Anchor University Journal of Science and Technology (AUJST)
A publication of the Faculty of Science Applied and Health Science, Anchor University Lagos

URL: journal.aul.edu.ng

In AJOL: https://www.ajol.info/index.php/aujst

Vol. 5 No 2, December 2024, Pp. 152-170

ISSN: 2736-0059 (Print); 2736-0067 (Online)

Integration of Heavy Metal Indexes and Health Risk Assessment in Groundwater Studies in Urban Area of Port Harcourt, Niger Delta Region of Nigeria

[1]W.O. Osisanya, [2]B.H. Akpeji, [3] I.F Agho, [4] S.A. Saleh, AS, [5]O. E. Oyanameh

[1,]Department of Physics, University of Benin, Benin City, Edo State, Nigeria.
[2]Department of Chemistry, Federal University of Petroleum Resources, P.M.B 1221, Effurun, Delta State.
[3]Department of Microbiology, University of Benin, Benin City, Edo state, Nigeria
[4]Department of Petroleum Engineering and Geosciences, Petroleum Training Institute, Effurun, Nigeria. Department of Earth Sciences, Anchor University, Lagos, Nigeria.

***Corresponding author Email**:
wasiu.osisanya@uniben.edu
Submitted 28 June, 2024
Accepted 20 September, 2024

Competing Interests.
The authors declare no competing interests.

ABSTRACT

The Niger Delta region of Nigeria is faced with a serious environmental hazard from heavy metal (HM) pollution in groundwater, mostly as a result of local oil corporations' operations within the communities and its suburbs.. Physical characteristics such as pH, and Ec, heavy metals (Fe, Pb, Mn, As, Ni, Co, Cu, Zn, and Cr) were measured in 17 groundwater samples that were collected. The influence of heavy metals on groundwater chemistry is revealed by the principal component analysis (PCA) analysis results. According to the child population's dermal techniques, findings showed that 6 % of samples with low risk, 41 % with medium risk, and 51 % with high risk. Yet, 29 % of adults are at medium risk and 71 % of adults pose insignificant to low risk. According to the evaluated Carcinogenic Risk (CR) scores of the groundwater samples that were considered in this study, there was a very high propensity to effect the development of cancer in consumers, including adults and children. The research area's Heacy Metal Pollution Index (HPI) ranges from 7.15 to 63.08with an average value of 27.16 according to the HPI data. This suggests that there is generally safe water because the HPI throughout the research area is below 100. Fe was found to be positive in 12 (70.59%) samples (FET/01,02,03,07,08,10,11,12,14,15,16, and 17) and zero in 5 (29.41%) samples (FET/04/05/06/09,13) based on the results of the Quantification of Contamination (QoC).For Ni, 58.82% of samples (FET/01, 02, 03, 08, 09, 10, 11, 12, 14, and 16) had negative QoC scores, while seven (41.18%) samples (FET/04, 05, 06, 07, 13, 15, and 17) had positive QoC scores. These findings underscore the urgent need for continued groundwater monitoring and implementation of effective purification technologies before consumption to mitigate health risks associated with heavy metal contamination in the Niger Delta region.. The present investigation concluded that this location's groundwater needed to have its HM level measured

Keyword s: Contamination, Pollution, Standard, Analysis, Hydro-chemical

1. Introduction

Water is an important, infinite and expendable natural resource which forms a center of ecological system via hydrological cycle. According to Eyankware, et al. (2023), 96.5 % (1338 9 106 km^3) of the world's water is in oceans, but high salinity renders the oceans virtually unusable for humans. The remainder is distributed in glaciers (1.74 % or 24.1 9 106 km^3), groundwater (1.70 % or 23.4 9 106 km^3), permafrost, lakes, rivers and atmospheric water as a freshwater stock. Groundwater is considered safe from pathogens and other chemical contaminants due to natural infiltration capacity of aquifer material and, thus, necessitates a little infection. So, the groundwater has become an appropriate alternative over surface freshwater reservoirs for different purposes, such as drinking, irrigation and various industrial processes (Raju and Reddy 1998; Nampak et al. 2014; Singh et al. 2015). Geochemical behaviour of groundwater becomes altered in due course of time while circulating in the hydrological cycle and streaming from recharge to discharge areas. Through factors such as rock weathering, aquifer lithology, evaporation, cation exchange, quality of recharge water, selective uptake by vegetation, atmospheric precipitation, leaching of fertilizers, industrialization and urbanization (Raju and Reddy 2007). So, an understanding of its characterization and exploration is helpful in groundwater sustainable management and quality (Raju et al. 1996, 2012; Reddy et al. 2000; Ayenew et al. 2008; Rao et al. 2013; Zouahri et al. 2014). Quality of groundwater also depends on various geogenic activities Highly localized factors such as topography and lithology cause quality to vary within short distances in the area studied (Kadam et al. 2021a, 2021b; Huzefa et al. 2020; Subba Rao et al. 2018; Raju et al. 2009; Nageswara Rao et al. 2019). The quantity is also subject to weathering, groundwater movement, individual ion content and ion exchange, environment and time variability in the recharge and discharge cycle. The geochemistry of waters is governed by the following factors: (i) the geochemistry of rocks and soils (ii) the semi-arid climate with abundant water in monsoon and scarcity of water in summer (iii) interchange among aquifers due to pressure differentials resulting from

https://dx.doi.org/10.4314/aujst.v5i2.1

continuous withdrawal (iv); contamination of ground water by polluted surface water; (v) direct entry of sewage water into wells of poor design; and (vi) the extent of use of water. Rock or mineral composition is reflected by its elemental constituents in the form of major elements or trace elements (Karunanidhi et al., 2019). While non-detrimental non-detrital rocks like argillaceous and calcareous sedimentary rocks, chemical analysis is diagnostic value, in the case of detrimental detrital rocks of sedimentary origin, determination of grain size, fabric, roundness, and sphere shape of grains is used to decipher their genetic history (Subba Rao, 2018; Alomran et al. 2016). This may reflect the nature of the source material, conditions of transport and environmental conditions of deposition. Though the uniformity of chemical composition is expected over wide areas, because of the uniformity in the environmental conditions of deposition with low amplitude of fluctuation, the conditions are usually far from ideal and ever changing both in time and space affecting considerable change in the composition of different lithological units, either vertically or horizontally (Adams et al. 2001).

2. Location and accessibility

The research area is situated in Port Harcourt, River State, as indicated in Fig. 1a, it is physically positioned between latitudes 4°47′N–5°04′N and longitudes 6°41′N –6°59′E. The research region is tropical, with two distinct seasons namely the rainy and dry .. Orji et al. (2022) reported that the research area experiences 1000–2000 mm of rainfall on average. They also noted that the rainy season lasts from mid-April to early November, with July and October seeing the highest amounts of precipitation. The research region has a temperature range of 26 to 28 degrees Celsius, and its vegetation is primarily mangrove swamp forest, while human activities like farming, logging, and exploration have significantly changed it and frequently replaced it with grassland. The Tropical Continental Air Mass, also known as the North-East Trade winds, originate from Arabia-Eurasia with a high pressure belt and are associated with cloudy, dry, and dusty winds (Nwankwor et al., 2016). According to Edokpa and Nwagbara (2017), the coastal region of the Niger Delta experiences an average monthly wind speed pattern ranging from 0 to 3 m/s, with periods of lower and greater trend noted during the night and evening hours. The research region has mild topography, with an average elevation of roughly 18 meters above sea level, and few prominent hills rising over the surrounding terrain. After rain, flooding is frequently encouraged by the area's fop and low-relief features. Many streams with a dendritic drainage pattern cross the study area, and some of their tributaries discharge into the Atlantic Ocean.

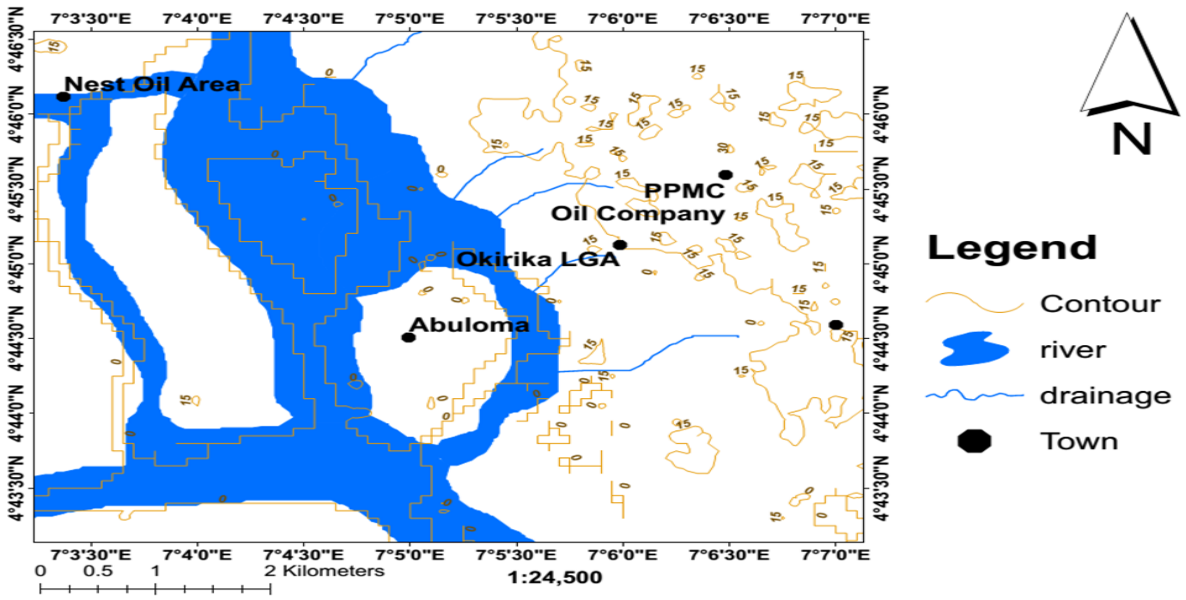


Fig. 1: Topographic Map of the study area.

https://dx.doi.org/10.4314/aujst.v5i2.1

2.1. Geology and Hydrogeology

A large saline/brackish mangrove swamp belt separates the study region from the sea, particularly along the coast (Oteri and Atolagbe, 2003). The saline mangrove swamp and its associated sandy islands and barrier ridges along the coast are the only places with salinity-related water supply difficulties. Short and Stauble (1967) divided the Niger Delta Formation into three groups: Akata, Agbada, and Benin (Fig. 1). In the delta, the Benin Formation is a system of several aquifers made up primarily of huge, extremely porous sands and gravels with thin shale/clay interbeds. Although numerous boreholes into the Benin Formation aquifers have been drilled with encouraging results, many of them have been abandoned because of excessive salinity (Oteri and Atolagbe, 2003). According to Weber and Daukoru (1976), the Benin Formation, which was created during the Niger Delta's continental period, has a sediment thickness of roughly 2100 m. According to Onyeagocha (1980), the Benin Formation is largely made up of sandstone, sands, and gravel, with clays appearing in lenses. Sands and sandstones are fine to coarse grained, partially unconsolidated, and of varying thickness. The Benin Formation is mostly made up of high-resilience fresh water-bearing continental sand and gravel with intercalations of clay and shale (Oteri 1990). In the Niger Delta Basin, which is made up of large, porous sands and gravels, there is a multi-aquifer system. In the unconfined aquifer of the coastal beach ridges, a freshwater lens overlays sea water. In most confined aquifers within the study region, fresh water is underlain by salt water. With salt water-bearing sands overlying fresh water-bearing sands in specific zones of the Niger Delta, saltwater intrusion into limited aquifers has occurred. Salt water-bearing sands are then laid on top of these Oteri and Atolagbe (2003). The Niger Delta also experiences saltwater intrusion into both unconfined and confined aquifers. Freshwater lens float above the salt water-bearing sands that are present in the unconfined aquifers of coastal beach ridges or sandy islands within the saline mangrove belt (Oteri, 1990). Based on the depth of occurrence of saline water sands, the Benin Formation's confined aquifers were further divided into two major areas: areas where freshwater sands are encountered at shallow depths underlain by saline water sands, and areas where saline water sands are encountered at shallow depths underlain successively by freshwater sands and saline water sands (Oteri and Atolagbe, 2003).

3. Methods and Materials

A total of 17 water samples were collected systematically from various water sources across the study area (see Fig. 2). After the collection of the samples, they were stored in polypropylene beakers for examination. The sample beakers/containers to be utilized were well-cleansed and immersed in distilled water acidified with 1.0 ml of HNO3 for three (3) days before the field sampling exercise.. To obtain a representative sample that genuinely represents the water resources, borehole samples were collected after 5 – 10 min. of pumping. After rinsing the bottle with the aliquot, each sample was filtered into a sample bottle using disposable filters with a diameter of 0.45 m to ensure that all suspended pollutants were removed completely. To minimize the heavy metal (HM) precipitation, the samples were acidified in the field with 1.0 ml of conc. HNO3. To avoid sorption, new syringes were used in adding the three drops of HNO3. At a temperature of 4°C, the obtained samples were appropriately stored in ice-packed beakers that were tightly sealed. The temperature was kept constant to prevent evaporation (Singh et al. 2005; Sehgal et al. 2012). The samples were chemically analyzed using a fast sequential (FS) (Varian 240 AA) atomic absorption spectrophotometer for heavy metals (Fe, Cu, Co, Br, Mn, Zn, Cr, Ni, and Pb (AAS). Even though the temperature of each sample was taken with a potable thermometer, the pH values were obtained using a portable pH meter (WGS 84) with temperature electrode accessories. All data collection and analysis were done following APHA guidelines (1995, 2012).

https://dx.doi.org/10.4314/aujst.v5i2.1

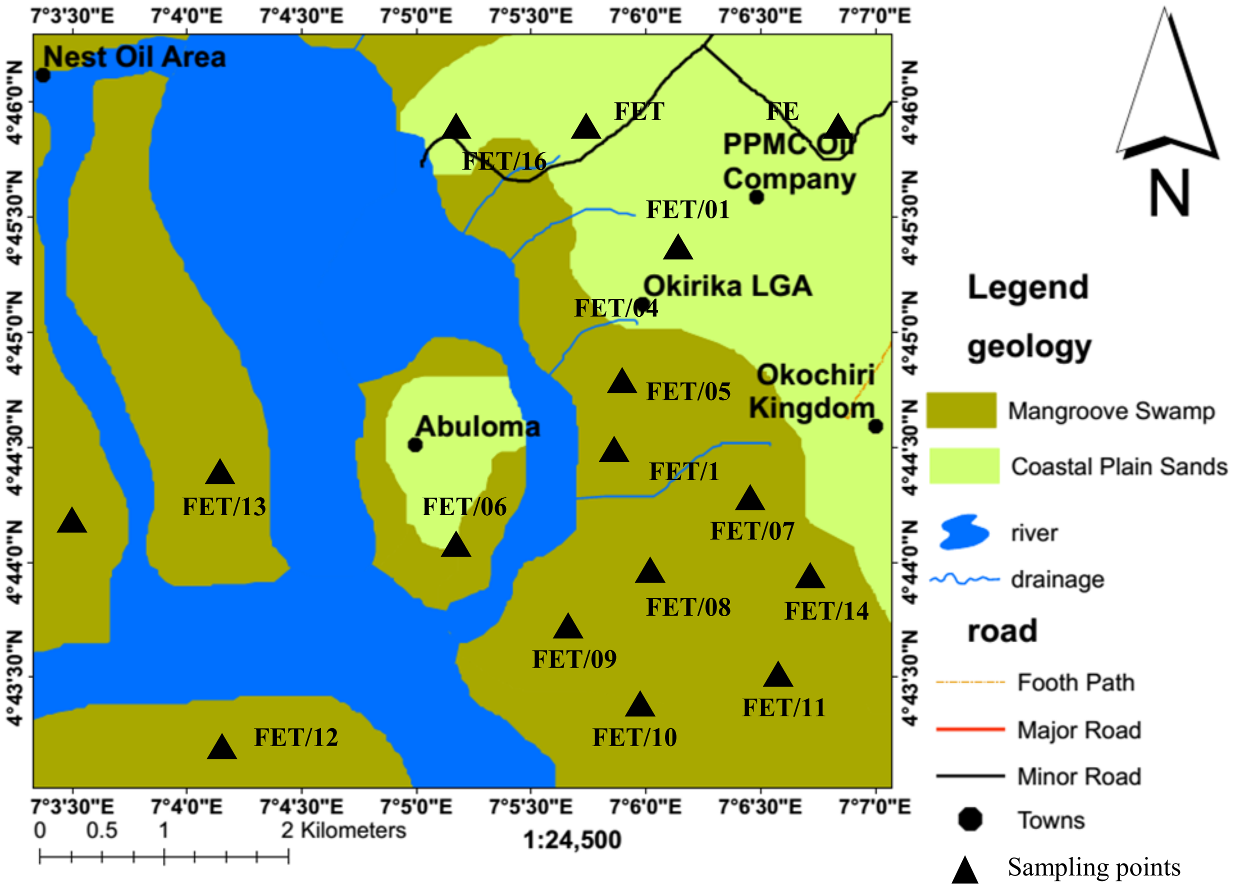


Fig. 2: Geology map of the study.

3.1. Metal Pollution Index (MPI)

The combined effect of individual heavy metals on water quality was calculated by MPI (Horton, 1965; Eyankware and Akakuru, 2022), was evaluated using Caeiro et al. (2005) Equation 1:

$$MPI = \sqrt[n]{M_1 \times M_2 \times M_3 \text{--------} Mn} \quad (1)$$

Where Mn = concentration of the metal.

3.2. Nemerow Pollution Index (NPI)

PNI (Nemerow 1974) is another numerical index that incorporates multiple factors into a single factor. The NPI value, on the other hand, represents the combined water quality level of various pollution parameters. In terms of empirical validity, using an integrated water quality index to evaluate an intrinsic groundwater risk assessment is preferable to merely examining the concentrations of one or two specific contaminants (Kowalska et al. 2018; Kong et al. 2019). NPI $(PI_{Nemerow})$ assesses the total degree of water pollution and takes into account the contents of all heavy metals tested (Gong et al., 2008; Cheng, et al., 2007). It's calculated with the following formula:

$$PI_{nemerow} = \sqrt{\frac{\left(\frac{1}{n}\sum_{i=1}^{n} PI\right)^2 PI_{max}^2}{n}} \quad (2)$$

where PI represents calculated Single Pollution Index values, PI max represents the highest value for the Single Pollution Index of all heavy metals, and "n" represents the number of heavy metals.

3.3. Modified Degree of Contamination (mC_d)

According to Eyankware and Akakuru, (2022) and Hakanson (1980) equation for determining the overall degree of contamination for a given sample or coring site is as follows: (i) The degree of contamination is defined as the sum of all contamination factors for a given set of estuarine pollutants divided by the number of analyzed pollutants; (ii) The mean concentration of a pollutant element is determined from at least three samples; and (iii) The baseline concentrations are calculated using the modified formula. standard earth materials. Eqn. 3 is a

https://dx.doi.org/10.4314/aujst.v5i2.1

modified equation for estimating the degree of contamination using an extended process.

$$mC_d = \frac{\sum_{i=1}^{i=n} C_f^i}{n} \quad (3)$$

where n is the number of elements examined and C_f^i denotes the contamination factor. The use of this broad and vague formula to determine the mC_d allows the study to include as many metals as it wants with no upper restriction.

3.4. Quantification of contamination (QoC)

QoC is a pollution assessment technique used to determine the source of a pollutant (geogenic or anthropogenic).

It was determined by the use of using equation 4

$$\frac{C_n - B_n}{C_n} x \frac{100}{1} \quad (4)$$

where QoC denotes the contamination index, Cn denotes the metal concentration in the sample, and Bn denotes the background metal concentration.

3.5. Contamination factor (CF)

The CF was calculated using the Hakanson (1980) formula

$$CF = \frac{C_n}{B_n} \quad (5)$$

Where Cn represents the metal concentration and Bn represents the background/target value (Eyankware and Akakuru 2022).

The concentration configuration and dispersion trend in the area were modeled using Microsoft Excel and Surfer 12 software. The Statistical Package for Social Science (SPSS) version 23 was used to calculate Pearson's correlation coefficient.

3.6. Health risk assessment

The non-carcinogenic risk associated with drinking contaminated river water was calculated using the criteria of the US Environmental Protection Agency (USEPA, 1989). In equation 6 the risk was calculated using the following function for both children and adults.

$$CDI = \frac{Cw\ X\ IRW\ X\ EF\ X\ ED}{BW\ X\ AT} \quad (6)$$

where CDI denotes Chronic Daily Intake or exposure dose (mg/kg/day), Cw denotes contaminant concentration in water (mg/L), IRW denotes ingestion rate (for adults, IRW is 2 L/day, while for children, IRW is 1 L/day), EF denotes Exposure Frequency (equivalent to 365 days/ year), ED denotes exposure duration (for adults and children, ED is 70 and 6 respectively (Bortey-Sam et al., 2015; Duggal et al., 2017; Barzegar et al., 2018). The non-carcinogenic risk posed by various elements in equation 7 was evaluated using the hazard quotient (HQ), as defined by Li et al. (2016) and Zhang et al. (2018):

$$HQ = \frac{CDI}{RFD} \quad (7)$$

RfD stands for reference dose (mg/kg/day) for a given element. RfD for various elements is similar to 0.7 (Fe), 0.3 (Zn), 0.0001 (Hg), 0.03 (Co), and 0.0035 (Co), according to Duggal et al. (2017) and Barzegar et al. (2018). (Pb). Finally, using equation 7 the total HQ values for the elements is computed to determine the hazard index (HI) of the water samples.

$$HI = \sum HQ \quad (8)$$

when HI and HQ values larger than 1 indicate that the given element's non-carcinogenic risk exceeds the limit of acceptance (HI = 1), while values less than 1 show that the non-carcinogenic risk is within acceptable limits (USEPA 1989; Su et al., 2017). As reported by Bortey-Sam et al. (2015), Barzegar et al. (2015), Table 1 illustrates the USEPA (1989) classification of non-carcinogenic risk.

https://dx.doi.org/10.4314/aujst.v5i2.1

Table 1: The United States Environmental Protection Agency (USEPA) classified non-carcinogenic risk in 1989.

Risk Level	Hazard Index (HI)	Chronic risk
1	<0.1	Negligible
2	0.1-1	Low
3	1-4	Medium
4	>4	High

Table 2: Results of Heavy metals

Sampling Points/ Code	Ec (µs/ cm)	pH	Fe (mg/ L)	Pb (mg/ L)	Mn (mg/ L)	As (mg/ L)	Ni (mg/ L)	Co (mg/ L)	Cu (mg/ L)	Zn (mg/ L)	Cr (mg/ L)
FET/01	464.2	6.2	1.002	BDL	0.090	BDL	0.012	0.011	0.002	0.021	0.002
FET/02	739.3	7.3	0.920	BDL	0.010	BDL	0.001	0.001	0.001	0.010	0.001
FET/03	189.3	7.1	0.422	BDL	0.030	BDL	0.027	0.001	0.011	1.382	0.022
FET/04	930.8	7.0	0.261	BDL	0.07	0.001	0.131	0.011	0.012	0.027	0.035
FET/05	742.1	7.2	0.0262	BDL	BDL	0.0001	0.272	0.012	0.001	0.811	0.026
FET/06	1092.1	7.4	0.0991	BDL	0.021	BDL	0.362	0.0001	BDL	1.223	0.011
FET/07	628.2	6.9	0.869	BDL	0.036	BDL	0.426	0.0010	0.037	0.021	0.002
FET/08	829.0	6.9	1.021	BDL	0.001	BDL	0.001	0.0001	0.003	0.532	0.010
FET/09	378.2	7.1	0.179	BDL	BDL	0.0010	0.029	0.001	0.001	0.202	0.020
FET/10	893.1	7.6	0.826	BDL	0.002	BDL	0.005	0.001	0.002	1.028	0.032
FET/12	749.4	6.9	1.087	BDL	0.012	BDL	0.012	0.0001	0.100	1.292	0.002
FET/13	682.3	7.0	1.002	BDL	BDL	BDL	0.016	0.001	0.001	0.827	0.011
FET/14	900.7	7.2	0.254	BDL	BDL	0.001	0.183	0.0001	0.001	BDL	0.003
FET/15	739.2	7.4	0.823	BDL	0.001	0.001	0.019	0.0012	0.011	0.101	0.037
FET/16	469.2	7.1	1.002	BDL	BDL	0.005	0.102	0.0001	0.001	0.272	0.012
FET/17	207.2	6.9	0.918	BDL	0.011	0.001	0.063	0.001	0.010	0.138	0.036
FET/18	330.2	6.8	0.715	BDL	0.002	0.001	0.109	0.001	0.002	0.321	0.003
Min.	189.3	6.2	0.02		0.001	0.0001	0.0001	0.001	0.001	0.01	0.001
Max.	1092.1	7.6	1.087		0.09	0.005	0.426	0.1	0.1	1.382	0.037
Aver.	644.52	7.04	0.65		0.02	0.000162	0.115	0.0029	0.0165	0.53	0.0159

4. Results and Discussions

The result for the measured heavy metals are shown in Table 2. The Health Risk Assessment considers two routes of human contamination by chemical substances. Equation. 6-8 shows the calculation of the dose for the exposure pathways used for human health risk assessment. These equations were taken from the U.S. EPA (2018) guidelines. The parameters used in these calculations were obtained from (USEPA, 2018). It is well known that the physicochemical properties of chemicals and the duration of exposure determine how severe their effects are (Egbueri, et al., 2020a). Chemical exposure are both carcinogenic and non-carcinogenic effects, which are handled differently when calculating

https://dx.doi.org/10.4314/aujst.v5i2.1

risk. No safe dosage threshold exists for the carcinogenic consequences, which are random in nature. Once a dosage threshold is exceeded, the non-carcinogenic effects start to manifest. The non-carcinogenic hazard quotient (HQ) and the potential carcinogenic risk (CR) are determined from Equation 8.

4.1. Non-carcinogenic risk assessment.

4.1.1. Hazard Quotient due to dermal contact.

Except for Fe, whose RfD the authors were unable to determine, and Pb, which was not detectable in any of the samples based on the analytical results, all of the assessed contaminants were used for the evaluation of non-carcinogenic risk assessment for both ingestion and dermal contact exposure routes. This assessment was completed for the adult and children groups. The findings of this study are presented in Tables 3 and 4.

Table 3: HQ for dermal in children population

	Non-Carcinogenic							Carcinogenic		
HQderm	As	Co	Cu	Zn	Cr	Ni	Mn	AS	Cr	NI
FET/01	0	0.01119	0.002713	0.005697	0.542527	0.036168	0.796099	0	0.002517	0.000302
FET/02	0	0.001017	0.001356	0.002713	0.271263	0.003014	0.088455	0	0.001259	2.52E-05
FET/03	0	0.001017	0.014919	0.374886	5.967793	0.081379	0.265366	0	0.027688	0.00068
FET/04	0.132324	0.01119	0.016276	0.007324	9.494216	0.394839	0.619188	4.49E-05	0.04405	0.003297
FET/05	0.013232	0.012207	0.001356	0.219995	7.052846	0.819818	0	4.49E-06	0.032723	0.006847
FET/06	0	0.000102	0	0.331755	2.983896	1.091081	0.185756	0	0.013844	0.009112
FET/07	0	0.001017	0.050184	0.005697	0.542527	1.28398	0.31844	0	0.002517	0.010723
FET/08	0	0.000102	0.004069	0.144312	2.712633	0.003014	0.008846	0	0.012586	2.52E-05
FET/09	0.132324	0.001017	0.001356	0.054795	5.425266	0.087407	0	4.49E-05	0.025171	0.00073
FET/10	0	0.001017	0.002713	0.278859	8.680426	0.01507	0.017691	0	0.040274	0.000126
FET/11	0	0.000102	0.135632	0.350472	0.542527	0.036168	0.106147	0	0.002517	0.000302
FET/12	0	0.001017	0.001356	0.224335	2.983896	0.048225	0	0	0.013844	0.000403
FET/13	0.132324	0.000102	0.001356	0	0.81379	0.551569	0	4.49E-05	0.003776	0.004606
FET/14	0.132324	0.001221	0.014919	0.027398	10.03674	0.057267	0.008846	4.49E-05	0.046567	0.000478
FET/15	0.661618	0.000102	0.001356	0.073784	3.25516	0.307432	0	0.000225	0.015103	0.002567
FET/16	0.132324	0.001017	0.013563	0.037434	9.765479	0.189884	0.097301	4.49E-05	0.045308	0.001586
FET/17	0.132324	0.001017	0.002713	0.087076	0.81379	0.32853	0.017691	4.49E-05	0.003776	0.002744
Min.	0	0.000102	0	0	0.271263	0.003014	0.0		0.001259	0.0000252
Max.	0.66162	0.012207	0.135632	0.374886	10.03674	1.28398	0.796099	0.000225	0.046567	0.010723
Aver-age.	0.0864	0.002615	0.015637	0.130972	4.228516	0.313814	0.148813	2.93465E-05	0.019619	0.0026208

https://dx.doi.org/10.4314/aujst.v5i2.1

Table 4: HQ for dermal in Adults population

	Non-Carcinogenic							Carcinogenic		
HQ_{DERM}	As	Co	Cu	Zn	Cr	Ni	Mn	As	Cr	Ni
FET/01	BDL	0.017976	0.015345	0.002859	0.092456	0.184626	0.164983	0	0.002537	0.000302
FET/02	BDL	0.001634	0.007673	0.001361	0.046228	0.015386	0.018331	0	0.001259	2.52E-05
FET/03	BDL	0.001634	0.084399	0.188125	1.017011	0.415409	0.054994	0	0.027704	0.00068
FET/04	0.317335	0.017976	0.092072	0.003675	1.617972	2.015505	0.12832	5.29E-05	0.044075	0.003297
FET/05	0.031734	0.01961	0.007673	0.110397	1.201922	4.184865	BDL	5.29E-06	0.032741	0.006847
FET/06	BDL	0.000163	BDL	0.166481	0.508506	5.569563	0.038496	0	0.013852	0.009112
FET/07	BDL	0.001634	0.283887	0.002859	0.092456	6.554238	0.065993	0	0.002519	0.010723
FET/08	BDL	0.000163	0.023018	0.072419	0.462278	0.015386	0.001833	0	0.012593	2.52E-05
FET/09	0.317335	0.001634	0.007673	0.027497	0.924556	0.44618	BDL	5.29E-05	0.025186	0.00073
FET/10	BDL	0.001634	0.015345	0.139937	1.479289	0.076928	0.003666	0	0.040297	0.000126
FET/11	BDL	0.000163	0.767263	0.175874	0.092456	0.184626	0.021998	0	0.002519	0.000302
FET/12	BDL	0.001634	0.007673	0.112575	0.508506	0.246169	BDL	0	0.013852	0.000403
FET/14	0.317335	0.000163	0.007673	BDL	0.138683	2.815553	BDL	5.29E-05	0.003778	0.004606
FET/15	0.317335	0.001961	0.084399	0.013749	1.710428	0.292325	0.001833	5.29E-05	0.046593	0.000478
FET/16	1.586676	0.000163	0.007673	0.037026	0.554733	1.569325	BDL	0.000265	0.015111	0.002567
FET/17	0.317335	0.001634	0.076726	0.018785	1.6642	0.969289	0.020165	5.29E-05	0.045334	0.001586
FET/18	0.317335	0.001634	0.015345	0.043696	0.138683	1.677023	0.003666	5.29E-05	0.003778	0.002744

A level of exposure below RfD (HQ<1) is judged by the HQ to not pose a risk immediately to the population. Nonetheless, the assessed HQ scores indicate the following pollutants' order of impact for both adults and children based on the dermal route: Ni>Mn>Zn>As>Cu>Co>Cr.(Table 1). Only two pollutants, however, were shown to have a stronger influence on the water samples' chronic risk status (Cr and Ni) with HQ > 1. Pollutants, such Mn, Zn, Co, As, and Cu, were seen to have HQ <1. table 1. reveals that 64.7% of the entire sample population had HQ>1 for chromium (Cr) and 18% for nickel.

4.1.2. Health Hazard Index (HI) due to dermal contact.

The study uses the health hazard index (HI) to determine the combined effects of the different HQs. HI is the sum of more than one hazard quotient that reflects the cumulative impact of the pollutants on the water samples. It can be categorized as insignificant (risk level 1; HI < 0.1), low risk (risk level 2; HI ≥ 0.1<1), medium risk (risk level 3; HI ≥1<4), and high risk (risk level 4; HI > 4) for the purpose easy evaluation of the potential risk hazard(US-EPA 2018; Mgbenu and Egbueri, 2019;Egbueri, et al.,2020a). Based on the dermal routes for the children population as shown in Table 5. 6 % of the total samples pose low risk, 41 % pose medium risk while high risk. On the other hand, for the adult population, 71 % pose negligible to low risk while 29 % pose medium risk as shown in Table 6. However, the evaluation based on the ingestion route for the children population, reveals that 30 % of the total samples pose negligible to medium risk, 41 % pose a medium risk and 29 % pose a high risk. On the other hand, 41 % pose negligible to low risk, 41 % pose medium risk and 18 % pose high risk to the adult population.

https://dx.doi.org/10.4314/aujst.v5i2.1

Table 5: HQ for Ingestion Route in the Children population

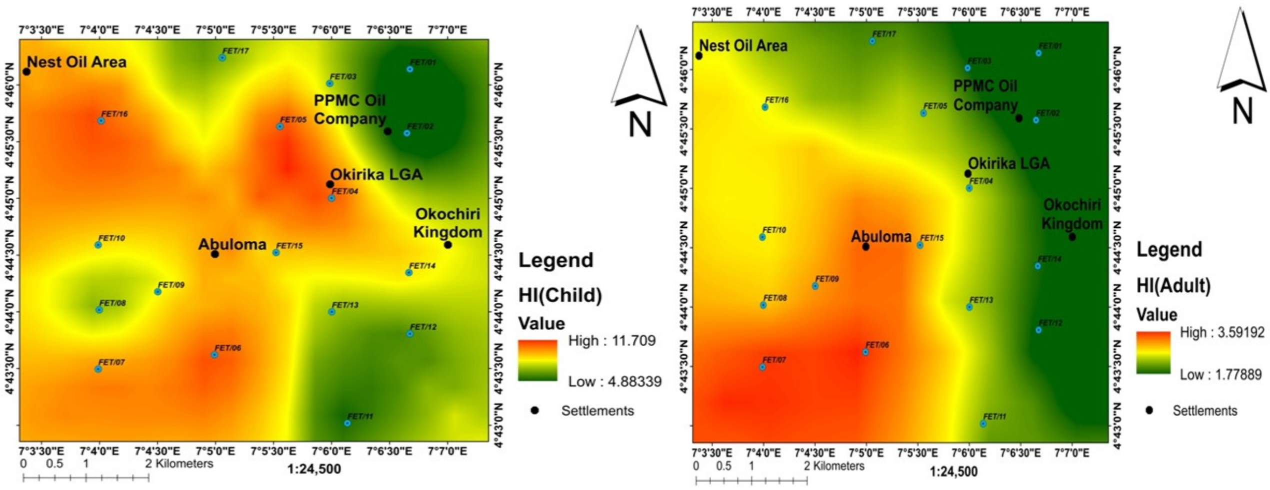
HQing	As	Co	Cu	Zn	Cr	Ni	Mn
FET/01	0	0.027425	0.024932	0.00349	0.033242	0.299178	0.097558
FET/02	0	0.002493	0.012466	0.001662	0.016621	0.024932	0.01084
FET/03	0	0.002493	0.137123	0.229702	0.365662	0.673151	0.032519
FET/04	0.49863	0.027425	0.149589	0.004488	0.581735	3.266027	0.075878
FET/05	0.049863	0.029918	0.012466	0.134796	0.432146	6.78137	0
FET/06	0	0.000249	0	0.203275	0.182831	9.025205	0.022764
FET/07	0	0.002493	0.461233	0.00349	0.033242	10.62082	0.039023
FET/08	0	0.000249	0.037397	0.088424	0.16621	0.024932	0.001084
FET/09	0.49863	0.002493	0.012466	0.033574	0.33242	0.723014	0
FET/10	0	0.002493	0.024932	0.170864	0.531872	0.124658	0.002168
FET/11	0	0.000249	1.246575	0.214743	0.033242	0.299178	0.013008
FET/12	0	0.002493	0.012466	0.137456	0.182831	0.398904	0
FET/13	0.49863	0.000249	0.012466	0	0.049863	4.562466	0
FET/14	0.49863	0.002992	0.137123	0.016787	0.614977	0.473699	0.001084
FET/15	2.493151	0.000249	0.012466	0.045209	0.199452	2.543014	0
FET/16	0.49863	0.002493	0.124658	0.022937	0.598356	1.570685	0.011924
FET/17	0.49863	0.002493	0.024932	0.053353	0.049863	2.717534	0.002168

Table 6: **HQ for Ingestion Routes in Adults population**

	Non- Carcinogenic							Carcinogenic		
HQing	As	Co	Cu	Zn	Cr	Ni	Mn	AS	Cr	NI
FET/01	0	0.016481	0.014983	0.002098	0.019977	0.179795	0.058629	0	0.002517	0.000302
FET/02	0	0.001498	0.007491	0.000999	0.009989	0.014983	0.006514	0	0.001259	2.52E-05
FET/03	0	0.001498	0.082406	0.138042	0.219749	0.404538	0.019543	0	0.027688	0.00068
FET/04	0.299658	0.016481	0.089897	0.002697	0.3496	1.962757	0.0456	4.49E-05	0.04405	0.003297
FET/05	0.029966	0.017979	0.007491	0.081007	0.259703	4.075342	0	4.49E-06	0.032723	0.006847
FET/06	0	0.00015	0	0.12216	0.109874	5.423801	0.01368	0	0.013844	0.009112
FET/07	0	0.001498	0.277183	0.002098	0.019977	6.382705	0.023451	0	0.002517	0.010723
FET/08	0	0.00015	0.022474	0.053139	0.099886	0.014983	0.000651	0	0.012586	2.52E-05
FET/09	0.299658	0.001498	0.007491	0.020177	0.199772	0.434503	0	4.49E-05	0.025171	0.00073
FET/10	0	0.001498	0.014983	0.102683	0.319635	0.074914	0.001303	0	0.040274	0.000126
FET/11	0	0.00015	0.749144	0.129053	0.019977	0.179795	0.007817	0	0.002517	0.000302
FET/12	0	0.001498	0.007491	0.082606	0.109874	0.239726	0	0	0.013844	0.000403
FET/13	0.299658	0.00015	0.007491	0	0.029966	2.741866	0	4.49E-05	0.003776	0.004606
FET/14	0.299658	0.001798	0.082406	0.010088	0.369578	0.284675	0.000651	4.49E-05	0.046567	0.000478
FET/15	1.498288	0.00015	0.007491	0.027169	0.119863	1.528253	0	0.000225	0.015103	0.002567
FET/16	0.299658	0.001498	0.074914	0.013784	0.359589	0.943921	0.007166	4.49E-05	0.045308	0.001586
FET/17	0.299658	0.001498	0.014983	0.032063	0.029966	1.633134	0.001303	4.49E-05	0.003776	0.002744

https://dx.doi.org/10.4314/aujst.v5i2.1

The information provided by the evaluated HI indicates that the water samples present a greater threat to the children population due to ingestion. Results from Fig. 3a revealed that HI (child) values increase towards the to northwestern and southwestern parts , extremely high values were found to be around PPMC oil company while very low values were found at the northeastern and southeastern part of the study areas. Findings from Fig. 3b showed HI (adult) increase towards the southwestern parts of the study area, while low value was observed around the selected parts of northeastern and southeastern parts of the study area, this is in line with study conducted by Eyankware, et al., (2023) in Port Harcourt, River State Nigeria.



Figs. 3: Spatial distribution (a) Health Index (Child) and (b) Health Index (Adult)

4.1.3. Carcinogenic Risk due to dermal contact.

Additionally, an assessment of the carcinogenic risk (CR) associated with dermal exposure to water was conducted for both adults and children. The cumulative risk of developing cancer throughout a lifetime as a result of drinking water contaminated with carcinogens was calculated using the CR evaluation (Egbueri 2020a). The acceptable CR value is ≤ 1×10^{-6} benchmark indicates that, on average, roughly, 1 in 1,000,000 individuals (consumers) will probably acquire cancer as a result of exposure to a carcinogen (US-EPA 2018; Mgbenu and Egbueri, 2019;Egbueri, et al.,2020a). The findings of this study demonstrated that the majority of the carcinogens (As, Cr, and Ni) examined were higher than the threshold of < 1×10-6. All of the groundwater samples taken into consideration in this study showed a very high propensity to affect the development of cancer in consumers, including children and adults, based on the evaluated CR scores of the samples (Table 7).

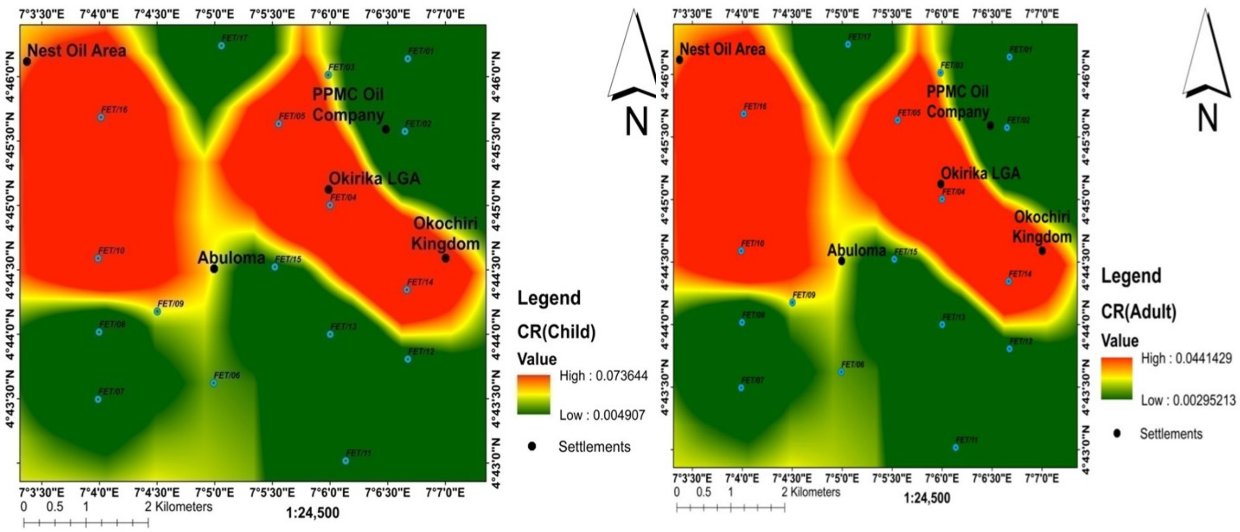
4.1.4. Ingestion route

However, the assessment of the children's population based on the ingestion route shows that 29 % pose high danger, 41 % post medium risk, and 30 % pose minimal to medium risk. Conversely, 41% of the adult population is at insignificant to low risk, 41 % is at medium risk, and 18 % is at high risk. The data from the assessed HI indicates that the water presents a greater danger to youngsters because of ingesting contact with the toxins. However, to further evaluate the combined risk posed by the water to the entire population, the study evaluated the aggregated risk based on the exposure pathways evaluated. Deductions from Fig. 4a suggested that CR (child) values increase towards to northwestern, and selected parts southeastern and northeastern (Okirika, PPMC oil company, and Okochiri) of the study area. Deductions from Fig. 4b suggested that CR (adult) values increase towards to northwestern, and selected parts southeastern and northeastern (Okirika, PPMC oil company, and Okochiri) of the study area. Aggregate risk refers to the overall impact of the HI for several exposure paths. The total health risk associated with the pollutants in the water that were examined was determined by adding up the two exposure routes, as indicated in Table 8. This was calculated for the population of adults as well as children.

https://dx.doi.org/10.4314/aujst.v5i2.1

Table 7: Health Index assessment and Carcinogenic Risk assessment

Non-Carcinogenic risk assessment					Carcinogenic risk assessment			
	HI(child)	HI(adult)	HI(child)	HI(adult)	ΣCR(child)	ΣCR(adult)	ΣC(child)	ΣCR(adult)
FET/01	1.394393	0.186283	0.485825	0.291962	3.29E-05	1.98E-05	0.004691	0.002819
FET/02	0.367819	0.049138	0.069013	0.041474	5.37E-06	7.18E-07	0.002136	0.001284
FET/03	6.705361	0.895797	1.440651	0.865776	0.000118	1.58E-05	0.047204	0.028368
FET/04	10.67536	1.426165	4.603773	2.76669	0.000248	3.31E-05	0.07886	0.047392
FET/05	8.119454	1.084712	7.440559	4.47149	0.000146	1.95E-05	0.065851	0.039574
FET/06	4.592591	0.613543	9.434324	5.669666	5.91E-05	7.89E-06	0.038199	0.022956
FET/07	2.201843	0.294153	11.1603	6.706913	1.07E-05	1.44E-06	0.022031	0.01324
FET/08	2.872976	0.383813	0.318296	0.191284	5.37E-05	7.18E-06	0.020984	0.012611
FET/09	5.702166	0.761776	1.602597	0.963099	0.000167	2.23E-05	0.043174	0.025946
FET/10	8.995776	1.201783	0.856986	0.515016	0.000172	2.3E-05	0.067225	0.0404
FET/11	1.171047	0.156445	1.806996	1.085935	1.07E-05	1.44E-06	0.004691	0.002819
FET/12	3.258829	0.435361	0.73415	0.441196	5.91E-05	7.89E-06	0.023707	0.014247
FET/13	1.49914	0.200276	5.123674	3.079131	7.57E-05	1.01E-05	0.014022	0.008427
FET/14	10.27872	1.373177	1.745292	1.048853	0.000258	3.45E-05	0.078358	0.04709
FET/15	4.299451	0.574382	5.293541	3.181214	0.000362	4.84E-05	0.029777	0.017895
FET/16	10.237	1.367604	2.829683	1.70053	0.000253	3.38E-05	0.078106	0.046939
FET/17	1.38314	0.184779	3.348973	2.012604	7.57E-05	1.01E-05	0.010923	0.006564



Figs. 4: Spatial distribution (a) Carcinogenic Risk (Child) and (b) Carcinogenic Risk (Adult)

The findings demonstrated that a number of the pollutants provide serious combined risks to adult and children populations' health. For non-carcinogens, their average values were higher than the limit of 1, while for carcinogens, it was greater than 1×10^{-6}. Based on their HQ average ratings, the combined non-carcinogenic risk assessment for children reveals that just 6 % of the total samples had a minimal effect (Table 8). However, the total carcinogenic health risk for children indicated that there is a carcinogenic risk present in every sample. Additionally, the location's overall non-carcinogenic health risk assessment for the adult population revealed that just 24 % of it posed a minimal risk.

Overall, the adult population's scores were lower, suggesting that children are more susceptible to health hazards that might cause cancer as well as non-cancerous ones. This findings is synonymous with the observation from the study carried out by Egbueri, et al. (2020a) on evaluation of the Groundwater Quality of the Ameka Region of Southeast Nigeria and find out that the children population are more vulnerable to both carcinogenic and non-carcinogenic threat.

Table 8: Health Index Aggregate for the children and Adults population.

Locations	Non-Carcinogenic risk assessment		Carcinogenic risk assessment	
	HI_{agg}(child)	HI_{agg}(adult)	CR_{agg}(child)	CR_{agg}(adult)
FET/01	1.880217	0.478245	0.004724	0.002839
FET/02	0.436832	0.090613	0.002142	0.001284
FET/03	8.146012	1.761573	0.047322	0.028384
FET/04	15.27913	4.192856	0.079108	0.047425
FET/05	15.56001	5.556202	0.065996	0.039593
FET/06	14.02692	6.283209	0.038258	0.022964
FET/07	13.36215	7.001067	0.022042	0.013242
FET/08	3.191271	0.575096	0.021038	0.012618
FET/09	7.304763	1.724875	0.043341	0.025968
FET/10	9.852762	1.716799	0.067397	0.040423
FET/11	2.978043	1.24238	0.004702	0.002821
FET/12	3.992979	0.876556	0.023766	0.014255
FET/13	6.622814	3.279407	0.014098	0.008437
FET/14	12.02401	2.42203	0.078616	0.047124
FET/15	9.592992	3.755596	0.030139	0.017943
FET/16	13.06669	3.068134	0.078359	0.046973
FET/17	4.732113	2.197384	0.010999	0.006574

4.2. Heavy metal indexes

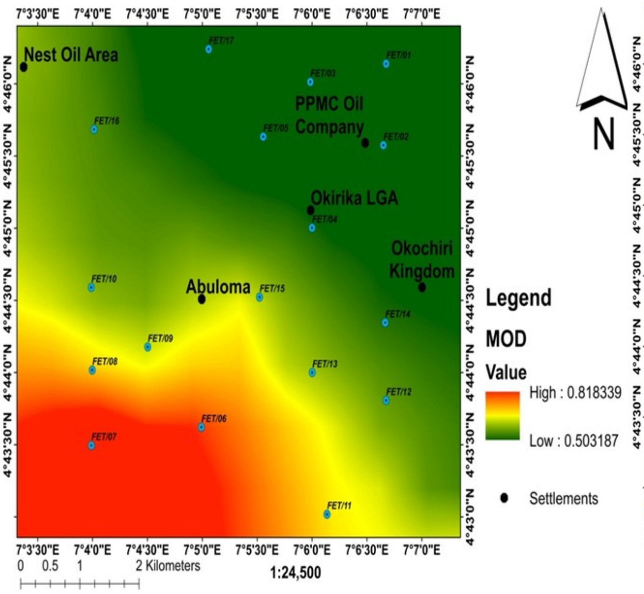
4.2.1. Contamination factor (CF)

The contamination factor is a single pollution index method that evaluates the contribution of individual contaminants to the overall water quality. Cf < 1, Low contamination; 1 ≤ CF ≥ 2, Moderate contamination, 3 ≤ CF ≥ 6, Significant Contamination and CF > 6, Very High Contamination (Bhutiani et al.,2017).Table 9 reveals the entire samples shows low contamination for Mn, As, Co, Cu, Zn and Cr. Meanwhile about 29.4% of the entire samples has CF value less than unity indicating low contamination for Fe, while 29.4 % and 41.2 % (FET/03, 7, 10, 15,18 and FET/01, 02, 08, 12, 13, 16, 17) indicate moderate and significant contamination. 35 % of the sample population (FET/03,4,7,13,,16,17) reveals moderate contamination for Ni, while 12 % (FET/05,and 06) and 6 % (FET/07) fell within the significant and very high contamination categories. The cumulative effect of the contaminants on the water was evaluated using modified contamination index. MCd give the overview of the water quality. Mcd ≤ 1.5, Nil to very low; 1.5 ≤ MCd < 2 low; 2 ≤ Cd <4, moderate; 4 ≤ Mcd < 8, High; 8 ≤ Mcd < 16, Very high; 16 ≤ Mcd < 32, Extremely High; ≥ 32, Ultra High (Vineethkumar et al., 2020). The evaluated MCd in Table 8 reveals that 100 % of the samples has MCd ≤ 1.5, indicating Nil to low contamination. Observations from Mcd (Fig. 5a) showed that the value of Mcd increases towards the southwestern parts of the study area. Extreme low values of Mcd were noticeable towards the northeastern, and selected parts of southeastern parts of the study area.

https://dx.doi.org/10.4314/aujst.v5i2.1

Table 9: Contamination factor and modified degree of contamination

CF	Fe	Mn	As	Ni	Co	Cu	Zn	Cr	MCd
FET/01	3.34	0.225	N/A	0.171429	0.157143	0.001	0.0042	0.04	0.562682
FET/02	3.066667	0.025	N/A	0.014286	0.014286	0.0005	0.002	0.02	0.448963
FET/03	1.406667	0.075	N/A	0.385714	0.014286	0.0055	0.2764	0.44	0.371938
FET/04	0.87	0.175	0.1	1.871429	0.157143	0.006	0.0054	0.7	0.485621
FET/05	0.087333	N/A	0.01	3.885714	0.171429	0.0005	0.1622	0.52	0.691025
FET/06	0.330333	0.0525	N/A	5.171429	0.001429	N/A	0.2446	0.22	1.003382
FET/07	2.896667	0.09	N/A	6.085714	0.014286	0.0185	0.0042	0.04	1.307052
FET/08	3.403333	0.0025	N/A	0.014286	0.001429	0.0015	0.1064	0.2	0.532778
FET/09	0.596667	N/A	0.1	0.414286	0.014286	0.0005	0.0404	0.4	0.223734
FET/10	2.753333	0.005	N/A	0.071429	0.014286	0.001	0.2056	0.64	0.527235
FET/11	3.623333	0.03	N/A	0.171429	0.001429	0.05	0.2584	0.04	0.59637
FET/12	3.34	N/A	N/A	0.228571	0.014286	0.0005	0.1654	0.22	0.66146
FET/13	0.846667	N/A	0.1	2.614286	0.001429	0.0005	N/A	0.06	0.603813
FET/14	2.743333	0.0025	0.1	0.271429	0.017143	0.0055	0.0202	0.74	0.487513
FET/15	3.34	N/A	0.5	1.457143	0.001429	0.0005	0.0544	0.24	0.799067
FET/16	3.06	0.0275	0.1	0.9	0.014286	0.005	0.0276	0.72	0.606798
FET/17	2.383333	0.005	0.1	1.557143	0.014286	0.001	0.0642	0.06	0.52312



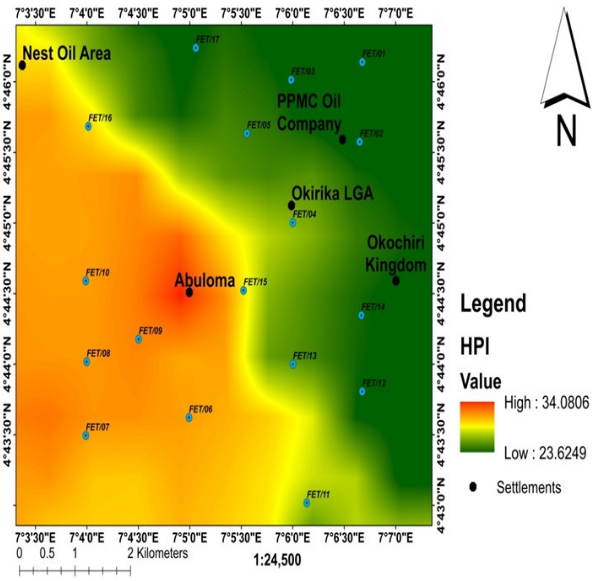


Fig.5 (a). Spatial Distribution of modified contamination index Fig.5 (b). Spatial Distribution of heavy metal pollution index (HPI)

4.2.2. Heavy metal pollution index (HPI)

HPI method was further utilized to gain better understanding on the quality state of the water. The results from the quality rating evaluations (Table 10) reveal that 70.5 % of the total samples has quality ratings above 100 for Iron, this include FET/01, 02, 03, 07, 08, 10, 11, 12, 14, 15, 16 and 17 where the percentage contribution of iron to the total HPI varies from 12 % - 92 %. Meanwhile 47 % of the entire samples has quality rating greater than 100 for Nickel this include FET 04, 05/06/07/13, 15 and 17, having percentage contribution ranging from 23 % to 92 %. This findings compliment the observation from CF, nevertheless both the Cf and qi reveals that approximately 71 % of the entire samples are contaminated with Fe. It is therefore important to understand that while qi gives individual evaluation of each elements, the CF rate the degree of contamination of each element. However, the HPI summarizes the overall effect of the heavy metals to the water. The results obtained from the HPI has shown that the HPI across the study area ranges from 7.152 to 63.076 with an average value of 27.164. This implies that the HPI across the study area is generally below 100, which implies safe water. This is consistent with the MCd's observations. The MCd, like the Cf, rates the overall level of water quality in classes, whereas HPI provides a comprehensive evaluation of the water. Figure 5b shows that HPI values increase towards the PPMC oil company Okirika and Okochiri axis of the study area. Low HPI values were particularly noticeable in Nest oil and Abuloma areas.

Table 10: Quality ratings and heavy metal pollution index

Qi	Fe	Mn	As	Ni	Co	cu	zn	Cr	HPI=∑Wi*Qi/Wi
FET/01	334.0	22.5	0	17.1	15.7	0.1	0.42	4	11.084
FET/02	306.7	2.5	0	1.4	1.4	0.1	0.2	2	7.152
FET/03	140.7	7.5	0	38.6	1.4	0.6	27.64	44	12.539
FET/04	87.0	17.5	10	187.1	15.7	0.6	0.54	70	36.312
FET/05	8.7	0	1	388.6	17.1	0.1	16.22	52	44.926
FET/06	33.0	5.25	0	517.1	0.1	0.0	24.46	22	51.307
FET/07	289.7	9	0	608.6	1.4	1.9	0.42	4	63.076
FET/08	340.3	0.25	0	1.4	0.1	0.2	10.64	20	10.056
FET/09	59.7	0	10	41.4	1.4	0.1	4.04	40	16.840
FET/10	275.3	0.5	0	7.1	1.4	0.1	20.56	64	14.994
FET/11	362.3	3	0	17.1	0.1	5.0	25.84	4	9.993
FET/12	334.0	0	0	22.9	1.4	0.1	16.54	22	12.273
FET/13	84.7	0	10	261.4	0.1	0.1	0	6	33.132
FET/14	274.3	0.25	10	27.1	1.7	0.6	2.02	74	24.551
FET/15	334.0	0	50	145.7	0.1	0.1	5.44	24	55.950
FET/16	306.0	2.75	10	90.0	1.4	0.5	2.76	72	30.778
FET/17	238.3	0.5	10	155.7	1.4	0.1	6.42	6	26.833

https://dx.doi.org/10.4314/aujst.v5i2.1

Since heavy metals were seen as the major pollutants in the study area, it was necessary to also utilize the QoC model for heavy metal source analysis. Therefore, the QoC model was introduced in this study to verify the source apportionment. Obtained QoC values for each analyzed heavy metal are presented in Table 10. Traditionally, positive QoC values indicate anthropogenic influence while negative QoC values indicate geogenic influence (Bhutiani et al.,2017; Egbueri, et al.,2020). In regards to this, the QoC values for Mn, As, Co, Cu, Zn, and Cr were all negative indicating a geogenic source. However, Fe was positive in 12 (70.59 %) samples , negative in 5 (29.41 %) samples (FET/04/05/06/09,13). QoC scores for Ni were positive in 7 (41.18 %) samples which are FET/04, 05, 06, 07, 13, 15 and 17) and negative in 58.82 % of samples including (FET/01,02,03,08,09,10,11,12,14, and 16) as shown in Table 11. This finding is synonymous with the finding of (Egbueri, et al.,2020) who used Quantification of contamination (QoC) successfully in demarcating the proportions of contribution by geogenic and anthropogenic activities in the pollution of drinking water sources in Ojoto area, South Eastern Nigeria. Elsewhere in Niger Delta of Nigeria, Izah et al.,(2017) also successfully evaluated the anthropogenic influence of contaminants in soil from cassava processing mill.

Table 11: QoC for each heavy metal analyzed in this study

Sampling	Fe	Mn	As	Ni	Co	Cu	Zn	Cr
FET/01	70.06	-344.4	BDL	-483.3	-536.4	-99900.0	-23709.5	-2400.0
FET/02	67.39	-3900.0	BDL	-6900.0	-6900.0	-199900.0	-49900.0	-4900.0
FET/03	28.91	-1233.3	BDL	-159.3	-6900.0	-18081.8	-261.8	-127.3
FET/04	-14.94	-471.4	-900	46.6	-536.4	-16566.7	-18418.5	-42.9
FET/05	-1045.04	BDL	-9900	74.3	-483.3	-199900.0	-516.5	-92.3
FET/06	-202.72	-1804.8	BDL	80.7	-69900.0	BDL	-308.8	-354.5
FET/07	65.48	-1011.1	BDL	83.6	-6900.0	-5305.4	-23709.5	-2400.0
FET/08	70.62	-39900.0	BDL	-6900.0	-69900.0	-66566.7	-839.8	-400.0
FET/09	-67.60	BDL	-900	-141.4	-6900.0	-199900.0	-2375.2	-150.0
FET/10	63.68	-19900.0	BDL	-1300.0	-6900.0	-99900.0	-386.4	-56.3
FET/12	72.40	-3233.3	BDL	-483.3	-69900.0	-1900.0	-287.0	-2400.0
FET/13	70.06	BDL	BDL	-337.5	-6900.0	-199900.0	-504.6	-354.5
FET/14	-18.11	BDL	-900	61.7	-69900.0	-199900.0	BDL	-1566.7
FET/15	63.55	-39900.0	-900	-268.4	-5733.3	-18081.8	-4850.5	-35.1
FET/16	70.06	BDL	-100	31.4	-69900.0	-199900.0	-1738.2	-316.7
FET/17	67.32	-3536.4	-900	-11.1	-6900.0	-19900.0	-3523.2	-38.9
FET/18	58.04	-19900.0	-900	35.8	-6900.0	-99900.0	-1457.6	-1566.7

4.3. Correlation Matrix, Component Analysis and Source Attribution

4.3.1. Correlation Matrix

The degree of the linear relationships between every pair of variables is displayed in the correlation matrix. This study used the Pearson correlation coefficient to quantify the strength of the relationships between the variables (Table 12). Principal Component Analysis (PCA) in Table 13, was utilized alongside the correlation matrix to identify the most significant underlying patterns within the datasets retaining most of the variance.

4.3.2. Component Analysis and Source Attribution

Component 1 accounts for 25.22% of the variance and has high factor loadings for Mn and Co (0.911 and 0.850). This suggests that Mn and Co originate from the same source. This observation is supported by the positive correlation coefficient between Mn and Co (r = 0.395), as shown in Table 12.

Table 12: Correlation Matrix of the data set

		Fe	Mn	As	Ni	Co	Cu	Zn	Cr
Sig. (1-tailed)	Fe	??	.495	.356	.426	.107	.106	.322	.149
	Mn	.495	??	.222	.359	.003	.395	.203	.415
	As	.356	.222	??	.450	.295	.245	.106	.365
	Ni	.426	.359	.450		.326	.096	.461	.273
	Co	.107	.003	.295	.326		.282	.232	.180
	Cu	.106	.395	.245	.096	.282		.118	.194
	Zn	.322	.203	.106	.461	.232	.118	??	.431
	Cr	.149	.415	.365	.273	.180	.194	.431	??

Table 13: Principal Component Aanlysis

Rotated Component Matrix[a]

	Component 1	2	3	4
Fe	-.079	.806	-.094	.442
Mn	.911	-.018	.018	.148
As	-.295	.070	-.730	-.059
Ni	.064	-.881	-.025	.578
Co	.850	-.171	-.017	-.292
Cu	-.003	.240	.536	.521
Zn	-.327	-.058	.819	-.121
Cr	.049	.077	.031	-.876

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

The findings are consistent with the Quality of Contaminants (QoC) results, which reflect geogenic sources of origin. Component 2 explains 19.66% of the total variance with a high factor loading for Fe (0.806) and a low factor loading for Cu (0.240). Despite this, the Pearson correlation matrix (Table 13) reveals a very weak correlation between Fe and Cu (r = 0.106), which could be attributed to dilution effects. This observation is in agreement with the QoC findings. Component 3 accounts for 18.11% of the variance and shows high factor loadings for Cu and Zn (0.536 and 0.819). This indicates that Cu and Zn are derived from similar sources. However, the QoC data confirm geogenic sources of these contaminants. This is supported by the weak and positive correlation between Cu and Zn (r = 0.118). Component 4 explains 14.82% of the total variance with high factor loadings for Ni, Fe, and Cu (0.578, 0.442, and 0.521). This suggests a possible common source for these elements. However, the QoC findings contradict this, showing that Ni and Cu may not share the same origin. This is supported by the correlation coefficient between Ni and Cu (r = 0.096). The correlation coefficient between Ni and Fe (r = 0.426) further indicates that anthropogenic activities are likely the major sources of Ni and Fe in the groundwater, as reflected in the QoC results. The use of the Pearson correlation matrix, in conjunction with QoC, to delineate sources of contaminants has also been demonstrated in the assessment of metal contamination risk in sediments of the Hara Biosphere Reserve, southern Iran, by Zarei (2014).

5. Conclusion

The Niger Delta region of Nigeria faces significant environmental hazards due to heavy metal pollution in groundwater, largely attributed to the operations of local oil corporations. This study assessed the contamination levels of various heavy metals, including Fe, Pb, Mn, As, Ni, Co, Cu, Zn, and Cr, across 17 groundwater samples. The principal component analysis (PCA) revealed substantial correlations among the measured traits, indicating that both saline water intrusion and heavy metal contamination are influencing groundwater chemistry. The Carcinogenic Risk (CR) scores highlighted a very high potential for cancer development due to groundwater consumption, affecting both children and adults. Specifically, the study found that 6% of samples posed a low risk, 41% a medium risk, and 51% a high risk for children, while 29% of samples posed a medium risk and 71% a low to insignificant risk for adults. The Heavy Metal Pollution Index (HPI) ranged from 7.15 to 63.08, with an average of 27.16, suggesting generally safe water with respect to HPI values below 100. However, the presence of Fe and Ni at varying levels—70.59% of samples testing positive for Fe and 41.18% for Ni—points to significant anthropogenic contributions to contamination. Given these findings, there is an urgent need for ongoing groundwater monitoring and the implementation of effective purification technologies to mitigate health risks. The study underscores the critical need for continuous evaluation and management of heavy metal levels in groundwater to protect public health, particularly in vulnerable populations such as children. Both geological and anthropogenic sources contribute to the contamination, highlighting the complexity of the issue and the need for comprehensive strategies to address and remediate heavy metal pollution in the Niger Delta.

References

Al-Omran AM, Aly AA, Al-Wabel MI, Sallam AS, Al-Shayaa MS (2016) Hydrochemical characterization of groundwater under agricultural land in arid environment: a case study of Al-Kharj, Saudi Arabia. Arab J Geosci 9:68–85. doi:10.1007/s12517-015-2136-5

American Public Health Association (APHA). (1995). *Standard methods for the examination for water and wastewater* (19th ed.). Byrd Prepress. American Public Health Association (APHA). (2012). *Standards methods for the examination of water and wastewater* (22nd ed., p. 1360). American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF).

Barzegar R, Moghaddam AA, Adamowski J, Nazemi AM (2018) Assessing the potential origins and human health risks of trace elements in groundwater: a case study in the Khoy plain, Iran. Environ Geochem Health. https ://doi.org/10.1007/s1065 3-018-0194-9

Barzegar R., Asghari Moghaddam A.A., Nadiri A., Fijani E.,(2015). Using different fuzzy logic methods to optimize DRASTIC model case study: Tabriz plain aquifer, *Sci. Quart. J. Geosci.* 24 (95) (2015) 211–222.

Bortey-Sam, N., Nakayama, S.M., Ikenaka, Y., Akoto, O., Baidoo, E., Yohannes, Y.B; Mizukawa, H., Ishizuka, M. (2014).Human health risks from metals and metalloid via consumption of food animals near gold mines in Tarkwa, Ghana: Estimation of the daily intakes and target hazard quotients (THQs). *Ecotoxicol. Environ. Safety*. 111, 160

Edokpa DO, Nwagbara MO (2017) Atmospheric stability pattern over Port Harcourt, Nigeria. J Atmos Pollut 5(1):9–17

Egbueri, J. C., Ameh, P. D., &Unigwe, C. O. (2020b). Integrating entropy-weighted water quality index and multiple pollution indices towards a better understanding of drinking water quality in Ojoto area, SE Nigeria. *Scientific African*, *10*, e00644.

Eyankware, M. O. & Akakuru, O. C. (2022). Appraisal of groundwater to risk contamination near an abandoned limestone quarry pit in Nkalagu, Nigeria, using enrichment factor and statistical approaches. *Int. J. Ener. Water Resour.* https://doi.org/10.1007/s42108-022-00186-0

Izah, S. C., Bassey, S. E., &Ohimain, E. I. (2017). Geo-accumulation index, enrichment factor and quantification of contamination of heavy metals in soil receiving cassava mill effluents in a rural community in the Niger Delta region of Nigeria. *Molecular Soil Biology*, *8*.

Bhutiani, R., Kulkarni, D. B., Khanna, D. R., &Gautam, A. (2017). Geochemical distribution and environmental risk assessment of heavy metals in groundwater of an industrial area and its surroundings, Haridwar, India. *Energy, ecology and environment*, *2*, 155-167.

Caeiro, S., Costa, M. H., Ramos, T. B., Fernandes, F., Silveira, N., Coimbra, A., Medeiros, G., & Painho, M. (2015). Assessing heavy metal contamination in Sado estuary sediment: An index nnuivsis approach. *Ecological Indicators, 5*, 151–169.

Cheng J, Shi Z, Zhu Y (2007) Assessment and mapping of environmental quality in agricultural soils of Zhejiang Province. China J Environ Sci 19:50–54

Edokpa DO, Nwagbara MO (2017) Atmospheric stability pattern over Port Harcourt, Nigeria. J Atmos Pollut 5(1):9–17

Egbueri, J. C., Ameh, P. D., Enyigwe, M. T., &Unigwe, C. O. (2020a). Entropy-based analysis of the impact of environmentally sensitive elements on groundwater quality of the Ameka region of southeast Nigeria: medical geology implications. *Analytical letters*, *54*(7), 1193-1223.

Eyankware, M.O., Akakuru, O. C., Osisanya, W. O., Umayah, S. O., Ukor, K. P. (2023). Assessment of heavy metal pollution on groundwater quality in the Niger Delta Region of Nigeria. Sustainable Water Resources Management (2023) 9:189. https://doi.org/10.1007/s40899-023-00955-7

Gong Q, Deng J, Xiang Y, Wang Q, Yang L (2008) Calculating pollution indices by heavy metals in ecological geochemistry assessment and a case study in parks of Beijing. J China Univ Geosci 19:230–241

Hakanson, L. (1980) An Ecological Risk Index for Aquatic Pollution Control a Sedimentological Approach. Water Research, 14, 975-1001. http://dx.doi.org/10.1016/0043-1354(80)90143-8

Huzefa, S., Himanshu, G., Ajaykumar, K., & Bhavana, U. (2020). Hydrogeochemical characterization of groundwater from semiarid region of western India for drinking and agricultural purposes with special reference to water quality index and potential health risks assessment. *Applied Water Science*. https://doi.org/10.1007/s13201-020-01287-z

Onyeagocha AC (1980) Petrography and depositional environment of the Benin Formation, Nigeria. J Min Geol 17:147–151

Oteri, A. U. (1990). Delineation of sea water intrusion in a coastal beach ridge of Forcados. *Journal of Mining and Geology, 26*(2), 225–229.

Oteri, A. U., Atolagbe, F. P. (2003). Saltwater intrusion into coastal aquifers in Nigeria. *The Second International Conference on Saltwater Intrusion and Coastal Aquifers*

Orji Prince Orji, Obiegbuna Dominic Chukwuebuka, Robert James James (2022). Assessment of seasonal variation of rainfall over tropical Monsoon zone of Nigeria. *The international journal of Science & technoledge.* Vol 10 Issue 2 DOI No.: 10.24940/theijst/2022/v10/i2/ST2202-004

Raju, N. J (2007) Hydrogeochemical parameters for assessment of groundwater quality in the upper Gunjanaeru river basin, Cuddapah district, Andhra Pradesh, South India. Environ Geol 52:1067–1074

Subba Rao, N., Sunitha, B., Rambabu, R., Nageswara Rao, P. V., Surya Rao, P., Spandana, B. D., Sravanthi, M., & Marghade, D. (2018). Quality and degree of pollution of groundwater, using PIG from a rural part of Telangana State India. *Applied Water Science., 8*, 227. https://doi.org/10.1007/s13201-018-3950864-x.

Short, K. C., Stauble, A. J. (1967) Outline of Geology of Niger Delta.*Bull AAPG 51*(5), 761-779

US Environmental Protection Agency. (2018). 2018 Edition of the drinking water standards and health a dvisories tables.

Vineethkumar, V., Sayooj, V. V., Shimod, K. P., & Prakash, V. (2020). Estimation of pollution indices and hazard evaluation from trace elements concentration in coastal sediments of Kerala, Southwest Coast of India. *Bulletin of the National Research Centre*, *44*, 1-16.

Weber KJ, Dankoru EM (1976) Petroleum geology of Niger Delta, Tokyo. In: 9th World Petroleum Congress Proceedings, London Applied Publishers, Ltd., 2, 209–221

https://dx.doi.org/10.4314/aujst.v5i2.1