.01^{b}	0.41 ± 0.02^{b}	0.53 ± 0.02^{c}	0.55 ± 0.05^{c}	0.36 ± 0.04^{a}
Nitrite (mg/l)	2.71 ± 0.98^{a}	2.95 ± 0.49^{a}	4.57 ± 0.07^{c}	4.53 ± 0.08^{c}	3.06 ± 0.13^{b}	3.55 ± 0.18^{b}	3.35 ± 0.66^{b}	2.31 ± 0.02^{a}	2.64 ± 0.05^{a}

	Location								
Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Nitrate (mg/l)	3.98 ± 1.16[b]	3.46 ± 0.04[b]	4.57 ± 0.33[c]	4.32 ± 0.84[c]	3.46 ± 0.04[b]	2.23 ± 0.03[a]	3.39 ± 0.04[b]	2.05 ± 0.49[a]	2.14 ± 0.05[a]
Nickel (mg/l)	1.32 ± 0.72[a]	1.24 ± 0.16[a]	1.40 ± 0.27[a]	1.17 ± 0.00[a]	1.16 ± 0.01[a]	1.16 ± 0.01[a]	1.17 ± 0.01[a]	1.17 ± 0.04[a]	1.14 ± 0.01[a]
TPH (mg/l)	3.92 ± 1.43[b]	13.40 ± 1.67[d]	11.60 ± 0.89[d]	12.80 ± 1.48[d]	1.44 ± 0.96[a]	3.10 ± 0.34[b]	9.76 ± 3.36[c]	1.04 ± 0.19[a]	0.00 ± 0.00[a]

Table 3.
Comparison of the parameters in the different locations during dry season.

ranging from acidic to alkaline. The main variables affecting pH in any milieu are: dissolved oxygen, water temperature, land runoff, decomposition of organic matter and processes such as precipitation and oxidation reduction. The highest pH was found in location 2, possibly due to more intensified human activity. The lowest was detected in location 9, indicating that gas flaring at Ebocha-Obrikom area of Rivers State affected groundwater acidity [1–3, 6, 12–14, 19]. Similarly, the analytical results during the dry season discovered that pH ranged from 5.99 to 7.23, which was within the WHO [20] acceptable pH range of 6.5-8.5 for drinking water, except at sampling location 1, which had the highest pH value. Thus, water with a pH of 7 denotes neutral water, and a value less than 7 denotes acidic water. Increasing pH values could lead to increase in the rate of corrosion. In any of the groundwater tests, nonetheless, no location was determined to remain beyond the maximum permissible limit. The pH ground water variance in the Ebocha-Obrikom area was below the allowable range and thus not dangerous for drinking [1–3, 6, 14]. Electric conductivity (EC) is a measurement of an ion's ability to carry electric current in a solution [1, 2, 14, 21]. The higher the conductivity, the warmer the water. Oil, alcohol, phenol, as well as sugar are organic compounds that do not transmit electrical current well. The EC is often used to calculate the ionic concentration of groundwater, which fluctuates based on the concentration, ions type and temperature of water. The most important test that reveals the total concentration of soluble salts is the conductivity test, according to Kanga et al., [22]. Thus, electrical conductivity (EC) diverges from (24.22–52.29) (11.93–46.76) μs/cm, with an average of (31.83–26.81) μs/cm (**Tables 2** and 3). Electrical conductivity (EC) remains a measure of a material's capacity toward conducting an electric current, and suggests a wide range of salts existing in groundwater. The percolation of agrochemicals and natural groundwater recharge processes increase the EC value [1, 2, 14, 21, 23]. Hence, higher values for conductivity at location 2&4 could be attributed to excessive accumulation of dissolved salts, spilled oil through possible emission of flared gases or salinization of groundwater [1, 2, 12, 14, 21, 24]. The findings were supported by Ehirim and Nwankwo, [25]; Morufu and Clinton, [13]; Olalekan et al., [14] and Morufu et al., [2] which established that electrical conductivity values of the ground water samples collected from the studied location are observed to be low throughout the sampling locations, as the variations in their mean concentrations at different distances. According to Okafor and Opuene [26]; Morufu and Clinton, [13] and Olalekan et al., [14], electrical conductivity reflects the degree of salinity; thus, it has a significant impact on water taste as well as user approval. The American Public Health Association (APHA) [16] and Morufu and Clinton [13] defines turbidity as "the optical quality of water sample that causes light to remain dispersed rather than diffused". The capacity of light to flow through water is related to the suspended particles volume. The more suspended particles there are in the water, the cloudier it becomes. An electronic turbidity meter is used to measure turbidity. APHA recommends that the turbidity of drinking water not exceed 5 NTUs. If turbidity is mostly caused by organic particles, depletion of dissolved oxygen in the water may occur [1, 2, 7, 8, 13, 27–29]. As a result, high turbidity levels may raise the risk of waterborne disease [1, 2, 6, 14, 21, 27–29]. Highest value of turbidity was noticed at location 7 (48.24–16.75) NTU during the rainy and dry season. Groundwater turbidities remained below the typical maximum tolerable limit of 5NTU for drinking water at location 6 & 9 for rainy season and location 5, 6, 8 & 9 for dry seasons. Despite this, location 8 (rainy season) and 1 & 2 (dry seasons) were close to the maximum permitted limit for drinking water. Thus, turbidity levels were higher during rainy season than the dry season. Hence, the wet season has a greater influence on turbidity than the dry season. This could be due to the research area's consistent and large tendency to receiving massive volumes of organic and inorganic material produced by gas flaring and oil spillage contaminating ground water. Dissolved Oxygen studies in water continue to be important since it is recognized as one of the most critical limiting elements for aquatic species' survival. It is an important metric in measuring pollution levels since sewage pollution is an organic pollutant that affects fish and other aquatic life. Bacteria devour oxygen as organic matter decomposes. As a result of this, an oxygen deficient milieu can emerge in lakes and rivers. The highest value of Dissolved Oxygen (DO) in groundwater was observed at location 3 (17.84–19.10) mg/l during both the rainy and dry seasons. These conditions can eventually lead to fish kills, restricted growth, disturbance of life cycles, migration to avoid unfavorable condition and mortality of benthic animals' creatures [1, 2, 6, 12–14, 21, 30, 31]. The BOD is the amount of oxygen required by bacteria during the breakdown of organic materials. It contains the oxygen required for the oxidation of numerous compounds found in water, such as sulfides, ferrous iron, and ammonia [1, 2, 7, 8, 9, 32]. Meanwhile, research by Chapman and Kimstach [32]; Morufu and Clinton, [13]; Raimi and Sabinus, [12]; Olalekan et al., [14] and Morufu et al., [2] discovered that DO concentration below 5 mg/l have a deleterious impact on the survival of biological communities. This measure represents the ability of microbial respiration to break down organic material in water, which results in low DO and may be a cause of hypoxia [1, 2, 12–14]. Despite this, biological oxygen demand (BOD) reflects the amount of oxygen needed by bacteria. It is used to determine any receiver environment pollution potential as well as assimilation capacity. The present study for BOD had its highest value at location 4 & 6 (5.48–6.09) mg/l during rainy and dry seasons. The values were higher during the dry season than during the rainy season. As a result, it is possible to extrapolate those anthropogenic activities may affect greater BOD during the dry season while supporting higher metabolic activity. Regardless of seasonal changes, both seasons influenced BOD. This pattern could have been caused by gas flaring. The chemical oxygen demand (COD) remain the amount of oxygen required to oxidize organic compounds in waste water using a powerful oxidant and convert them to carbon dioxide and water. The COD test is used to measure the pollution level in a certain location. COD readings are always greater than BOD_5 values because numerous organic molecules can be chemically oxidized but not physiologically [1, 2, 21, 33, 34]. As a result, the chemical oxygen demand (COD) is used to determine the level of pollution in water. When the COD level in the water surpasses 25 mg/l, it indicates that there is a larger concentration of contaminants. While, COD values were found to be highest at location 4 (41.78–32.49) mg/l during rainy and dry season. This indicates that organic pollution of water is more severe during rainy season than dry seasons. COD is used to calculate the amount of oxygen required by organic and inorganic substances. All reported values in this investigation were above the maximum acceptable limit of 10 mg/l for COD [1, 2, 21, 33, 34]. In unpolluted surface and ground waters, the existence of dissolved carbon dioxide is commonly the dominant acidifying agent. Apart from a palatability problem in very acidic waters, there is no specific implication [1, 2, 35]. The water acidity affects its corrosiveness as well as its speciation of other components. Thus, acidity values range from highest at location 3 (101.18–168.82) mg/l for both rainy season and dry season (**Tables 2** and **3**). There is currently no maximum value set for acidity according to WHO/SON/NAFDAC standards of potability. Alkalinity is a measure of water's ability toward neutralizing acids as well as indicates its buffer capacity [6, 12–14, 21, 35]. Also, the existence of bicarbonates generated in soil reactions via which water infiltrates contributes to the alkalinity of the natural water body. The eutrophication effects on water are also influenced by their pH. Thus, alkalinity was highest at location 4&8 (134.96–64.58) during the rainy and dry season and lowest at location 3&5 (18.17–23.66). Water hardness is a measure of water's ability toward reacting with soap as well as characterizes its ability toward binding soap to form scum or lather which is a reaction that is chemically harmful toward the process of washing [1, 2, 6, 12–14, 21]. The high rate might remain attributed toward constant discharge of acidic and chemicalized substances through oil spillage and gas flaring which latter find their way into the groundwater bodies and adjoining environment. Because calcium as well as magnesium remain the only remarkable minerals that are known to induce hardness. The sources of the metallic ions remain often found in sedimentary rocks, the most prevalent of which remain limestone ($CaCO_3$) as well as dolomite ($CaMg(CO_3)_2$) [1, 2, 6, 12–14, 21]. The concentration of TH levels varied from 39.17 mg/l to 44.02 mg/l [both rainy and dry season]. More than half of the sample's groundwater in Ebocha-Obrikom area of Rivers State possess TH below 100 mg/l. Thus, total hardness (TH) of the aquifers fluctuated on average from 39.17 mg/l for rainy season to 44.02 mg/l for dry seasons, with the lowest confined groundwater (mean = 35.02 at location 5) (35.78 at location 9), and highest confined groundwater (mean = 42.22 mg/l at location 3) (51.66 at location 5). Groundwater hardness varied from 198.5 to 409.5 mg/l, with a mean of 289.1 in the Upper Tigris River Basin, Diyarbakır-Batman, Turkey, Koffi et al. [36] discovered that the increased groundwater hardness was caused by carbonate sources. The research results contradicted Disli [37] who had found that the TH level varied "from 198 to 400 mg/l" in this region, but were mostly caused by mineral dissolution like carbonates and gypsum [1, 2, 6, 12–14, 21, 38, 39]. In the crystalline basement complex rock of India, Adimalla et al. [40] obtained TH values ranging from 60 to 750 mg/l, with approximately 18% of the samples falling into the moderately hard category, whereas Koffi et al. [36] recorded TH values ranging from 50.8 to 272 mg/l, with 60.6% of samples falling into the moderately hard category. Despite this, the maximum allowable level of TH for drinking purposes is 500 mg/l, with a suggested limit of less than 100 mg/l [20]. The groundwater in the Ebocha-Obrikom oil and gas area was found to be 100% safe, with all samples falling within the maximum permitted 500 mg/l limit. Conversely, Ezekwe et al., [41] claims that subsurface waters remain often tougher than surface waters. Total Dissolved Solids (TDS) refers to the various minerals that remain existent in water in dissolved form and is a pointer of water salinity as well as signifies dissolved salts in water [1, 2, 12–14, 42]. Consuming water of high TDS for an extended period of time can result in kidney stones as well as promote gastrointestinal discomfort in consumers [1, 2, 6, 27]. TDS levels above a certain threshold impair the palatability of water and promote gastrointestinal discomfort in consumers. It is also, an important metric for determining the appropriateness of irrigation as well as drinking water. WHO [20] claims that groundwater taste with a TDS level of less than 600 mg/l is regarded good for aquatic lives and residential water supply protection? High (TDS) levels in groundwater may cause unpleasant taste as well as gastrointestinal complications, according to the World Health Organization (WHO) [1, 2, 12–14, 43]. High TDS maybe derived from intensive or massive usage of agrochemical, dissolution of salts, ion exchange, organic materials, and sediment dissolution, aquifer percolation and allied substances emanating from oil related activities such as gas flaring. Thus, groundwater contamination in this wise could be due to the continuous contamination of groundwater by industrial pollutants as suggested by Olalekan et al., [14] and Olalekan et al., [6]. The total dissolved solids (TDS) show a very weak variability as seen by their low standard deviation (SD). The overall hydro chemical groundwater characteristics are regulated by major ions [1, 2, 12–14, 21, 44]. Hence, the groundwater samples were desirable as well as allowed for purposes of drinking based on the TDS categorization. WHO [20] recommends a concentration of 1500 mg/l for fisheries and aquatic life protection, and for household water supply? Because all values remained below the tolerable limit, they remain safe for drinking on TDS basis as supported by researches from Dami et al. [45]; Morufu and Clinton [13]; Raimi and Sabinus [12] and Olalekan et al. [14]. The difference in TDS indicates a wide variation in the geochemical processes. Concentrations of TDS in Ebocha-Obrikom area remain below the optimal threshold in all locations, according to earlier research, Besides, TDS concentrations remained sufficient in quality for drinking in all areas. According to Adimalla and Qian [46], about 95% of the total samples remained below ideal drinking threshold. The mean values for total suspended solids (TSS), demonstrate that the greatest value in groundwater was witnessed at location 1&8 (39.80–34.76) mg/l for rainy and dry seasons. The least value of (34.00–29.56) mg/l at location 9 for rainy or dry seasons respectively. All of the values noted in this investigation were above the maximum allowable limit. Indicating that gas flaring and oil spillage releases persistent non-combustible chemicals and less dense volatile chemicals into the environment. All groundwater comprises salts solution; and documented salt contents extend from less than 25 mg/l in a quartzite spring to above 300,000 mg/l in brines [1, 47]. Because of the larger exposure toward soluble elements in geologic strata, groundwater often has a larger concentration of dissolved components than surface water. Bicarbonate, which is typically the predominant groundwater anion, is produced from the released of carbon dioxide in the soil by organic breakdown. Salinity values range from highest at location 7 (25.71) mg/l for rainy season to location 3 (16.00) mg/l (**Tables 2** and **3**). The maximum value is set at 600 mg/l according to WHO/SON/NAFDAC standards of potability. All of the readings obtained in this study were less than the maximum allowable limit of 600 mg/l for drinking water. Chloride can be present in a variety of chemical and non-chemical components in the body. It is an essential component of the salt found in many foods and used in cooking. Even in small children, too much chloride from salted meals can raise blood pressure [1, 2, 12–14, 48, 49]. Excessive use of drinking water containing sodium chloride at concentrations greater than 2.5 g/l linked to hypertension [1, 2, 14]. Thus, a number of studies alleged that Cl excess in groundwater is an indicator pollution index and has a harmful influence on human health [1, 2, 12–14, 40, 50]. Though, chloride is also one of the prominent anions in Rivers State oil and gas producing area of Ebocha-Obrokom, ranging from (28.33–32.16) (25.26–31.27) mg/l for both rainy and dry season with a mean of (30.60–28.21) mg/l (**Tables 2** and **3**). It has been noted that while water with low chloride ions is not dangerous, but chloride ions at large concentrations can kill floras when used for horticultural or agricultural applications. It may also be to blame for the unpleasant taste of water consumed [51]. While samples at location (3 & 5) for rainy and dry season were high in the Ebocha-Obrikom region. High levels of chloride may perhaps remain linked to domestic waste effluents, septic tanks leakage, as well as chloride bearing rocks dissolution [1, 2, 6, 12–14, 21, 36, 52, 53]. In spite of the fact that no health dangers have been established, residents of Ebocha-Obrikom areas remain hesitant toward drinking water due to texture and taste issues. High Cl^- groundwater concentrations remain seen as a symptom of pollution from a number of sources, and they impart a salty flavor to the water [1, 2, 12–14, 54]. Furthermore, chloride concentration in drinking water above 200 mg/l has been linked to heart disease, asthma and possibly cancer. It is usually safe to drink water within the limits of 0.5–1.5 mg/l according to the suggested guidelines [1, 2, 6, 12–14, 20, 21, 55]. Fluoride becomes harmful to health at quantities above/below this recommendation, and is denoted as a double-edged sword [6]. Water consumers remain prone to dental carries at lower concentration, while at larger concentrations, it can induce skeletal fluorosis, debilitating fluorosis, dental fluorosis, as well as kidney damage [1, 2, 12–14]. Fluorine remains the 13th most prevalent element in the earth's crust but it is essential to human life. Excess consumption of fluoride has been associated to infertility, abortion, fertility, as well as hypertension [56]. Water ingestion and skin absorption remain the primary sources of trace elements intake in the milieu [1, 2, 12–14, 57, 58]. Heavy groundwater fluoride concentrations are a pervasive problem around the globe; particularly in the global south, where individuals remain disproportionately impacted by fluorosis due to high reliance on groundwater. Excessive levels of fluoride in drinking water might result in a decrease in total erythrocyte, hematocrit value and hemoglobin percentage, as well as protein content. In trace amounts, fluoride is advantageous to the human health as it can minimize dental caries risk even though encouraging strong bones formation [1, 2, 59, 60]. Fluorine ($F-$) in groundwater in this study either falls below or within the WHO/SON/NAFDAC limit. The lowest as well as highest values (0.00 and 0.85 mg/l) (0.00 and 1.02 mg/l) for rainy and dry season were observed in Ebocha-Obrikom area of Rivers State. Aside from increased hydrodynamics during gas flaring production, water mixing from diverse aquifers might also affect $F-$ in location 4, 5, 6, 7, and 8 [both rainy and dry season]. Thus, chronic exposure toward fluoride raises the risk of developing tooth decay, as well as other dental diseases [9]. Aluminum had highest recorded value of (0.03) (0.02) mg/l at location 7 during the rainy and dry season. However, its presence in other locations could be attributed to gas flaring and this of course calls for serious concern. Sodium [Na^+] is abundant in rocks and soils. It is always present in natural water and is used medicinally as a laxative. In the Ebocha-Obrikom oil and gas area of Nigeria, Na^+ varied from 14.33 mg/l in rainy season to 11.39 mg/l during dry season. Still, the highest [Na^+], 16.39 mg/l was observed in location 7 of the unconfined groundwater, while the lowest mean [Na^+], 12.22 mg/l, was observed in location 3 of the unconfined groundwater. This suggests that the region's groundwater is affected by more complex factors. Overall, Na^+ had the highest concentration in location 2, 4, 5, 6, 7 & 8. Na^+ ions in groundwater are largely regulated by weathering and water-rock interactions. Excess of Na^+ also indirectly indicates the process of ion exchange in water formation [61, 62]. In the Ebocha-Obrikom oil and gas area, principal lithology is occupied by crystalline rocks. Weathering of these rock forming minerals might likely be the chief source for elevated Na^+ concentration. For potassium (K^+), it usually exists at low concentrations in groundwater because of weak mobility [63]. The highest [K^+] (3.29 mg/l) was observed in location 8 of the shallow confined groundwater. Mg^+ possesses the highest SD value, indicating a very high spatial variability. Ca^{2+}, Mg^{2+}, and Na^+ range between (50.31–59.98) (40.37–50.73) (129.26–146.67) (149.44–184.68), and (12.22–16.39) (9.22–13.33) mg/l, respectively. As a result, He and Wu [64] reported that K^+ in groundwater is one of the essential trace elements for human health. K^+ occurs naturally in drinking water in amounts considerably below those deemed hazardous to human health; it is the most vital nutrient for humans, and too much of it can cause constipation [20]. However, high levels of K^+ in drinking water (beyond the regulatory limit) might cause hypertension, high blood pressure, hyperkalemia, and, in the worst-case scenario, a heart attack. Ca^{2+} is one of the dominant cations in the Ebocha-Obrikom oil and gas area of Rivers State groundwater, ranging from (50.31–59.98) (40.37–50.73) mg/l with a mean of (54.80–45.37) mg/l. There is some evidence that the incidence of heart disease is reduced in areas served by public water supply with a high degree of hardness, the primary constituent of which is calcium, so that the presence of the element in a water supply is beneficial to health. While, calcium and magnesium contribute to the formation and solidification of bones and teeth and play a role in the decrease of neuromuscular excitability, myocardial system, heart, and muscle contractility, intracellular information, transmission, and blood contractility [1, 2, 46]. They also play a major role in the metabolism of almost all cells of the body and interacts with many nutrients [1–3, 61]. However, inadequate, or excess intake of either nutrient can result in adverse health consequences [9]. Magnesium (Mg^{2+}) concentration in groundwater in the Ebocha-Obrikom oil and gas producing area of River State were between (129.26–146.67) and (149.44–184.68) mg/l throughout rainy and dry season. The main source of Mg^{2+} in groundwater was magnesium containing minerals in the host rocks and also animal, domestic, and industrial wastes [1, 2, 6, 14, 53, 65]. However, all groundwater samples collected above the maximum allowable limit of 150 mg/l. Thus, the presence of exchangeable Na^{+} in the soil may explain the high concentration of Mg^{2+} in groundwater [61, 66]. Although values higher or equal to 100 mg/l are stored particularly in cold climates [1, 2, 46, 67]. Low magnesium status has been implicated in hypertension, coronary heart disease, type 2 diabetes mellitus and metabolic syndrome, endothelial dysfunction, increased vascular reactions, elevated circulating levels of C-reactive protein (a proinflammatory marker that is a risk factor for coronary heart disease) and decreased insulin sensitivity [1, 2, 6, 14, 18, 67, 68]. The concentration of Fe ranges from (1.21–5.16) (0.95–4.42) mg/l both rainy and dry season, and four samples in rainy seasons have the Fe concentration higher than the permissible limit for drinking purpose. While, it is evident that trace metal can be toxic to human health if they are consumed in excess and accumulated in human bodies [1, 2, 6, 12–14, 21, 69]. High concentrations of iron could result in hemochromatosis which is characterized by tiredness, pains in the joints and abdomen [1, 2, 6, 12–14, 21, 70]. This condition is caused by rapid dissolution of iron species in anoxic groundwater. It is well-known that water-quality thresholds may be frequently breached for iron. While, the highest value for zinc was observed at location 3 (0.77) mg/l for rainy season and location 4 (1.01) mg/l for dry season. It was noticed that the maximum permissible limit of 3.00 mg/l for zinc was not exceeded by any of the locations. Zinc at these limit does not pose serious health and environmental effects though significant values were noticed at locations stated above between the seasons. Thus, zinc could be deposited in those locations due to oil related activities, especially during dry season. Zinc deficiency can cause nausea, lack of moisture, tiredness, pains in the abdomen, coordination of the muscles, and kidney failure. It can also cause malabsorption, Acrodermatitis enteropathica, liver damage, renal damage, sickle cell damage, diabetes, malignancy, and other chronic diseases. People most at risk are the elderly, children in rising nations, and individuals with renal deficiency. Signs of mild zinc insufficiency are varied but generally due to unsatisfactory dietary consumption [1, 2, 6, 7, 8, 9, 18, 21, 42]. Physiological consequences of eating a diet high in protein contain depressed development, diarrhea, weakness and late sexual development, alopecia, eye and skin abrasions, decreased appetite, changed perception, decreased host protection possessions, defects in carbohydrate utilization, and reproductive spermatogenesis [1, 2, 6, 12–14, 21]. Two (2) samples are not suitable for drinking (location 2&3–4&5) because of high Mn concentration in groundwater. Manganese is an essential nutrient but neurotoxic at high levels and evidence suggests infants could be uniquely vulnerable to its effects. Manganese exposure in drinking water has been associated with neurodevelopmental outcomes that include reduced IQ or poorer memory, hyperactivity, impulsivity and motor function in children [1, 2, 6, 12–14, 18, 21, 71–73]. Groundwater in Ebocha-Obrikom area of Rivers State contain widely varying amounts of manganese. Water that exceeds the state's reference dose (RfD) is likely to cause harmful effects over a lifetime of exposure. This finding should be seen as a wake-up call for many communities in the Niger Delta region to be aware of their groundwater levels. Cadmium (Cd) are known to increase the risks of lung cancer and renal carcinoma. The highest value for cadmium was observed at location 2, 7 & 8 (0.02) mg/l during the rainy season and location 4 &7 (0.06) mg/l during the dry season. All values recorded in this study area were above the maximum permissible limit of 0.003 mg/l for WHO/SON/NAFDAC. Thus, Cadmium (Cd) is known to cause damage to the kidney, bones in both young and old, also responsible for bronchitis, anemia [1, 2, 6, 12–14, 21]. Lead is classified as a prevalent toxic metal and a major environmental health hazard. Excessive lead causes problems in the synthesis of hemoglobin, kidney disease, mental retardation, anemia and acute or chronic damage to the nervous system. The primary cause of lead's toxicity is its interference with a variety of enzymes since it binds to sulfhydryl groups found in many enzymes. Lead also interferes with the activity of an essential enzyme called delta-aminolevulinic acid dehydrates, or ALAD and ferrochelatase which are important in the biosynthesis of heme, the cofactor found in hemoglobin. Extreme level of lead absorption in the human body can cause death or perpetual harm to the brain, central nervous system and kidneys [1, 2, 6, 12–14, 21, 74]. During the wet season, the greatest value for lead was found at location 7 (0.14) mg/l, whereas during the dry season, the highest value was observed at location 3 (0.03) mg/l. All levels obtained in this research region were either within or above the WHO/SON/NAFDAC maximum acceptable limit of 0.01 mg/l. Long-term lead exposure can be damaging to the circulatory and nervous systems. Lead is found in the human body mostly through water and food. It can be inhaled as lead particles in paints or as excess gases from leaded petroleum products. It is originated in minor quantities in several water bodies and food, particularly fish, which remain seriously focus to industrialized toxic waste. The capability of lead to permit above the barrier blood and brain is mostly due to its capability to extra for calcium ions. Major toxicity of lead causing the brain prefrontal hippocampus, cerebellum and cerebral cortex can lead to a variability of neurological disorder, such as brain injury, psychological delay and nerve injury [1, 2, 6, 12–14, 21, 41, 75]. Long-term exposure to copper can cause irritation of the nose, mouth and eyes and it causes headaches, stomachaches, dizziness, vomiting and diarrhea. Intentionally high uptakes of copper may cause liver and kidney damage even death [76–80]. Copper is a ductile metal with very high thermal and electrical conductivity. The metal and its alloys have been used for thousands of years. Copper had its highest of (0.05) mg/l at location 6 for rainy season and (2.81 mg/l at locations 4 during the dry season. Contamination of drinking water by copper could be by directly polluting water sources or through rusting of copper pipes and materials. High values of copper could lead to the development of chronic anemia [1, 2, 6, 12–14, 21, 81]. One of the most prevalent contaminants detected in industrial effluents is copper. Excessive copper consumption causes gastrointestinal issues, kidney damage, anemia, and lung cancer. Copper is deadly to humans in concentrations ranging from 4 to 400 mg/kg body weight. Lower concentrations of copper ions might elicit food poisoning symptoms (headache, nausea, vomiting, diarrhea) [1, 2, 6, 12–14, 21]. The liver is the major organ affected by copper poisoning in humans. Finally, copper intoxication produces Wilson's disease in humans. In this study, chromium had its highest of (1.29) mg/l at location 5 for rainy season and (2.81) mg/l at locations 4 throughout the dry season. All values remained above the maximum permissible chromium level. Thus, inhaling hexavalent chromium compounds on a regular basis raises lung cancer risk. Chromium (VI) ingestion can potentially induce stomach and intestinal discomfort or ulcers. Although, chromium does not pose any known serious environmental and public health threat, its current concentration must be continuously monitored since it may perhaps be attributable to gas flaring. While, chromium is a highly toxic element due to its ability to penetrate cell membranes and at high exposure level can cause liver damage. Levels more than 0.05 mg/l of chromium (VI) in drinking water can result in convulsions, diarrhea, abdominal pain, vomiting, indigestion, as well as damage to liver and kidney. Chromium is essential for human nutrition and is considered non-toxic [1, 2, 6, 12–14, 21, 82–86] Chromium exposure in the environment involves compound mixtures identified to cause multi organ poisonousness like allergy, asthma, kidney damage and, in severe cases, cancer of the respiratory tract in humans [1, 2, 6, 14, 87]. Impatience as well as small intestine ulceration and anemia are some of the most serious health problems reported in humans after consuming chromium combinations. Despite the fact that evidence of chromium carcinogenicity in humans and other living things appears to be difficult to come by [1, 2, 6, 12–14, 21, 88]. The highest value of sulphate at location 4 & 2 could remain found in water body (**Tables 2** and **3**), indicating a significant sulphate sensitivity toward changes in geochemical characteristics within the aquifer system. High sulphate concentrations are widely recognized to be caused by minerals dissolution that govern its water natural abundance or by land use. It may be said that sulphate is particularly unstable in the atmosphere, where it is transformed into forms ideal for its long-term presence in groundwater's. Ammonia (NH_3^-) values range from highest at location 6 (2.80) mg/l for rainy season to location 3 (4.39) mg/l (**Tables 2** and **3**). The maximum value is set at 3.0 mg/l according to WHO/SON/NAFDAC standards of potability. Nutrient salts (nitrite, nitrate and ammonia) are vital to the metabolism and growth of aquatic life, and when their concentrations rise, the biological balance shifts. Human activity has caused a significant increase in the amount of nutrients and salts in aquatic ecosystems, causing an issue with water quality. Extensive use of mineral fertilizers in some areas has resulted in atmospheric pollution, greenhouse gas emissions and eutrophication of water [1, 2, 6, 12–14, 21, 76, 78, 79, 89]. Nickel intake is determined by its physicochemical technique, with water-soluble techniques (nitrate, sulphate, chloride) providing additional readily consumed nickel. Thus, the values for nickel was higher at location 4 (1.00) mg/l for rainy season and location 3 (1.40) mg/l for dry season respectively. The values were higher than the WHO/SON/NAFDAC tolerable limits of 0.02 mg/l. The nickel values differed remarkably. Even though nickel has been identified as a vital trace metal, it could also be highly poisonous at higher doses. Hair loss, lung fibrosis, allergies of the skin, eczema, and various degrees of kidney and heart poisoning have been associated with humans exposed to high concentrations. Nickel also has the propensity of replacing iron and zinc in the body, thus interfering in the normal biochemistry [1, 2, 41, 82, 90]. Exposure to highly polluted water is likely to cause a number of clinical consequences in humans. Among these are skin allergies, respiratory cancer, lung fibrosis, and iatrogenic nickel toxicity. It has been established that nickel exposure has hematological implications in both animals and humans. Even if no reproductive repercussions have remained reported with humans' exposure to nickel. Location 1, 2, 3, 4 & 6 have higher TPH concentrations, while location 5, 7 & 8 have lower TPH concentration and in location 9 TPH was not detected for rainy season. The content of TPH in groundwater, on the other hand indicated that locations 2, 3, 4, & 7 had higher concentration above WHO/SON/NAFDAC standards. But location 9 did not show any presence of T PH for dry season. The findings found that five (5) locations in the rainy season and four (4) locations in the dry season did not fulfill the WHO/SON/NAFDAC criteria. Accordingly, the result show that TPH concentrations in drinking water remain much higher, signaling that water quality may have a detrimental effect on fish survival, eggs and larvae production and ecosystem development. Because of the high tidal velocities, the pollution is dispersed over a large area. There is also concern about the lengthy period required for total biodegradation of the heavier components, which contain extremely dangerous aromatic compounds with low boiling points. The high TPH values in those sites are a cautionary sign that everything is not well, since some water company and vendors

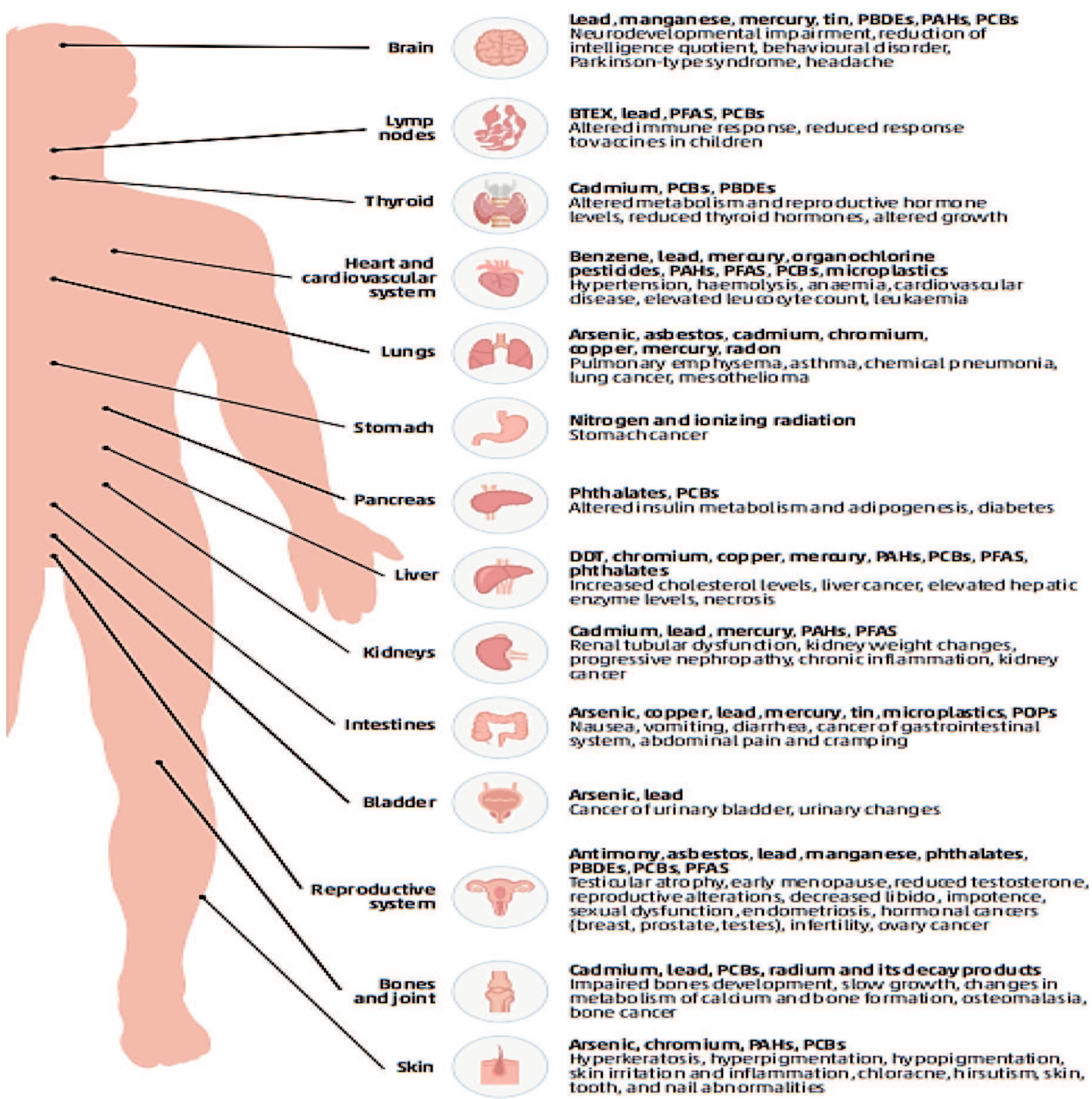

Figure 3.
Main effects of contaminants on human health, indicating the organs or systems affected and the contaminants causing them. Source: Adapted from Morufu et al. [1].

use ground water for production as well as sell it in places nearby or as far away as Yenagoa and Imo. Apart from its deadly effects, oil can induce death via producing narcosis, which causes animals to get detached from substrate. Total recovery may perhaps take close to 20 years. Oil coatings on the water surface in damaged areas impede light transmission and thus photosynthetic primary production. As a result, we must not forget that the general pollution effect on water bodies as well as ecosystem is significantly more problematic to anticipate. Summarily, trace metals cause respiratory irritation, kidney failure, neurological impairments, immunosuppression, anemia, gastrointestinal as well as cancer of liver, skeletal system abnormalities, liver inflammation, cardiovascular diseases following chronic exposure. The main contaminants effects on human health (see **Figure 3**) is represented thus:

4. Conclusion and recommendations

The Ebocha-Obrikom oil and gas producing area of River State, was chosen as the study area in order to gain awareness into the hydrochemistry as well as perspective of groundwater health. The aim of the research was to make available decision-useful information that could assist in taken action to solve the urgent threats facing societies across the Niger Delta. Thus, the following highlights are offered after the broad research findings:

- Development partners as well as local governments must be involved in the artificial recharge schemes implementation as well as maintenance at the community level.

- The relevant stakeholders have an urgent task ahead in closing down open wells in the Niger Delta region of Nigeria, for the sake of population likely to be affected through them, since they live near gas flaring area and make use of polluted groundwater, also because the indigenous population breath in toxins released from gas flaring. Groundwater pollution growth is inevitable in the Niger Delta, unless we act.

- This study found that groundwater contamination has a greater harmful impact on indigenous residents' life expectancy than COVID-19.

- Furthermore, open lines of communication among decision makers, academia, and society remain essential to guarantee that decision makers and other stakeholders have access to timely, science-based information on the possible hazards caused via contaminants.

- Eventually, public and school kids should be educated on groundwater quality and its management at the community level through a series of seminars, short videos, and other activities. Furthermore, seasonal groundwater quality monitoring, as well as other necessary actions to prevent further groundwater contamination, should continue.

- Appropriate management approaches, such as limiting human activities, implementing water treatments, developing public awareness, and establishing a groundwater quality monitoring network, are recommended to improve groundwater quality.

- Human interference (indiscriminate disposal of drainage wastes and unregulated use of agricultural pesticides) should be more effectively and rigidly monitored, as it is the most important technique of preventing groundwater contamination.

- It is strongly recommended that frequent monitoring and assessment of total water resource availability be encouraged. Waste management, land use, and agricultural practices that help to preserve the quality of water resources should all be implemented. The water should be thoroughly boiled before consumption.

- The first step in water pollution management is identifying and assessing risk at potentially polluted sites. If pollution at an assumed location remains at levels that may harm humans, evidence around that location should remain collected and made public, and appropriate remediation or risk-minimization actions should be taken, particularly if the location is utilized for water reservoir or production of food designed for human consumption.

- In light of the current global trend scenario of worsening groundwater pollution, stronger political, business, as well as social commitment is required to identify alternatives to the usage of extremely harmful pollutants as well as increased research investment in prevention as well as cleanup.

- Enhanced cooperation as well as partnership remain required to enable knowledge availability, the exchange of successful experiences, as well as worldwide access to safe and sustainable technologies, that leave no one behind.

- Agip should immediately begin replacing all old pipes in the Ebocha-Obrikom Oil Fields as soon as possible, and should collaborate with other agencies to complete a comprehensive Joint Investigation Visit (JIV) report. Furthermore, fair compensation should be provided to the impacted victims of Agip carelessness because their means of livelihood have been annihilated.

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References

[1] Raimi MO, Sawyerr HO, Ezekwe CI, Salako G. Many oil wells, one evil: Potentially toxic metals concentration, seasonal variation and human health risk assessment in drinking water quality in Ebocha-Obrikom Oil and Gas Area of Rivers State, Nigeria. medRxiv. 2021. DOI: 10.1101/2021.11.06.21266005 [Preprint]

[2] Raimi MO, Sawyerr OH, Ezekwe CI, et al. Quality Water not Everywhere: Exploratory Analysis of Water Quality Across Ebocha-Obrikom Oil and Gas Flaring Area in the Core Niger Delta Region of Nigeria, 04 October 2021, PREPRINT (Version 1) available at Research Square. DOI: 10.21203/rs.3.rs-953146/v1

[3] Olalekan RM, Ezekwe CI, Sawyerr OH. Problematic groundwater contaminants: Impact of surface and ground water quality on the environment in Ebocha-Obrikom oil and gas producing area of Rivers State, Nigeria. In: Oral Presentation Presented at the United Research Forum. 2nd International E-Conference on Geological and Environmental Sustainability during; July 29-30, 2021. Available from: https://assets.unitedresearchforum.com/documents/final-book-2021-91-309.pdf

[4] Raimi MO, Abdulraheem AF, Major I, Odipe OE, Isa HM, Onyeche C. The sources of water supply, sanitation facilities and hygiene practices in an island community: Amassoma, Bayelsa state, Nigeria. Public Health Open Access. 2019;**3**(1):000134. ISSN: 2578-5001. DOI: 10.23880/phoa-16000134

[5] United Nations Development Programme. Niger Delta Human Development Report. Abuja: UNDP; 2006

[6] Olalekan RM, Dodeye EO, Efegbere HA, Odipe OE, Deinkuro NS, Babatunde A, et al. Leaving No one behind? Drinking-water challenge on the rise in Niger Delta region of Nigeria: A review. Merit Research Journal of Environmental Science and Toxicology. 2020;**6**(1):031-049. DOI: 10.5281/zenodo.3779288. ISSN: 2350-2266

[7] Olalekan RM, Adedoyin OO, Ayibatonbira A, et al. “Digging deeper” evidence on water crisis and its solution in Nigeria for Bayelsa state: A study of current scenario. International Journal of Hydrology. 2019;**3**(4):244-257. DOI: 10.15406/ijh.2019.03.00187

[8] Olalekan RM, Omidiji Adedoyin O, Adedotun AT, Emmanuel OO, Anu B. An analysis of Bayelsa state water challenges on the rise and its possible solutions. Acta Scientific Agriculture. 2019;**3**(8):110-125. DOI: 10.31080/ASAG.2019.03.0572

[9] World Health Organization (WHO). Guidelines for drinking-water quality. WHO Chronicle. 2011;**38**(4):104-108

[10] Gift RA, Olalekan RM. Access to electricity and water in Nigeria: A panacea to slow the spread of Covid-19. Open Access Journal of Science. 2020;**4**(2):34. DOI: 10.15406/oajs.2020.04.00148. https://medcrave.com/index.php?/articles/det/21409/

[11] Gift RA, Olalekan RM, Owobi OE, Oluwakemi RM, Anu B, Funmilayo AA. Nigerians crying for availability of electricity and water: A key driver to life coping measures for deepening stay at home inclusion to slow covid-19 spread. Open Access Journal of Science. 2020;**4**(3):69-80. DOI: 10.15406/oajs.2020.04.00155

[12] Raimi MO, Sabinus CE. An assessment of trace elements in surface

and ground water quality in the Ebocha-Obrikom oil and gas producing area of Rivers state, Nigeria. International Journal for Scientific and Engineering Research (IJSER). 2017;**8**:6. ISSN: 2229-5518

[13] Morufu R, Clinton E. Assessment of Trace Elements in Surface and Ground Water Quality. Mauritius: LAP Lambert Academic Publishing; 2017. ISBN: 978-3-659-38813-2. Available from: www.omniscriptum.com

[14] Olalekan RM, Omidiji AO, Nimisngha D, Odipe OE, Olalekan AS. Health risk assessment on heavy metals ingestion through groundwater drinking pathway for residents in an oil and gas producing area of Rivers State, Nigeria. Open Journal of Yangtze Gas and Oil. 2018;**3**:191-206. DOI: 10.4236/ojogas.2018.33017

[15] Raimi MO. 21st century emerging issues in pollution control. In: 6th Global Summit and Expo on Pollution Control; May 06-07, 2019; Holiday Inn Amsterdam, Netherlands. 2019. Available from: https://pollutioncontrol.global-summit.com/2019

[16] American Public Health Association (APHA). Standard Methods for the Examination of Water and Waste Water. 22nd ed. American Public Health Association, American Water Works Association, Water Environment Federation; 2012

[17] Alloway BJ. Sources of heavy metals and metalloids in soils. In: Alloway BJ, editor. Heavy Metals in Soils: Trace Metals and Metalloids in Soils and Their Bioavailability, Environmental Pollution. Vol. 22. Dordrecht: Springer; 2012. pp. 11-50

[18] Ukah BU, Egbueri JC, Unigwe CO, Ubido OE. Extent of heavy metals pollution and health risk assessment of groundwater in a densely populated industrial area, Lagos, Nigeria. International Journal of Energy and Water Resources. 2019. DOI: 10.1007/s42108-019-00039-3

[19] Egbueri JC, Mgbenu CN, Chukwu CN. Investigating the hydrogeochemical processes and quality of water resources in Ojoto and environs using integrated classical methods. Modeling Earth Systems and Environment. 2019;**5**(4):1443-1461. DOI: 10.1007/s40808-01900613-y

[20] World Health Organization (WHO). Guidelines for Drinking-water Quality, Fourth Edition Incorporating the First Addendum. 2017. Available from: https://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/ [Accessed: 29 June 2020]

[21] Afolabi AS, Raimi MO. When water turns deadly: Investigating source identification and quality of drjinking water in Piwoyi community of federal capital territory, Abuja Nigeria. Online Journal of Chemistry. 2021;**1**:38-58. DOI: 10.31586/ojc.2021.010105. Available from: www.scipublications.org/journal/index.php/ojc

[22] Kanga IS, Naimi M, Chikhaoui M. Groundwater quality assessment using water quality index and geographic information system based in Sebou River Basin in the North-west region of Morocco. International Journal of Energy Water Resources. 2020;**4**(4):347-355. DOI: 10.1007/s42108-020-00089-y

[23] Ako AA, Eyong GET, Shimada J, et al. Nitrate contamination of groundwater in two areas of the Cameroon volcanic line (Banana plain and Mount Cameroon area). Applied Water Science. 2014;**4**:99-113

[24] Olobaniyi SB, Owoyemi FB. Characterization by factor analysis of

the chemical facies of groundwater in the deltaic Plain Sands aquifer of Warri, Western Niger Delta. UNESCO/African journal of Science and Technology: Science and Engineering Series. 2006;**7**(1):73-81

[25] Ehirim CN, Nwankwo CN. Evaluation of aquifer characteristics and groundwater quality using Geoelectric method in Choba, Port Harcourt. Archives of Applied Sciences in Research. 2010;**2**(2):396-403

[26] Okafor EC, Opuene K. Preliminary assessment of trace metals and polycyclic aromatic hydrocarbons in the sediments. International Journal of Environmental Sciences and Technologies. 2007;**4**(2): 233-240

[27] Raimi MO, Pigha TK, Ochayi EO. Water-related problems and health conditions in the oil producing communities in central Senatorial District of Bayelsa state. Imperial Journal of Interdisciplinary Research (IJIR). 2017;**3**:6. ISSN: 2454-1362

[28] Suleiman RM, Raimi MO, Sawyerr HO. A deep dive into the review of national environmental standards and regulations enforcement agency (NESREA) act. International Research Journal of Applied Sciences. 2019. DOI: Irjas.2019.123.123. pISSN: 2663-5577, eISSN: 2663-5585. Available from: www.scirange.com. https://scirange.com/abstract/irjas.2019.108.125

[29] Raimi MO, Sabinus CE. Influence of organic amendment on microbial activities and growth of pepper cultured on crude oil contaminated Niger Delta soil. International Journal of Economy, Energy and Environment. 2017;**2**(4): 56-76. DOI: 10.11648/j.ijeee.20170204.12

[30] Amiri V, Rezaei M, Sohrabi N. Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran. Environmental Earth Sciences. 2014;**72**:3479-3490

[31] Amiri V, Sohrabi N, Dadgar MA. Evaluation of groundwater chemistry and its suitability for drinking and agricultural uses in the Lenjanat plain, Central Iran. Environment and Earth Science. 2015;**74**(7):6163-6176

[32] Chapman D, Kimstach V. Selection of water quality variable. In: Chapman D, editor. Water Quality Assessments. London: Chapman and Hall; 1992. pp. 51-119

[33] Odipe OE, Raimi MO, Suleiman F. Assessment of heavy metals in effluent water discharges from textile industry and river water at close proximity: A comparison of two textile industries from Funtua and Zaria, North Western Nigeria. Madridge Journal of Agriculture and Environmental Sciences. 2018;**1**(1):1-6. DOI: 10.18689/mjaes-1000101. https://madridge.org/journal-of-agriculture-and-environmental-sciences/mjaes-1000101.php

[34] Henry OS, Odipe EO, Olawale SA, Raimi MO. Bacteriological assessment of selected hand dug wells in students' residential area: A case study of Osun State College of Health Technology, Ilesa, Nigeria. Global Scientific Journal. 2019;**7**:1. ISSN 2320-9186. Available from: www.globalscientificjournal.com

[35] USEPA. Regional Screening Levels (RSLs) Generic Tables. 2015. Available from: https://www.epa.gov/risk/regional-screening-levels-rsls-generictables-November-2015 [Accessed: 15 September 2016]

[36] Koffi KV, Obuobie E, Banning A, et al. Hydrochemical characteristics of groundwater and surface water for

domestic and irrigation purposes in Vea catchment, Northern Ghana. Environmental Earth Sciences. 2017;**76**:185. DOI: 10.1007/s12665-017-6490-3

[37] Disli E. Hydrochemical characteristics of surface and groundwater and suitability for drinking and agricultural use in the Upper Tigris River Basin, Diyarbakır–Batman, Turkey. Environmental Earth Sciences. 2017;**76**:500. DOI: 10.1007/s12665-017-6820-5

[38] Mahato MK, Singh PK, Singh AK, et al. Assessment of hydrogeochemical processes and mine water suitability for domestic, irrigation, and industrial purposes in East Bokaro Coalfield, India. Mine Water and the Environment. 2018;**37**:493-504

[39] Li P, Wu J, Qian H, Zhang Y, Yang N, Jing L, et al. Hydrogeochemical characterization of groundwater in and around a wastewater irrigated forest in the southeastern edge of the Tengger Desert, Northwest China. Exposure and Health. 2016;**8**(3):331-348. DOI: 10.1007/s12403-016-0193-y

[40] Adimalla N, Li P, Venkatayogi S. Hydrogeochemical evaluation of groundwater quality for drinking and irrigation purposes and integrated interpretation with water quality index studies. Environmental Processes. 2018;**5**(2):363-383. DOI: 10.1007/s40710-018-0297-4

[41] Ezekwe IC, Odubo E, Chima GN, Onwuchekwa IS. Groundwater occurrence and flow patterns in the Ishiagu mining area of southeastern Nigeria. Frontiers in Earth Science. 2012;**6**:18-28

[42] World Health Organisation. Guidelines for Drinking-Water Quality: Incorporating First Addendum, Recommendations. 3rd ed. Vol. 1. Geneva; 2006

[43] Chabukdhara M, Gupta SK, Kotecha Y, Nema AK. Groundwater quality in Ghaziabad district, Uttar Pradesh, India: Multivariate and health risk assessment. Chemosphere. 2017;**179**:167-178. DOI: 10.1016/j.chemosphere.2017.03.086

[44] Li P, He S, H, e X., Tian, R. Seasonal hydrochemical characterization and groundwater quality delineation based on matter element extension analysis in a paper wastewater irrigation area, Northwest China. Exposure and Health. 2018;**10**(4):241-258. DOI: 10.1007/s12403-17-0258-6

[45] Dami A, Ayuba HK, Amukali O. Effects of gas flaring and oil spillage on rainwater collected for drinking in Okpai and Beneku, Delta State, Nigeria. Global Journal of Human Social Sciences. 2012;**12**(13):7-10

[46] Adimalla N, Qian H. Groundwater chemistry, distribution and potential health risk appraisal of nitrate enriched groundwater: A case study from the semi-urban region of South India. Ecotoxicology and Environmental Safety. 2021;**207**:1-10. DOI: 10.1016/j.ecoenv.2020. 111277

[47] David KT. Groundwater Hydrology. 2nd ed, John Wiley and Sons, Inc; 2006

[48] Goldman LR et al. Low birth weight, prematurity and birth defects in children living near the hazardous waste site, Love Canal. Hazardous Waste and Hazardous Materials. 1985;**2**:209-223

[49] www.health.nytimes.com

[50] Li P, He S, Yang N, Xiang G. Groundwater quality assessment for

domestic and agricultural purposes in Yan'an City, Northwest China: Implications to sustainable groundwater quality management on the loess plateau. Environment and Earth Science. 2018;**77**(23). DOI: 10.1007/s12665-018-7968-3

[51] WHO. Guideline for Drinking-Water Quality, 3rd Edition (Recommendations). Geneva: World Health Organization; 2004

[52] Adimalla N, Li P. Occurrence, health risks, and geochemical mechanisms of fluoride and nitrate in groundwater of the rock-dominant semi-arid region, Telangana State, India. Human and Ecological Risk Assessment: An International Journal. 2018:1-23. DOI: 10.1080/10807039.2018.1480353

[53] Adimalla N, Venkatayogi S. Geochemical characterization and evaluation of groundwater suitability for domestic and agricultural utility in semi-arid region of Basara, Telangana State, South India. Applied Water Science. 2018;**8**:44. DOI: 10.1007/s13201-018-0682-1

[54] Marghade D, Malpe DB, Zade AB. Major ion chemistry of shallow groundwater of a fast growing city of Central India. Environmental Monitoring and Assessment. 2012;**184**:2405-2418

[55] Olalekan RM, Oluwatoyin OA, Olawale SH, Emmanuel OO, Olalekan AZ. A critical review of health impact assessment: Towards strengthening the knowledge of decision makers understand sustainable development goals in the twenty-first century: Necessity today; essentiality tomorrow. Research and Advances: Environmental Sciences. 2020;**1**:72-84. DOI: 10.33513/RAES/2001-13. Available from: https://ospopac.com/journal/environmental-sciences/early-online

[56] Olalekan RM, Oluwatoyin O, Olalekan A. Health impact assessment: A tool to advance the knowledge of policy makers understand sustainable development goals: A review. ES Journal of Public Health. 2020;**1**(1):1002. Available from: https://escientificlibrary.com/public-health/in-press.php

[57] Raimi MO, Ihuoma BA, Esther OU, Abdulraheem AF, Opufou T, Deinkuro NS, et al. Health impact assessment: Expanding public policy tools for promoting sustainable development goals (SDGs) in Nigeria. EC Emergency Medicine and Critical Care. 2020;**4**:9

[58] Zhai Y, Zhao X, Teng Y, et al. Groundwater nitrate pollution and human health risk assessment by using HHRA model in an agricultural area, NE China. Ecotoxicology and Environmental Safety. 2017;**137**:130-142

[59] Li P, Wu J, Qian H, Lyu X, Liu H. Origin and assessment of groundwater pollution and associated health risk: A case study in an industrial park, Northwest China. Environmental Geochemistry and Health. 2014;**36**:693-712

[60] Sun Y, Ling P, Li Y, Li Q, Sun Q, Wang J. Influences of coal mining water irrigation on the maize losses in the Xingdong mine area, China. Environmental Geochemistry and Health. 2014;**36**(1):99-106

[61] Olalekan MR, Abiola I, Ogah A, Dodeye EO. Exploring how human activities disturb the balance of biogeochemical cycles: Evidence from the carbon, nitrogen and hydrologic cycles. Research on World Agricultural Economy. 2021;**02**:03. DOI: 10.36956/rwae.v2i3.426. Available from: http://ojs.nassg.org/index.php/rwae

[62] Zhang Y, Wu J, Xu B. Human health risk assessment of groundwater nitrogen pollution in Jinghui canal irrigation area of the loess region, Northwest China. Environmental Earth Sciences. 2018;**77**(7):273. DOI: 10.1007/s12665-018-7456-9

[63] Wu J, Zhou H, He S, Zhang Y. Comprehensive understanding of groundwater quality for domestic and agricultural purposes in terms of health risks in a coal mine area of the Ordos basin, north of the Chinese Loess Plateau. Environment and Earth Science. 2019;**78**(15):446. DOI: 10.1007/s12665-019-8471-1

[64] He S, Wu J. Relationships of groundwater quality and associated health risks with land use/land cover patterns: A case study in a loess area, Northwest China. Human and Ecological Risk Assessment. 2019;**25**(1-2):354-373. DOI: 10.1080/10807039.2019.1570463

[65] Marghade D, Malpe DB, Duraisamy K, Patil PD, Li P. Hydrogeochemical evaluation, suitability, and health risk assessment of groundwater in the watershed of Godavari basin, Maharashtra, Central India. Environmental Science and Pollution Research. 2021;**28**(15):18471-18494. DOI: 10.1007/s11356-020-10032-7

[66] Henry OS, Morufu OR, Adedotun TA & Oluwaseun EO. Measures of harm from heavy metal pollution in battery technicians' workshop within Ilorin Metropolis, Kwara State, Nigeria. Scholink Communication, Society and Media 2019;**2**(2). ISSN 2576-5388 (Print) ISSN 2576-5396 (Online). Available from: www.scholink.org/ojs/index.php/csm. https://doi.org/10.22158/csm.v2n2p73

[67] Egbueri JC, Mgbenu CN. Chemometric analysis for pollution source identifcation and human health risk assessment of water resources in Ojoto Province, southeast. Applied Water Science. 2020:1-18. DOI: 10.1007/s13201-020-01180-9

[68] Edokpayi JN, Enitan AM, Mutileni N, Odiyo JO. Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane area of Vhembe District, Limpopo Province, South Africa. Chemistry Central journal. 2018;**12**(1):1-16. DOI: 10.1186/s13065-017-0369-y

[69] He X, Wu J, He S. Hydrochemical characteristics and quality evaluation of groundwater in terms of health risks in Luohe aquifer in Wuqi County of the Chinese Loess Plateau, Northwest China. Human and Ecological Risk Assessment: An International Journal. 2018:1-20. DOI: 10.1080/10807039.2018.1531693

[70] Standards Organization of Nigeria (SON). Nigerian Standard for Drinking Water Quality. Vol. 554. Abuja: Nigerian Industrial Standard; 2015. pp. 13-14

[71] Erikson KM, Thompson K, Aschner J, Aschner M. Manganese neurotoxicity: A focus on the neonate. Pharmacology & Therapeutics. 2007;**112**(2):369-377. DOI: 10.1016/j.pharmthera.2006.09.002

[72] Blanc PD. The early history of manganese and the recognition of its neurotoxicity, 1837-1936. Neurotoxicology. 2018;**64**:5-11. DOI: 10.1016/j.neuro.2017.04.006

[73] Oulhote Y, Mergler D, Barbeau B, Bellinger DC, Bouffard T, Brodeur MÈ, et al. Neurobehavioral function in school-age children exposed to manganese in drinking water. Environmental Health Perspectives. 2014;**122**(12):1343-1350. DOI: 10.1289/ehp.1307918

[74] United States Geological Survey (USGS). Arsenic Statistics and

Information. 2019. Available from: https://www.usgs.gov/centers/nmic/arsenic-statistics-and-information [Accessed: 15 June 2019]

[75] Khan AF, Srinivasamoorthy K, Rabina C. Hydrochemical characteristics and quality assessment of groundwater along the coastal tracts of Tamil Nadu and Puducherry, India. Applied Water Science. 2020;**10**(2):74. DOI: 10.1007/s13201-020-1158-7

[76] Raimi MO, Adeolu AT, Enabulele CE, Awogbami SO. Assessment of air quality indices and its health impacts in Ilorin Metropolis, Kwara State, Nigeria. Science Park Journals of Scientific Research and Impact. 2018;**4**(4):060-074. ISSN: 2315-5396. DOI: 10.14412/SRI2018.074. Available from: http://www.scienceparkjournals.org/sri/pdf/2018/September/Olalekan_et_al.pdf http://www.scienceparkjournals.org/sri/Content/2018/September/2018.htm

[77] Oluwaseun EO, Raimi MO, Nimisingha DS, Abdulraheem AF, Okolosi-Patainnocent E, Habeeb ML, et al. Assessment of environmental sanitation, food safety knowledge, handling practice among food handlers of Bukateria complexes in Iju Town, Akure North of Ondo-State, Nigeria. Acta Scientific Nutritional Health. 2019;**3**(6):186-200. DOI: 10.31080/ASNH.2019.03.0308

[78] Raimi MO, Adio ZO, Odipe OE, Timothy KS, Ajayi BS, Ogunleye TJ. Impact of sawmill industry on ambient air quality: A case study of Ilorin Metropolis, Kwara State, Nigeria. Energy and Earth Science. 2020;**3**(1):2020. DOI: 10.22158/ees.v3n1p1. Available from: www.scholink.org/ojs/index.php/ees

[79] Raimi OM, Samson TK, Sunday AB, Olalekan AZ, Emmanuel OO, Jide OT. Air of uncertainty from pollution profiteers: Status of ambient air quality of sawmill industry in Ilorin Metropolis, Kwara State, Nigeria. Research Journal of Ecology and Environmental Sciences. 2021;**1**(1):17-38. DOI: 10.31586/rjees.2021.010102. Available from: https://www.scipublications.com/journal/index.php/rjees/article/view/60

[80] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profiles, Toxic Substances Portal. 2015. Available from: https://www.atsdr.cdc.gov/toxprofiles/index [Accessed: Nov 2015]

[81] Iqbal J, Nazzal Y, Howari F, Xavier C, Yousef A. Hydrochemical processes determining the groundwater quality for irrigation use in an arid environment: The case of Liwa Aquifer, Abu Dhabi, United Arab Emirates. Groundwater for Sustainable Development. 2018. DOI: 10.1016/j.gsd.2018.06.004

[82] Olalekan RM, Vivien OT, Adedoyin OO, et al. The sources of water supply, sanitation facilities and hygiene practices in oil producing communities in central senatorial district of Bayelsa State, Nigeria. MedCrave Online Journal of Public Health. 2018;**7**(6):337-345. DOI: 10.15406/mojph.2018.07.00265

[83] Egbueri JC. Heavy metals pollution source identifcation and probabilistic health risk assessment of shallow groundwater in Onitsha, Nigeria. Analytical Letters. 2020;**53**:1620-1638. DOI: 10.1080/00032 719.2020.1712606

[84] Adeyeye OA, Xiao C, Zhang Z, Yawe AS, Liang X. Groundwater fluoride chemistry and health risk assessment of multi-aquifers in Jilin Qianan, Northeastern China. Ecotoxicology and Environmental Safety. 2021;**211**:111926-112014. DOI: 10.1016/j.ecoenv.2021.111926

[85] Wang J, Liu G, Liu H, Lam PKS. Multivariate statistical evaluation of dissolved trace elements and a water quality assessment in the middle reaches of Huaihe River, Anhui, China. Science of the Total Environment. 2017;**583**:421-431

[86] National Agency for Food and Drug Administration and Control (NAFDAC). National Agency for Food and Drug Administration and Control, Ministry Safety Bulletin. Recommendation. Vol. 2. Lagos, Nigeria: National Agency for Food, Drug, Administration and Control; 2008

[87] Goyal SK, Chaudhary BS, Singh O, Sethi GK, Thakur PK. GIS based spatial distribution mapping and suitability evaluation of groundwater quality for domestic and agricultural purpose in Kaithal district, Haryana state, India. Environmental Earth Sciences. 2010;**61**(8):1587-1597

[88] Chen J, Qian H, Wu H, Gao Y, Li X. Assessment of arsenic and fluoride pollution in groundwater in Dawukou area, Northwest China, and the associated health risk for inhabitants. Environmental Earth Sciences. 2017;**73**:314

[89] Premoboere EA, Raimi MO. Corporate civil liability and compensation regime for environmental pollution in the Niger Delta. International Journal of Recent Advances in Multidisciplinary Research. 2018;**05**(06):3870-3893

[90] Okoyen E, Raimi MO, Omidiji AO, Ebuete AW. Governing the environmental impact of dredging: Consequences for marine biodiversity in the Niger Delta region of Nigeria. Insights Mining Science and Technology. 2020;**2**(3):555586. DOI: 10.19080/IMST.2020.02.555586