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(RESEARCH ARTICLE)

Evaluation of water quality and ecological risk assessment index from highly oil-contaminated sites in the Niger Delta Nigeria

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Abstract

Multi-element indices in an aquatic ecosystem provide insight into the synergistic effects of many ecological parameters. Using standard analytical techniques and pollution indicators, the eco-toxicological state of oil-contaminated water in three communities in Warri Southwest, Niger Delta, Nigeria, was assessed. Water samples were examined for physicochemical properties, heavy metals, PAH and TPH levels. The ANOVA results showed no significant difference ($p > 0.05$) between the means of the physicochemical parameters and the study stations for the combined parameters. Out of the twenty-five parameters evaluated, the Nemerow Pollution Index (NPI) results revealed thirteen contributing parameters to overall water contamination in the research areas. Conductivity, TSS, TDS, DO, BOD, COD, Oil and Grease, Heavy Metals (Cu, Ni, Mn, and Cd), and Hydrocarbons are among them. These parameters also exceeded the maximum permitted limits set by NESREA. Heavy metal evaluation index (HEI) and geo-accumulation index (Igeo) in water were both found to be high. The PERI (potential ecological risk index) had values >100, indicating a high level of ecological risks. The study areas' overall water quality index (WQI) indicated poor to unsuitable water quality. Water pollution in the selected communities is attributed to various industrial and domestic activities along the waterways, crude oil spills, illegal refining, dredging, and ship and speed boat movement. Periodic monitoring and preventive measures are required in the study areas to keep the aquatic ecosystems from entirely degrading. Adequate legislation and proper effluent management could aid in the prevention of indiscriminate toxic compound discharge into water.

Keywords: Heavy metals; Ecological Risk Assessments; Polycyclic Aromatic Hydrocarbon; Contamination; Toxicity

1 Introduction

Nigeria is Africa's largest oil producer and the world's sixth-largest [1], and the Niger Delta remains the country's centre for oil and gas production and related operations. The discovery and rise of oil in Nigeria's Niger Delta have drawn considerable industrial, economic, and social development over the decades [2]. Unsustainable oil exploration activities in Nigeria, on the other hand, have placed the Niger Delta region among the world's top five most petroleum-damaged ecosystems [3].

Due to uncontrolled disposal of urban effluents, runoff, atmospheric deposition, municipal, and industrial effluent into these water bodies, water quality monitoring has been a source of concern in marine, stream, and river water. Oil theft, artisanal refining, oil spills, and increased human population are all putting pressure on the environment's quality [4]. Oil spills from crude oil explorations, theft, and illegal bunkering cause environmental degradation, aquatic life loss, water contamination, land loss, and other livelihood structures in coastal communities [5]. The majority of Niger Deltans fish and engage in subsistence cultivation. Although, due to low harvests caused by oil exploration and production

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activity in the area, the majority have abandoned these primary occupations. Currently, fishing and farming are insufficient to provide a consistent income for the ordinary indigene's family. There is also evidence of socio-cultural consequences from the loss of the traditional first-year festival bathing of community members, which heralds them into a prosperous new year [4]. Burning hydrocarbons pollutes water and harms human health, including skin sores, respiratory problems, food poisoning, and cancer [5]; changes in ecosystem functions, extinction of wildlife, as well as changes in aquatic ecological principles including low aquatic life assemblage [4], infertile land, the disappearance of mangroves and the loss of mangrove services such as aeration and carbon sequestration, and the disappearance of mangroves and the loss of mangrove services such as aeration and carbon sequestration [6]. Crude oil is volatile, viscous, and has a high penetration capability, and it has found its way into the Niger Delta's ecosystems, water, and food chains [7]. Residents living near oil exploration activities have been exposed to hazardous consequences from gas flares or oil spills, according to McLoone et al. [8]. Although there is no comprehensive data to determine the degree of crude oil exposure impacts [7], there is evidence of such effects in other countries similar to Nigeria [9, 10].

The communities of the Gbamaratu kingdom are typical of Nigeria's oil-polluted regions. The area is known for its undulating mangroves and high-water tables, as well as a high level of industrial and oil exploration activity. The rising human population and subsequent domestic activities in the area have exacerbated waste disposal systems, with indiscriminate solid waste dumping into rivers, and most local communities and residents rely largely on the water [4, 11]. This is concerning because most individuals in this area get their drinking water from local natural sources and use it for agricultural purposes. In and around this area, there are numerous unreported and undocumented incidents of water-borne infections as well as unknown unexpected fatalities.

Onyena et al. [4] reported some anthropogenic sources of petroleum products into Chanomi creek located along the study region, including oil production, marine transportation, gas flaring, direct ocean dumping, illegal crude oil refining and bunkering activities, municipal and industrial wastes, and runoffs. This is the same situation in the current study's chosen communities, where exploration, production, transportation, and storage of crude oil along coastlines, creeks, rivers, and estuaries has resulted in massive depletion of people's sources of livelihood. The value of mass education in the Niger Delta region has long been questioned. Due to insurgencies, the proximity of the area, and the peculiarity of the ecosystem, researchers find it difficult to gain a comprehensive understanding of its current state. As a result, the knowledge of the concentration of contamination in the area is low. Because access to clean water is becoming increasingly difficult in developing countries, particularly those reliant on natural resource mining. Developing a framework for meeting the water needs of coastal communities, as a critical Sustainable Development Goal (SDG 6), will address various issues, including epidemics (e.g., cholera, dysentery, and typhoid). In Nigeria, crude oil and refined products have contributed significantly to water pollution in coastal communities, including the Gbaramatu Kingdom. However, little effort has been made to address the recurring water pollution in coastal communities with high crude oil spills. The purpose of this study is to assess the heavy metal contamination, Total Petroleum Hydrocarbon content and general water quality status of water from the highly contaminated Western Niger Delta environment. The findings will be useful as a tool for prioritizing water needs and provision as well as pollution mitigation in coastal communities.

2 Material and methods

2.1 Study area

The research was conducted in various nearby communities in the Gbamaratu Kingdom in Warri, Delta State, Nigeria. For the investigation, three sampling locations (Fig. 1) were chosen. The decision is based on their importance as sources of various toxins in the water as well as massive oil spills in the Gbamaratu Kingdom's towns. The sampling stations' coordinates were marked using the Global Positioning System (GPS) (Magellan SporTrak GPS receiver). Okpo gbene village is the name of the first station (Station A). Typical vegetation and mangroves characterise these communities. The red mangroves (two kinds) dominate the landscape (*Rhizophora racemosa* and *Rhizophora mangle*). Some other notable plant species include *Paspalum viginatum* and *Achrostichum aureum*.

The climate is tropical equatorial, with two seasons: wet season (May to October) and dry season (November to April) (November to April). However, there are brief periods of rain and drought in April and August, respectively [4]. The average temperature ranges from 26°C in the rainy months to 33°C in the undetected dry season, as it rains regularly even during the dry season, and the humidity is around 80%. Because no month of the year is completely dry, annual rainfall in the region usually is around and occasionally above 3000mm.

The main activities of the residents in this area are farming, fishing, and boat building, albeit their means of subsistence, have diminished owing to recurring oil pollution. The terrain has encountered waste disposal issues throughout time as generated trash from the villages have been disposed of indiscriminately and without proper treatment. As a result, a wide range of pollutants, including petroleum hydrocarbons, trace metals, and nutrients (from raw domestic sewage and industrial waste), have been directly discharged into the marine environment.

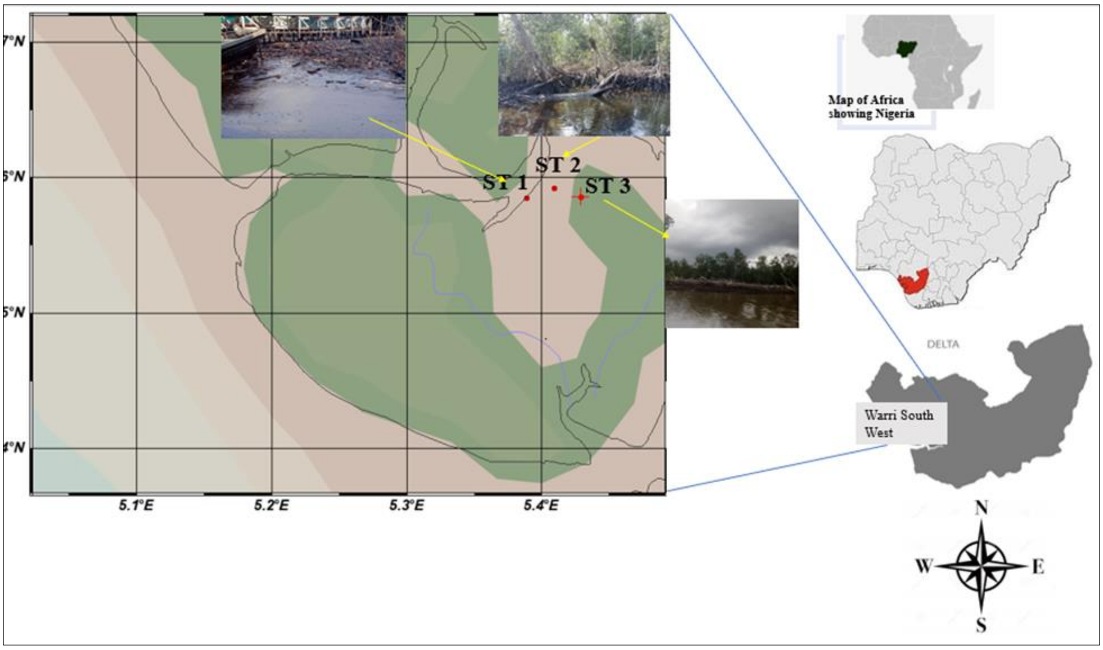

Figure 1 Map of the Study Area showing sampling stations

2.2 Collection and analysis of samples

2.2.1 Water samples

In November 2021, between 0700 and 0900 h, surface water samples were taken with a hydrobios sampler at each study location. Each station's water samples were obtained in triplicates at a random distance from each other. A thermometer and a Horiba water checker (Model U10) measured the surface water temperature in degrees Celsius and salinity in situ. Hannah pH-EC-TDS metre was used to detect pH, electrical conductivity, and total dissolved solids in situ (Model 9812). Dissolved oxygen (DO) in the water was assessed ex-situ using the iodometric method, and turbidity was determined using a turbidity metre as indicated in APHA [12]. FS 240 Varian Atomic Absorption Spectrophotometer (AAS) SpectrAA was used to determine the heavy metals Cd, Pb, Ni, Cu, As, Mn, Zn, Fe, and Cr. In contrast, the TPH was determined in the laboratory using Gas chromatography. The mean of the individual physicochemical parameters in the triplicate samples was obtained for further statistical analysis.

2.3 Statistical analysis

SPSS 21 was used to conduct the statistical analysis. The mean, standard deviation, and range of the physicochemical characteristics were evaluated using descriptive statistics. The statistical technique employed was determined by whether the data (parametric or non-parametric) satisfied the ANOVA assumptions (Residuals should be normally distributed; homogeneity of variance: all groups should have similar variances). However, the Kruskal Wallis tests are used if these conditions are not met. The Kolmogorov-Smirnov and the Shapiro-Wilk tests were used to evaluate the normality assumption. The Levene test was also employed to check for variance homogeneity. The Post HOC (Games-Howell Post HOC) test was used to see which of the non-parametric levels differed significantly from one another. Pearson Correlation was also used to show any significant relationship between the parameters.

The pollution indices were calculated using heavy metals and total petroleum hydrocarbon concentrations, and Pearson's correlation was used to check for relationships between the metals, TPH, and pollution indices.

2.4 Pollution and Ecological Risk Assessment

The Water Quality Index, Geo accumulation index, and heavy metal pollution index (HPI) were used to assess water pollution. In contrast, the Nemerow pollution index (PN) was used to determine the pollution status for irrigation, livestock watering, and marine habitat quality. The potential ecological risk index (PERI) model was used to assess the ecological risk of various water uses.

2.5 Water Quality Index (WQI)

The water quality index (WQI) explains the total water quality across a period for multiple water quality measures. Water quality data is turned into information that is available to the general public through WQI. The calculation and evaluation of WQI have been used by Odia and Nwaogazie [13] and Nwaogazie et al. [14], and the equation is given as follows:

$$WQI = \frac{\sum QjWj}{\sum wj} \quad (1)$$

The quality rating scale (Qj) for each parameter is calculated via Equation (2):

$$Qj = \frac{Vj - Vo}{Sj - Vo} \times 100 \quad (2)$$

where:

v_j is the estimated concentration of the nth parameter in the analyzed water samples

v_0 is the ideal value of analyzed water parameter in pure water sample which is usually zero except pH = 7.0 and dissolved oxygen, DO = 14 mg/l, s_j is the recommended standard value of the nth parameter which for this study was National Environmental Standards and Regulations Enforcement Agency [15].

The unit weight (wj) for each water quality parameter is evaluated using:

$$Wj = \frac{K}{Sj} \quad (3)$$

where k = proportionality constant and is evaluated by:

$$K = \frac{1}{\sum \frac{1}{Sj}} \quad (4)$$

The classification of the index ranges from 0 to 100 (Excellent to unsuitable water quality) depending on the values scored.

2.6 Heavy metal evaluation index (HEI)

The HEI gives an overall quality of the water sample with respect to heavy metals, and is calculated as shown in equation 5:

$$HEI = \sum_{i=1}^{n} \frac{Hc}{Hmac} \quad (5)$$

where Hc and Hmac are the measured value and maximum permissible concentration of the ith parameter, respectively. In this study, the Hmac was used as the guideline value for each metal, depicted in the guideline as the maximum permitted level by NESREA [15].

2.7 Geo-accumulation index (Igeo)

The Igeo determines the degree of contamination of any specific heavy metals of interest. This was introduced by Muller [16]. The index is classified into seven different grades with index classes ranging from 0 to 6 (Uncontaminated to extremely contaminated). It is calculated as:

$$Igeo = log_2 \frac{C_n}{1.5 x B_n} \quad (6)$$

Where, C_n is the mean concentration of the ith heavy metal in the water samples analysed. B_n is the reference value.

2.8 Nemerow Pollution Index (NPI)

The Nemerow Pollution Index, also called Row's Pollution Index, determines the overall degree of pollution and includes the parameters analysed in the water samples [17, 18]. It is calculated from the following formula:

$$\text{NPI} = \frac{C_n}{Sn}$$

where C_n = concentration of the nth parameter, S_n = prescribed maximum values of the nth parameter. Here, NPI ≤ 1 indicates that the parameters only contribute in a minute quantity of the general water pollution while NPI>1 indicates surplus concentrations of parameters identified, which shows their potential in contributing to the water pollution.

2.9 Potential Ecological Risk Index (PERI)

Potential ecological risk (RI) evaluates the degree of ecological risk caused by heavy metal concentrations in the water. This index was proposed by Hakanson [17], and it is equated using the following formula:

$$\text{PERI} = \sum_{i=1}^{n} E_r^i$$

where n = the number of heavy metals and E_r = single index of the ecological risk factor calculated as:

$$E_r = \text{PI x } T_r$$

and the Tr is "toxic- response" factor for a given metals; Ni = 5, Cd = 30, Cr = 2, Cu = 5, Zn =1 and Pb = 5 (17). Fe was not used in the calculation of PERI because it does not have value for the toxic response factor. Four classes of water quality were distinguished based on the potential ecological risk.

3 Results and discussion

Table 1 shows the descriptive statistics for the parameters measured. The Kolmogorov-Smirnov and Shapiro-Wilk tests were used to ensure that the data was normal. The Shapiro-Wilk test was adopted since it works well with small samples (50 samples). Except for turbidity, TSS, COD, Oil and Gas, nitrate, lead, iron, PAH, and TPH, which deviated considerably from a normal distribution ($P>0.05$), the rest of the physicochemical parameters had a normally distributed distribution ($P<0.05$). The ANOVA result revealed a significant difference in the mean of the samples obtained across the parameters ($P<0.05$) for parameters that passed the normality test. The ANOVA test (Table 2) revealed no significant difference ($P>0.05$) between the means of the physicochemical parameters and the study stations for the combined parameters. The uniqueness and originality of the different contaminants and parameters evaluated in each study station may account for this lack of significance. A Kruskal-Wallis' test for TSS, COD, Oil and Grease, Nitrate, Pb, Fe, PAH and TPH, which are non-parametric, showed a significant difference ($P<0.05$) in the distribution of samples collected between the stations and parameters except for Fe and COD. The non-significance in Fe and COD indicates that the concentrations in the creeks varied between study stations. Spatial changes in their concentrations in water samples can have an impact.

A Games-Howell Post HOC test for the pairwise comparison of the stations suggested that there was a significant difference between the mean of various stations and the parameters ($P<0.05$). However, no significant differences in Nitrate, Pb, or Fe were found ($P>0.05$). The statistical analysis also revealed spatial variations in the study stations and the parameters. The statistical significance results indicated that the various stations have diverse anthropogenic stressors linked to the rise in parameter concentrations [4]. This increase is dependent on the conditions at the different study locations.

3.1 Physicochemical parameters

The distribution of water temperature, pH, salinity, conductivity, and Total Dissolved Solids (TDS) was constant across the study stations (Fig 2). Their mean and standard deviation are as follows (see Table 1): 27.69±0.47°C, 7.13±0.12, 3.57±0.21ppt, 4.40±0.07mS/cm, and 2.22±0.028µg/L. The water temperature is within the tropical water temperature range. It compares favourably to the studies of Onyena et al. [4] and Onyena and Okoro [19]. The conductivity and TDS levels are above the NESREA standard. Nonetheless, the values obtained in this study were lower than those obtained by other researchers in similar ecosystems [4, 20]. Table 3 revealed a statistically significant, strong negative correlation between pH and conductivity ($r= -0.751$, $n=9$, $P<0.02$), which explained 56% of conductivity variability. The pH increased as the level of conductivity increased. Conductivity had a high negative correlation with Fe ($r= -0.765$, $n=9$, $P<0.016$). The spatial variations of turbidity, total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), and oil and grease (O/G) were measured. Turbidity and TSS recorded mean values of 54.90±37.56NTU and 50.83±37.45mg/L, respectively, with the highest levels in station B (104.5 NTU;

100.2 mg/L). The water is extremely turbid and exceeds the NESREA 5NTU standard [15]. Salinity was statistically significant, with a strong negative correlation with turbidity (r=-0.72, n=9, P<0.029), TSS (r=-0.716, n=9, P<0.03), and Pb (r=-0.743, n=9, P<0.02), and a strong positive correlation with Mn (r=0.732, n=9, P<0.025). The higher the salinity, the higher the TSS and Turbidity. Turbidity also had a strong negative correlation with cadmium (r= -0.671, n=9, P<0.048). The water is turbid compared to other Niger Delta aquatic ecosystems [4, 20, 21]. As a result, there is a chance that there will be little to no sunlight penetration to help the photosynthetic communities in the study area.

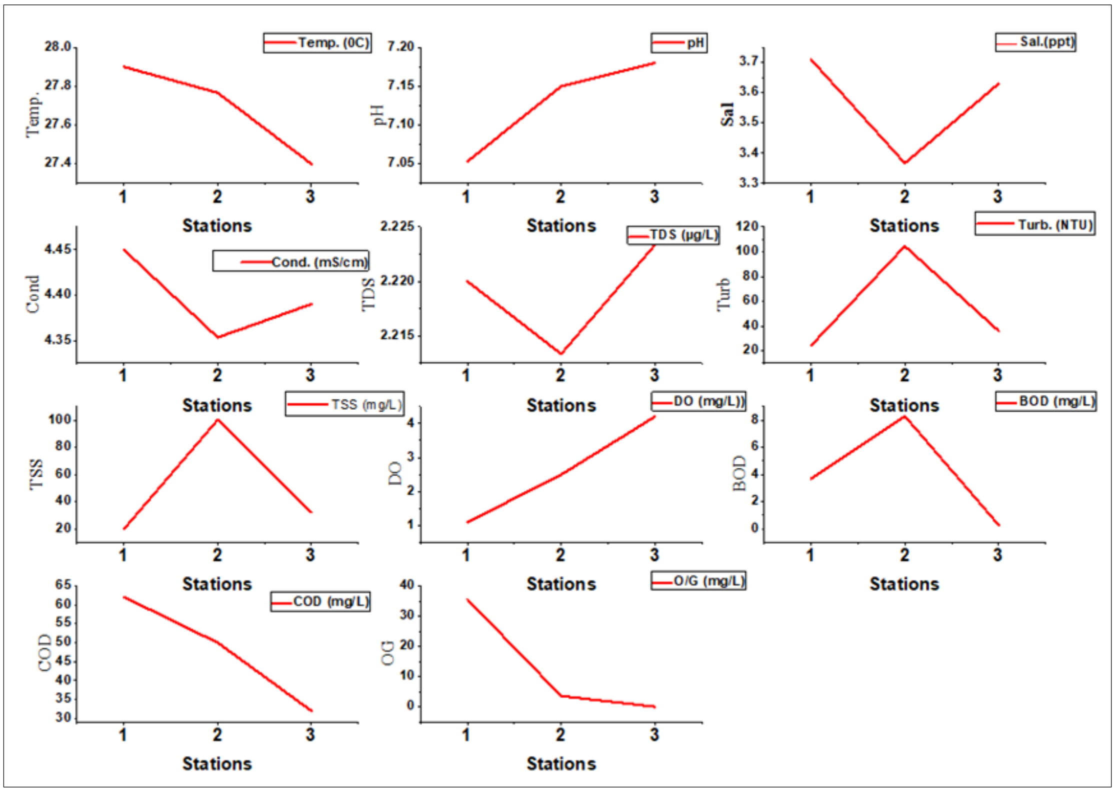

Figure 2 The result of the physicochemical parameters on water

Aquatic organisms' survival, composition, diversity, behaviour, and physiology are all influenced by dissolved oxygen [22]. DO levels as low as 1.1mg/L were measured at Station A. The mean dissolved oxygen value was 2.60±1.35mg/L, which was less than the NESREA standard of 6 mg/L. The low level of dissolved oxygen in the study stations is caused by oil sheen blocks that prevent aeration and decrease the level of oxygen, as well as a high level of organic pollution from waste dumps and sewage [23].

The mean dissolved oxygen was lower than the results from Chanomi Creek (5.37±1.35mg/l), which is close to the current study locations [4]. The mean BOD value was 4.10±3.5mg/L, with Station B having the highest value. A high BOD is connected to a low DO, which puts aquatic creatures under stress. The high BOD was due to a high quantity of organic compounds in the effluent discharged into the water, as well as the presence of a high concentration of aerobic bacteria that operated on the biodegradable wastes [24]. Station A had the highest COD readings (62.08mg/L), with a mean value of 48.02±15.42mg/L. DO have a statistically significant positive correlation with phosphate and cadmium (r=0.709, n=9, P<0.032; r=0.677, n=9, P<0.045, respectively). COD strongly correlated negatively with Oil and Gas (r= -0.758, n=9, P<0.018) and Cu (r= -0.79, n=9, P<0.011) but with strong positive correlation with TPH (r=0.726, n=9, P<0.027). COD-rich water indicates the presence of decomposing plant materials, human waste, and industrial effluents [25]. This is an example of a common study station scenario.

Oil and grease (O/G) were detected at Station A at 35.49 mg/L, while the mean value was 13.05±17.01 mg/L. In contrast to the high concentrations , Station B and C observed minute O/G concentrations of 3.6 and 0.05 mg/L, respectively (Fig 2). In comparison to the current investigation, Udofia et al. [26] found greater levels of oil and gas (15.6-19.0mg/L) in the New Calabar River. Oil and Gas were statistically different with strong positive correlation with PAH (r=0.77, n=9, P<0.014) and Mn (r=0.79, n=9, P<0.011) and strong negative correlation with silicate ((r=-0.693, n=9, P<0.039) and phosphate (r=-0.718, n=9, P<0.029). Oil and grease molecules can coat animals and plants, resulting in death, migration, and eventual low diversity. Furthermore, the high values found in the research regions resulted in oxygen deprivation [27]. The presence of petroleum hydrocarbons in the study stations is indicated by the high oil and grease levels.

3.2 Nutrient Composition

Station C had the highest sulphate content in the study area, followed by the other stations (Fig. 3). The total average sulphate concentration was 272.34±57.33mg/L. This value was significantly higher than the Igbedi Creek results (3.3-12.5mg/L; [28]). The high sulphate content is caused by the decomposition and combustion of organic matter, industrial effluents, and agricultural fertilizer runoff. Increased sulphate levels contribute to ocean acidification and acid rain, both of which can harm ecosystems [29]. Nitrogen and phosphorus are essential components of aquatic ecosystems. They are found in the form of nitrates and phosphates. Their concentrations in the study area were not excessive. Their mean values were 0.014±0.0123mg/L and 0.0067±0.0064mg/L, respectively. While the average Silicate concentration was 1.47±0.48mg/L. The cumulative nutrient composition of all study stations was highest in Station C and lowest in Station A. Station C receives waste discharges from open defecation and agricultural waste as inputs compared to other stations. Nitrate was statistically different with strong positive correlation with silicate (r=0.748, n=9, P<0.021), it was strong negative correlation with Pb (r=-0.703, n=9, P<0.035) and PAH (r=-0.769, n=9, P<0.015). There was a statistical difference strong positive correlation between phosphate and Cu (r=0.693, n=9, P<0.038) but strong negative correlation with TPH (r=-0.674, n=9, P<0.047).

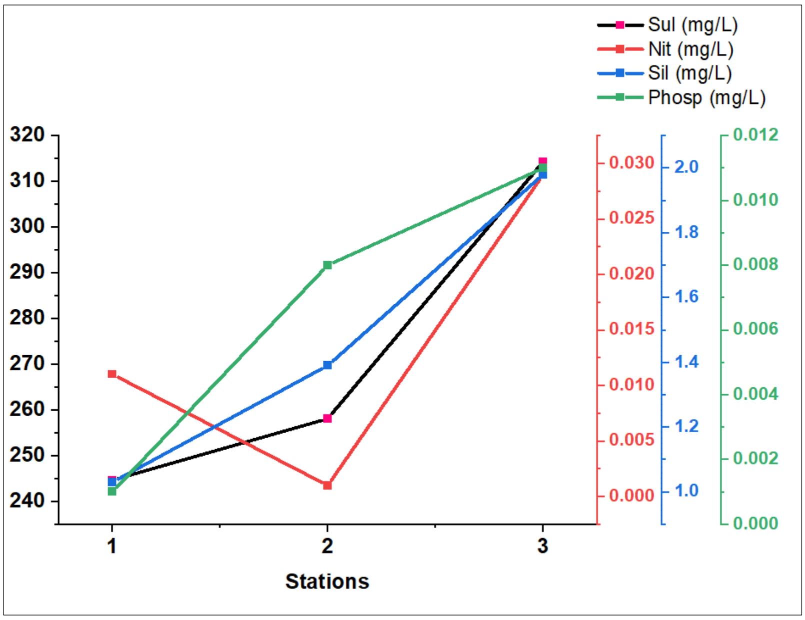

Figure 3 Nutrient composition in the study location

3.3 Heavy metal distribution

Significant heavy metals were detected in the study stations (Fig. 4). Cadmium, copper, and zinc concentrations were highest in Station C, at 0.043mg/L, 0.029mg/L, and 0.029mg/L, respectively. Their corresponding mean concentrations, however, are 0.021±.0.018mg/L, 0.023±0.007mg/L, and 0.026±0.004. The concentrations of nickel and arsenic were fairly evenly distributed across the study stations. The average Ni concentration was 0.044±0.002mg/L. Station B had the highest concentration of lead (0.004mg/L), while Station B had the lowest manganese concentration. On the other hand, Mn was found to be highest in Station A (0.149mg/L). The average Mn concentration in the study area is 0.08±0.04mg/L. The mean metal levels in the water were as follows: Mn>Fe>Ni=Cu>Zn>As>Pb=Cd>Cr. Cd, Mn, Ni, and Cu levels were above the recommended limit [15]. There was also a significant difference in negative correlation with Cu and Mn (r= -0.711, n=9, P<0.032), while a strong positive correlation exists between Mn and TPH (r= 0.793, n=9, P<0.011). The high concentrations of Cu, Ni, Cd, and Mn are derived from anthropogenic sources such as batteries and electrical, pigments and paints, alloys and solders, pesticides, glass, fertilizers, artisanal refineries and oil spills [30]. Antifouling paints, which are used as coatings for ship hulls and underwater surfaces, are a major source of copper in the study stations, as well as a contaminant from decking, pilings, and other marine structures. Cadmium results were statistically different and strong correlated negatively with Pb (r= -0.717, n=9, P<0.03) and PAH (r= -0.79, n=9, P<0.01). Cd enters the environment through mining, household waste, industries, and coal combustion. Heavy metals cause teratogenicity and chromosomal aberrations in fisheries [31, 32] and human health [33]. As a result, there are potential ecological and health risks associated with continuous heavy metal exposure and accumulation.

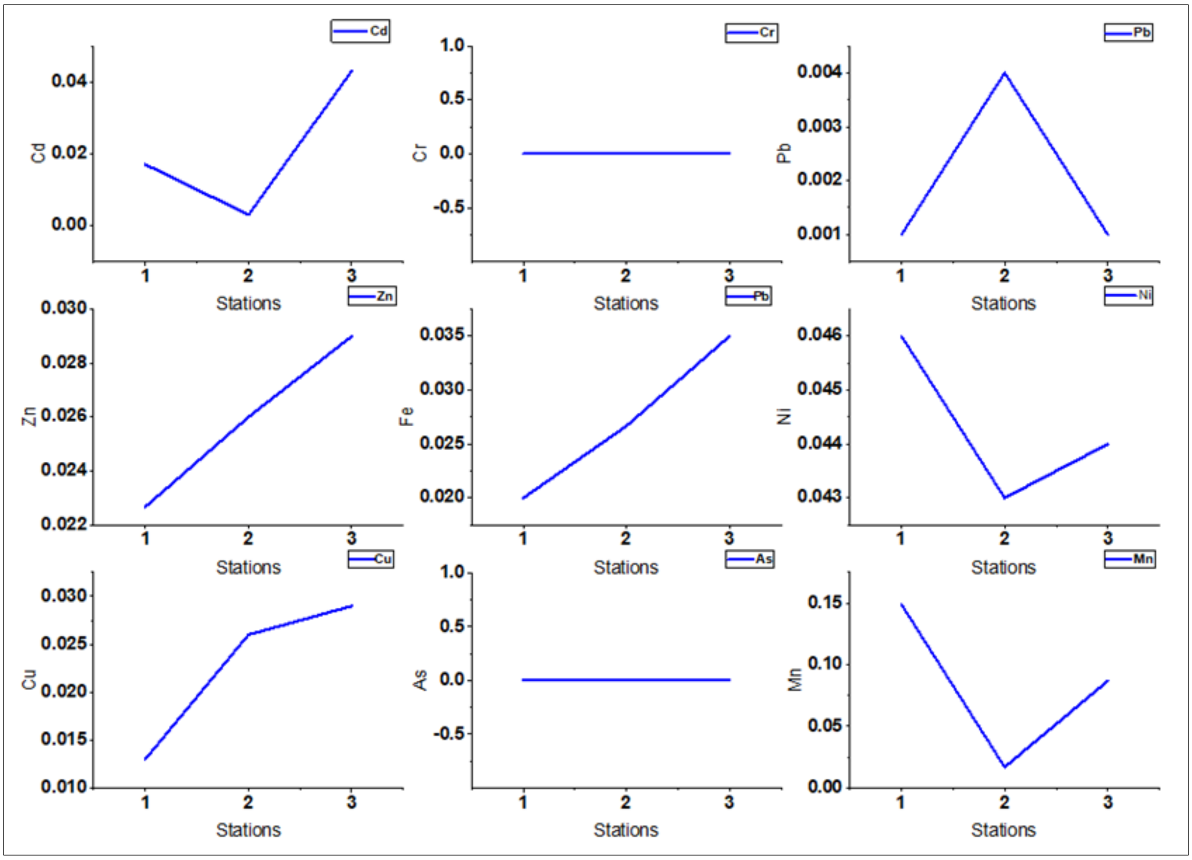

Figure 4 Heavy metal concentrations in the study area

3.4 Hydrocarbon Content

The result of PAH significantly differs with a strong positive correlation with TPH (r= 0.791, n=9, P<0.011). The average PAH concentration was 0.258±0.202mg/L, and the average TPH concentration was 11.159±14.433mg/L. In contrast to heavy metal concentrations, which were highest in Station C, PAH and TPH concentrations were highest in Station A, followed by Station B. (See Figure 5). PAH and TPH levels at Station A were 0.455mg/L and 30.306mg/L, respectively, while levels at Station B were 0.317 mg/L and 3.161mg/L. Minute PAH (0.001mg/L) and TPH (0.01mg/L) concentrations were measured at Station C. The 16 components of hydrocarbon studied including Naphthalene, Acenapthalene, Acenaphthene, Florene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Crysene, Benzo(a)fluoranthene, Benzo(a)pyrene, Benzo(k)fluoranthene, Florene, Phenanthrene, Anthracene, Indeno(1,2,3)perylene, Dibenzo(a,h)anthracene, and Benzo(g,h,i)perylene were not discovered in Station C. There was presence of minute aliphatic hydrocarbon. Station A recorded only 10 PAH compounds, while Station B recorded only 5 PAH compounds. Except for phenanthrene (0.040mg/L) recorded in Station B, the same hydrocarbons were absent in both stations. The aliphatic obtained in this study was high in Stations A and B, resulting in total petroleum hydrocarbon (TPH) values of 30.305 mg/L and 3.161 mg/L, respectively. Meanwhile, station C measured a TPH concentration of 0.010mg/L. The TPH levels obtained from Stations A and B are above the allowable limits and far exceed those obtained from other aquatic ecosystems in the Niger Delta [34, 35].

Because hydrocarbons are resistant to biological change, they can survive in any environment [36]. Continuous PAH chemical exposure and accumulation cause cancer in aquatic animals [37], as well as human health via the food chain. This could pose a threat to the residents of the research region. The high crude oil originating from oil spills, oil seepages, artisanal refining, oil theft, and transportation in the study area has resulted in the presence of these hydrocarbons in the studied locations.

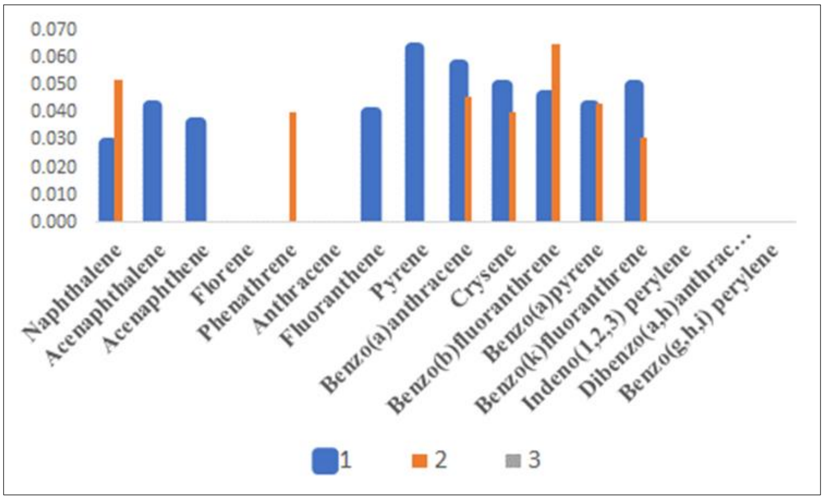

Figure 5 Spatial Distribution of the Polycyclic Aromatic Hydrocarbon

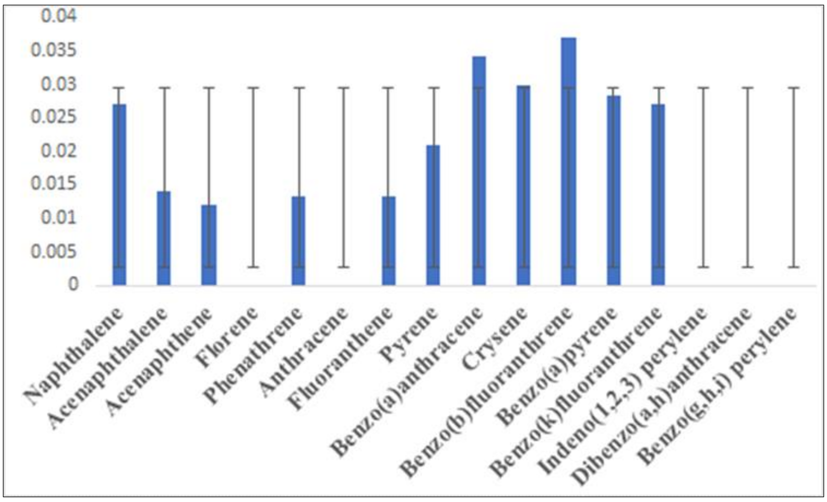

Figure 6 Mean Polycyclic Aromatic Hydrocarbon present in the study area

Table 1 Descriptive Statistics of the physicochemical parameters across the stations

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Temperature (oC)	OKpogbene	3	27.9000	0.45826	0.26458	26.7616	29.0384	27.40	28.30
	Ovuloyebebe	3	27.7667	0.68069	0.39299	26.0757	29.4576	27.00	28.30
	Governorgbene	3	27.4000	0.10000	0.05774	27.1516	27.6484	27.30	27.50
	Total	9	27.6889	0.47022	0.15674	27.3274	28.0503	27.00	28.30
pH	OKpogbene	3	7.0533	0.01528	0.00882	7.0154	7.0913	7.04	7.07
	Ovuloyebebe	3	7.1500	0.20000	0.11547	6.6532	7.6468	6.95	7.35
	Governorgbene	3	7.1800	0.02646	0.01528	7.1143	7.2457	7.15	7.20
	Total	9	7.1278	0.11627	0.03876	7.0384	7.2172	6.95	7.35
Salinity (ppt)	OKpogbene	3	3.7100	0.26058	0.15044	3.0627	4.3573	3.46	3.98

	Ovuloyebebe	3	3.3667	0.11547	0.06667	3.0798	3.6535	3.30	3.50
	Governorgbene	3	3.6300	0.08185	0.04726	3.4267	3.8333	3.54	3.70
	Total	9	3.5689	0.21491	0.07164	3.4037	3.7341	3.30	3.98
Conductivity (mS/cm)	OKpogbene	3	4.4500	0.01000	0.00577	4.4252	4.4748	4.44	4.46
	Ovuloyebebe	3	4.3533	0.09238	0.05333	4.1239	4.5828	4.30	4.46
	Governorgbene	3	4.3900	0.03606	0.02082	4.3004	4.4796	4.35	4.42
	Total	9	4.3978	0.06534	0.02178	4.3476	4.4480	4.30	4.46
Total Dissolved Solids (µg/L)	OKpogbene	3	2.2200	0.03606	0.02082	2.1304	2.3096	2.19	2.26
	Ovuloyebebe	3	2.2133	0.04041	0.02333	2.1129	2.3137	2.19	2.26
	Governorgbene	3	2.2243	0.00513	0.00296	2.2116	2.2371	2.22	2.23
	Total	9	2.2192	0.02762	0.00921	2.1980	2.2405	2.19	2.26
Turbidity (NTU)	OKpogbene	3	24.2000	0.52915	0.30551	22.8855	25.5145	23.80	24.80
	Ovuloyebebe	3	104.5000	0.61147	0.35303	102.9810	106.0190	104.07	105.20
	Governorgbene	3	36.0000	2.00000	1.15470	31.0317	40.9683	34.00	38.00
	Total	9	54.9000	37.56476	12.52159	26.0252	83.7748	23.80	105.20
TSS (mg/L)	OKpogbene	3	20.0000	0.45826	0.26458	18.8616	21.1384	19.50	20.40
	Ovuloyebebe	3	100.2000	1.75214	1.01160	95.8474	104.5526	98.50	102.00
	Governorgbene	3	32.3000	3.10000	1.78979	24.5992	40.0008	29.20	35.40
	Total	9	50.8333	37.44917	12.48306	22.0474	79.6193	19.50	102.00
Dissolved Oxygen (mg/L)	OKpogbene	3	1.1000	.01732	.01000	1.0570	1.1430	1.09	1.12
	Ovuloyebebe	3	2.5000	.20000	.11547	2.0032	2.9968	2.30	2.70
	Governorgbene	3	4.2000	.10000	.05774	3.9516	4.4484	4.10	4.30
	Total	9	2.6000	1.34910	.44970	1.5630	3.6370	1.09	4.30
Biological Oxygen Demand (mg/L)	OKpogbene	3	3.7000	.70000	.40415	1.9611	5.4389	3.00	4.40
	Ovuloyebebe	3	8.3000	.20000	.11547	7.8032	8.7968	8.10	8.50
	Governorgbene	3	.3000	.01000	.00577	.2752	.3248	.29	.31
	Total	9	4.1000	3.49607	1.16536	1.4127	6.7873	.29	8.50
Chemical Oxygen Demand (mg/L)	OKpogbene	3	62.0800	2.34572	1.35430	56.2529	67.9071	60.40	64.76
	Ovuloyebebe	3	49.9933	16.00746	9.24191	10.2286	89.7581	32.82	64.50
	Governorgbene	3	31.9800	.71190	.41102	30.2115	33.7485	31.52	32.80
	Total	9	48.0178	15.41539	5.13846	36.1685	59.8671	31.52	64.76
Oil and Gas (mg/L)	OKpogbene	3	35.4900	2.64766	1.52863	28.9128	42.0672	32.49	37.50
	Ovuloyebebe	3	3.6000	2.70000	1.55885	-3.1072	10.3072	.90	6.30
	Governorgbene	3	.0500	.00100	.00058	.0475	.0525	.05	.05
	Total	9	13.0467	17.00797	5.66932	-.0268	26.1201	.05	37.50
Sulfate (mg/L)	OKpogbene	3	244.6140	21.28990	12.29173	191.7270	297.5010	225.04	267.28
	Ovuloyebebe	3	258.1020	92.69800	53.51922	27.8274	488.3766	165.40	350.80
	Governorgbene	3	314.3020	.88415	.51046	312.1057	316.4983	313.45	315.21

	Total	9	272.3393	57.32659	19.10886	228.2742	316.4045	165.40	350.80
Nitrate (mg/L)	OKpogbene	3	.01100	.007211	.004163	-.00691	.02891	.005	.019
	Ovuloyebebe	3	.00100	.000000	.000000	.00100	.00100	.001	.001
	Governorgbene	3	.02900	.001000	.000577	.02652	.03148	.028	.030
	Total	9	.01367	.012816	.004272	.00382	.02352	.001	.030
Silicate (mg/L)	OKpogbene	3	1.03000	.470000	.271355	-.13754	2.19754	.560	1.500
	Ovuloyebebe	3	1.39000	.052915	.030551	1.25855	1.52145	1.350	1.450
	Governorgbene	3	1.98000	.070000	.040415	1.80611	2.15389	1.900	2.030
	Total	9	1.46667	.479244	.159748	1.09829	1.83505	.560	2.030
Phosphate (mg/L)	OKpogbene	3	.00103	.000058	.000033	.00089	.00118	.001	.001
	Ovuloyebebe	3	.00800	.009273	.005354	-.01504	.03104	.002	.019
	Governorgbene	3	.01100	.001000	.000577	.00852	.01348	.010	.012
	Total	9	.00668	.006431	.002144	.00173	.01162	.001	.019
Cadmium (mg/L)	OKpogbene	3	.01700	.002646	.001528	.01043	.02357	.015	.020
	Ovuloyebebe	3	.00300	.001000	.000577	.00052	.00548	.002	.004
	Governorgbene	3	.04300	.001000	.000577	.04052	.04548	.042	.044
	Total	9	.02100	.017642	.005881	.00744	.03456	.002	.044
Chromium (mg/L)	OKpogbene	3	.001000	0E-7	0E-7	.001000	.001000	.0010	.0010
	Ovuloyebebe	3	.001000	0E-7	0E-7	.001000	.001000	.0010	.0010
	Governorgbene	3	.001000	0E-7	0E-7	.001000	.001000	.0010	.0010
	Total	9	.001000	0E-7	0E-7	.001000	.001000	.0010	.0010
Lead (mg/L)	OKpogbene	3	.001000	0E-7	0E-7	.001000	.001000	.0010	.0010
	Ovuloyebebe	3	.004000	.0010000	.0005774	.001516	.006484	.0030	.0050
	Governorgbene	3	.001000	0E-7	0E-7	.001000	.001000	.0010	.0010
	Total	9	.002000	.0015811	.0005270	.000785	.003215	.0010	.0050
Zinc (mg/L)	OKpogbene	3	.02267	.006351	.003667	.00689	.03844	.019	.030
	Ovuloyebebe	3	.02600	.001000	.000577	.02352	.02848	.025	.027
	Governorgbene	3	.02900	.001732	.001000	.02470	.03330	.027	.030
	Total	9	.02589	.004314	.001438	.02257	.02920	.019	.030
Iron (mg/L)	OKpogbene	3	.02000	.005000	.002887	.00758	.03242	.015	.025
	Ovuloyebebe	3	.02667	.016166	.009333	-.01349	.06682	.008	.036
	Governorgbene	3	.03500	.001000	.000577	.03252	.03748	.034	.036
	Total	9	.02722	.010686	.003562	.01901	.03544	.008	.036
Nickel (mg/L)	OKpogbene	3	.04600	.003464	.002000	.03739	.05461	.042	.048
	Ovuloyebebe	3	.04300	.001000	.000577	.04052	.04548	.042	.044
	Governorgbene	3	.04400	.001000	.000577	.04152	.04648	.043	.045
	Total	9	.04433	.002291	.000764	.04257	.04609	.042	.048

Copper (mg/L)	OKpogbene	3	.01300	.002000	.001155	.00803	.01797	.011	.015
	Ovuloyebebe	3	.02600	.001000	.000577	.02352	.02848	.025	.027
	Governorgbene	3	.02900	.002646	.001528	.02243	.03557	.026	.031
	Total	9	.02267	.007566	.002522	.01685	.02848	.011	.031
Arsenic (mg/L)	OKpogbene	3	.00267	.000577	.000333	.00123	.00410	.002	.003
	Ovuloyebebe	3	.00267	.000416	.000240	.00163	.00370	.002	.003
	Governorgbene	3	.00267	.000404	.000233	.00166	.00367	.002	.003
	Total	9	.00267	.000409	.000136	.00235	.00298	.002	.003
Manganese (mg/L)	OKpogbene	3	.14900	.006557	.003786	.13271	.16529	.142	.155
	Ovuloyebebe	3	.01670	.000265	.000153	.01604	.01736	.017	.017
	Governorgbene	3	.08700	.000600	.000346	.08551	.08849	.086	.088
	Total	9	.08423	.057420	.019140	.04010	.12837	.017	.155
PAH (mg/L)	OKpogbene	3	.45500	.022913	.013229	.39808	.51192	.435	.480
	Ovuloyebebe	3	.31700	.020664	.011930	.26567	.36833	.295	.336
	Governorgbene	3	.00100	.000000	.000000	.00100	.00100	.001	.001
	Total	9	.25767	.202151	.067384	.10228	.41305	.001	.480
TPH (mg/L)	OKpogbene	3	30.30600	.973209	.561883	27.88841	32.72359	29.362	31.306
	Ovuloyebebe	3	3.16100	.009000	.005196	3.13864	3.18336	3.152	3.170
	Governorgbene	3	.01000	.000000	.000000	.01000	.01000	.010	.010
	Total	9	11.15900	14.433130	4.811043	.06471	22.25329	.010	31.306

Table 2 ANOVA results

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.046	5	.009	.438	.803
	Within Groups	.062	3	.021		
	Total	.108	8			
Salinity	Between Groups	.230	5	.046	.992	.538
	Within Groups	.139	3	.046		
	Total	.369	8			
Conductivity	Between Groups	.011	5	.002	.289	.893
	Within Groups	.023	3	.008		
	Total	.034	8			
Total Dissolved Solids	Between Groups	.003	5	.001	.782	.623
	Within Groups	.003	3	.001		
	Total	.006	8			
Turbidity	Between Groups	4694.761	5	938.952	.427	.810
	Within Groups	6594.126	3	2198.042		
	Total	11288.888	8			
TSS	Between Groups	4859.340	5	971.868	.458	.791

	Within Groups	6360.180	3	2120.060		
	Total	11219.520	8			
Dissolved Oxygen	Between Groups	7.778	5	1.556	.688	.667
	Within Groups	6.782	3	2.261		
	Total	14.561	8			
Biological Oxygen Demand	Between Groups	71.076	5	14.215	1.597	.372
	Within Groups	26.704	3	8.901		
	Total	97.780	8			
Chemical Oxygen Demand	Between Groups	1419.585	5	283.917	1.769	.339
	Within Groups	481.489	3	160.496		
	Total	1901.074	8			
Oil and Gas	Between Groups	746.523	5	149.305	.286	.894
	Within Groups	1567.645	3	522.548		
	Total	2314.168	8			
Sulfate	Between Groups	15696.006	5	3139.201	.889	.578
	Within Groups	10594.698	3	3531.566		
	Total	26290.705	8			
Nitrate	Between Groups	.001	5	.000	1.531	.385
	Within Groups	.000	3	.000		
	Total	.001	8			
Silicate	Between Groups	1.018	5	.204	.745	.640
	Within Groups	.820	3	.273		
	Total	1.837	8			
Phosphate	Between Groups	.000	5	.000	2.544	.236
	Within Groups	.000	3	.000		
	Total	.000	8			
Cadmium	Between Groups	.002	5	.000	1.845	.326
	Within Groups	.001	3	.000		
	Total	.002	8			
Chromium	Between Groups	0.000	5	0.000		
	Within Groups	0.000	3	0.000		
	Total	0.000	8			
Lead	Between Groups	.000	5	.000	1.246	.456
	Within Groups	.000	3	.000		
	Total	.000	8			
Zinc	Between Groups	.000	5	.000	.940	.557
	Within Groups	.000	3	.000		
	Total	.000	8			
Iron	Between Groups	.001	5	.000	.793	.618
	Within Groups	.000	3	.000		
	Total	.001	8			
Nickel	Between Groups	.000	5	.000	.496	.770
	Within Groups	.000	3	.000		
	Total	.000	8			
Copper	Between Groups	.000	5	.000	.513	.760

	Within Groups	.000	3	.000		
	Total	.000	8			
Arsenic	Between Groups	.000	5	.000	.740	.642
	Within Groups	.000	3	.000		
	Total	.000	8			
Manganese	Between Groups	.007	5	.001	.215	.935
	Within Groups	.019	3	.006		
	Total	.026	8			
Polyaromatic hydrocarbon	Between Groups	.204	5	.041	.990	.539
	Within Groups	.123	3	.041		
	Total	.327	8			
Total Petroleum Hydrocarbon	Between Groups	466.405	5	93.281	.233	.925
	Within Groups	1200.117	3	400.039		
	Total	1666.522	8			

3.5 Results of the Pollution Indices

3.5.1 Water Quality Index (WQI)

The overall water quality of the research areas was measured (Table 4). The results showed that the WQI of Stations A and B had poor water quality (WQI = 64 and 60, respectively), whereas Station C had unsuitable water quality for consumption (WQI = 2665). WQI values are similar in other Niger Delta ecosystems, though Station C showed higher levels when compared to their studies [38, 39].

3.5.2 Heavy metal evaluation index (HEI)

The study's overall heavy metal concentration revealed HEI values of 128. HEI can be used to determine the level of contamination (Cd). A very high degree of contamination is defined as a degree of contamination greater than 24. According to the findings of this study, the waters in the study area contain high concentrations of potentially toxic metals. Heavy metals accumulated in the study areas increased the contamination level.

3.6 Geo-accumulation index (Igeo)

The concentration of heavy metals in Station A revealed that Cd was moderately contaminated (Class 2), whereas Cu and Mn were severely contaminated (Class 3). (Table 5). On the other hand, Station B had moderately contaminated Ni and heavily contaminated Cu (Class 3). Station C, recorded Cd and Mn to be moderate to heavily contaminated (Class 4), while Cu was heavy to extremely contaminated (Class 5). Heavy metal constituents are an important ecological factor used for water suitability, species requirements, and ecosystem protection [40]. The assessment of the geo-accumulation index of the surface water in the study area reveals the level of each heavy metal examined. The status of each heavy metal in the water raises many concerns, as the regions are critically impacted by heavy metal contamination.

3.7 Nemerow Pollution Index (NPI)

According to the NPI study, nutrients such as nitrate, silicate, phosphate, chromium, zinc, and arsenic caused less water pollution in the current study (Table 6). However, conductivity, TDS, turbidity, TSS, COD, oil and grease, and sulphate, were the significant parameters that contributed to water pollution across all study areas. Except for Station C, BOD was also recorded as a contributing parameter. Furthermore, the presence of Sulphate, Nickel, Cu, Mn, PAH, and TPH in excess concentrations in all sample stations exacerbated the increased contamination levels in the water. Although the concentration of Fe was not necessarily a contributing pollutant in Stations A and B, as in Station B, Stations A and C also indicated that Cadmium was a significant pollutant.

Table 3 Pearson Correlation (r) matrix of the physicochemical parameters

		Temp	pH	Sal.	Cond.	TDS	Turb.	TSS	DO	BOD	COD	O&G	Sul.	Nit.	Sil.	Phos	Cd	Pb	Zn	Fe	Ni	Cu	As	Mn	PAH	TPH
Temp.	r	1																								
pH	r	0.4	1																							
	Sig	0.287																								
Salinity	r	0.227	-0.034	1																						
	Sig	0.556	0.931																							
Conductivity	r	-0.371	-.751*	0.236	1																					
	Sig.	0.325	0.02	0.542																						
TDS	r	-0.599	-0.489	-0.388	0.633	1																				
	Sig.	0.088	0.182	0.302	0.067																					
Turbidity	r	0.057	0.205	-.720*	-0.568	-0.154	1																			
	Sig.	0.884	0.598	0.029	0.111	0.693																				
TSS	r	0.039	0.194	-.716*	-0.557	-0.134	.999**	1																		
	Sig.	0.92	0.618	0.03	0.119	0.731	0																			
DO	r	-0.505	0.433	-0.128	-0.312	0.125	0.079	0.087	1																	
	Sig.	0.165	0.244	0.742	0.414	0.749	0.839	0.824																		
BOD	r	0.302	-0.101	-0.514	-0.282	-0.218	.835**	.831**	-0.468	1																
	Sig.	0.43	0.797	0.157	0.461	0.573	0.005	0.006	0.204																	

COD	r	.774*	0.063	0.132	-0.044	-0.374	-0.019	-0.034	-.870**	0.421	1																	
	Sig.	0.014	0.871	0.735	0.91	0.321	0.961	0.931	0.002	0.259																		
Oil and Gas	r	0.419	-0.422	0.501	0.517	-0.096	-0.535	-0.541	-.877**	0.01	.758*	1																
	Sig.	0.262	0.258	0.169	0.154	0.807	0.138	0.132	0.002	0.98	0.018																	
Sulfate	r	0.276	.930**	0.124	-0.594	-0.327	-0.113	-0.119	0.504	-0.431	-0.034	-0.347	1															
	Sig.	0.473	0	0.751	0.092	0.391	0.773	0.76	0.166	0.247	0.931	0.36																
Nitrate	r	-0.293	0.167	0.591	0.123	-0.004	-0.652	-0.649	0.647	-.897**	-0.603	-0.222	0.41	1														
	Sig.	0.444	0.667	0.094	0.753	0.993	0.057	0.059	0.06	0.001	0.086	0.567	0.273															
Silicate	r	-0.365	0.319	0.224	-0.261	-0.193	-0.003	0	.866**	-0.419	-.800**	-.693*	0.342	.748*	1													
	Sig.	0.335	0.403	0.562	0.498	0.619	0.993	1	0.003	0.262	0.01	0.039	0.367	0.021														
Phosphate	r	-.788*	-0.178	-0.319	0.184	0.551	0.239	0.26	.709*	-0.126	-.894**	-.718*	-0.169	0.297	0.603	1												
	Sig.	0.012	0.647	0.402	0.635	0.124	0.535	0.499	0.032	0.747	0.001	0.029	0.663	0.438	0.086													
Cd	r	-0.378	0.161	0.472	0.142	0.154	-.671*	-0.665	.677*	-.952**	-0.631	-0.256	0.446	.974**	.667*	0.326	1											
	Sig.	0.316	0.679	0.199	0.715	0.693	0.048	0.051	0.045	0	0.069	0.506	0.229	0	0.05	0.392												
Pb	r	-0.101	-0.136	-.743*	-0.29	0.049	.939**	.942**	-0.041	.864**	-0.071	-0.42	-0.432	-.703*	-0.097	0.339	-.717*	1										
	Sig.	0.796	0.727	0.022	0.448	0.901	0	0	0.917	0.003	0.855	0.26	0.245	0.035	0.803	0.372	0.03											
Zn	r	-0.303	0.234	-0.477	-0.183	0.557	0.102	0.119	0.627	-0.311	-0.544	-0.647	0.363	0.223	0.231	0.485	0.381	0.055	1									

	Sig.	0.429	0.545	0.194	0.638	0.119	0.794	0.76	0.071	0.416	0.13	0.06	0.336	0.564	0.549	0.186	0.312	0.888								
Fe	r	0.292	.833**	0.17	-.765*	-0.655	0.047	0.03	0.559	-0.286	-0.169	-0.463	.814**	0.464	0.603	-0.14	0.412	-0.244	0.161	1						
	Sig.	0.446	0.005	0.662	0.016	0.055	0.905	0.938	0.117	0.455	0.663	0.21	0.008	0.208	0.085	0.719	0.271	0.527	0.68							
Ni	r	-0.089	-0.452	0.658	0.515	-0.278	-0.483	-0.492	-0.333	-0.162	0.113	0.563	-0.423	0.251	0.073	-0.169	0.111	-0.345	-.818**	-0.197	1					
	Sig.	0.82	0.222	0.054	0.156	0.469	0.188	0.178	0.381	0.676	0.773	0.114	0.257	0.515	0.852	0.664	0.776	0.363	0.007	0.611						
Cu	r	-0.409	0.398	-0.283	-0.543	-0.047	0.453	0.464	.889**	-0.073	-.790*	-.959**	0.342	0.347	.808**	.693*	0.346	0.334	0.546	0.53	-0.425	1				
	Sig.	0.275	0.288	0.46	0.131	0.905	0.221	0.208	0.001	0.853	0.011	0	0.367	0.361	0.008	0.038	0.362	0.379	0.128	0.142	0.254					
As	r	0.316	0.308	0.378	-0.316	-.823**	-0.007	-0.02	-0.027	0.051	0.159	0.083	0.179	0.162	0.305	-0.343	0.002	-0.116	-0.547	0.539	0.493	0.052	1			
	Sig.	0.407	0.42	0.316	0.407	0.006	0.987	0.959	0.945	0.896	0.682	0.832	0.644	0.677	0.424	0.366	0.996	0.767	0.127	0.134	0.177	0.893				
Mn	r	0.111	-0.352	.732*	0.63	0.071	-.937**	-.939**	-0.416	-0.592	0.306	.794*	-0.093	0.384	-0.268	-0.451	0.38	-.837**	-0.352	-0.236	0.601	-.711*	0.037	1		
	Sig.	0.776	0.353	0.025	0.069	0.855	0	0	0.265	0.093	0.423	0.011	0.812	0.307	0.486	0.224	0.314	0.005	0.353	0.541	0.087	0.032	0.925			
PAH	r	0.437	-0.467	-0.044	0.307	-0.035	0.086	0.08	-.978**	0.604	.822**	.777*	-0.583	-.769*	-.886**	-0.59	-.790*	0.225	-0.569	-0.643	0.242	-.822**	-0.054	0.257	1	
	Sig.	0.239	0.205	0.91	0.421	0.93	0.827	0.838	0	0.085	0.007	0.014	0.099	0.015	0.001	0.094	0.011	0.561	0.11	0.062	0.53	0.007	0.89	0.504		
TPH	r	0.355	-0.49	0.448	0.572	-0.01	-0.535	-0.54	-.881**	0.01	.726*	.995**	-0.405	-0.243	-.723*	-.674*	-0.263	-0.394	-0.607	-0.533	0.546	-.968**	0.02	.793*	.791*	1
	Sig.	0.348	0.181	0.227	0.107	0.981	0.138	0.133	0.002	0.98	0.027	0	0.28	0.53	0.028	0.047	0.495	0.294	0.083	0.14	0.128	0	0.96	0.011	0.011	

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed); Chromium was not computed because at least one of the variables is constant.

3.8 Potential Ecological Risk Index (PERI)

The PERI result indicated an ecological risk for biological communities (Table 7). The PERI values of 195.76 and 177.02 for Stations A and B, respectively, indicated that the water's ecological risk for aquatic purposes was moderate. Station C, on the other hand, recorded a PERI of 431.08, indicating a severe ecological risk to aquatic life. The study station's trend is SC > SA > SB. Although Stations A and B had high levels of oil and grease and petroleum hydrocarbons, Station C had higher ecological risks due to other contributing contaminants that were higher in the study station. Aside from oil sheens on the water's surface in Station C, the area is prone to organic pollution and siltation. This high ecological risk level suggests that monitoring strategies in the study area urgently need to be improved. This risk could lead to agricultural, environmental, human health and social consequences.

4 Conclusion

There is currently a lack of information on the state of pollution in the waters of the selected communities, and potential ecological hazards. The pollution and ecological risk indices indicated that the communities' waters were moderate to highly contaminated following the discussion above. This was the case because the stations contained significant amounts of contaminants and pollutants from various point and non-point sources. The human population in the research area is increasing, and the overall reliance of the people and neighbouring communities on this water raises concerns because it poses health risks. As a result, immediate action is required to prevent indiscriminate oil spills, sewage discharge, and industrial effluent from entering the water. This can be accomplished by developing a Western Niger Delta water quality management strategy. Other recommendations include improved solid and liquid waste disposal facilities. There is also a need for strong advocacy for coastal communities and the supply different sources of income to discourage illegal refining, which frequently dispenses chunks of oil on the water's surface.

Table 4 The results of Water Quality index (WQI)

Study Station	WQI Value	Rate
A	64.3404	Poor
B	57.9375	Poor
C	2664.77	Unsuitable

WQI values	Rating of water quality	Grade
0 – 25	Excellent	A
26 – 50	Good	B
51 – 75	Poor	C
76 – 100	Very poor	D
Above 100	Unsuitable water quality	E

Table 5 The results of the Geo-accumulation Index (Igeo)

HM	Igeo Value S1	Igeo Class	Rate
Cd	1.181	2	Moderately contaminated
Cr	-0.585	0	Uncontaminated
Pb	-3.907	0	Uncontaminated
Zn	-2.528	0	Uncontaminated
Fe	-1.907	0	Uncontaminated
Ni	1.617	2	Moderately contaminated
Cu	3.115	4	Heavily contaminated
As	-2.322	0	Uncontaminated
Mn	3.312	4	Heavily contaminated

HM	Igeo Value S2	Igeo Class	Rate
Cd	-1.322	0	Uncontaminated
Cr+6	-0.585	0	Uncontaminated
Pb	-1.907	0	Uncontaminated
Zn	-1.528	0	Uncontaminated
Fe	0.057	0	Uncontaminated
Ni	1.519	2	Moderately contaminated
Cu	4.115	4	Heavily contaminated
As	-2.322	0	Uncontaminated
Mn	0.155	0	Uncontaminated
HM	Igeo Value S3	Igeo Class	Rate
Cd	2.519	3	Moderately to heavily contaminated
Cr+6	-0.585	0	Uncontaminated
Pb	-3.907	0	Uncontaminated
Zn	-1.371	0	Uncontaminated
Fe	-1.100	0	Uncontaminated
Ni	1.553	2	Moderately contaminated
Cu	4.273	5	Heavily to extremely contaminated
As	-2.322	0	Uncontaminated
Mn	2.536	3	Moderately to heavily contaminated

Index Class	Igeo Value	Level of contamination classification
0	Igeo<0	Uncontaminated
1	0<Igeo<1	Uncontaminated to moderately contaminated
2	1<Igeo<2	Moderately contaminated
3	2<Igeo<3	M0derately to heavily contaminated
4	3<Igeo<4	Heavily contaminated
5	4<Igeo<5	Heavily to extremely contaminated
6	Igeo>5	Extremely contaminated

Table 6 Nemerow Pollution Index (NPI) values

Parameters	**W/TEMP**	**pH**	**COND.**	**TDS**	**TURB**	**TSS**	**DO**	**BOD**	**COD**	**O/G**	**SUL**	**NIT**	**SIL**
Station A	0.7	0.83	4.45	4.44	4.84	80	0.18	1.23	2.07	3549	2.45	0	0
Station B	0.7	0.84	3.9	3.9	20.9	400.8	0.42	2.8	1.76	360	2.58	0	0
Station C	0.69	0.84	4.39	4.38	7.2	129.2	0.7	0.1	1.07	5	3.14	0	0
Parameters	PHOS	Cd	Cr	Pb	Zn	Fe	Ni	Cu	As	Mn	PAH	TPH	
Station A	0	3.4	1	0.1	0.26	0.4	4.6	13	0.3	14.9	1516.67	151530	
Station B	0	0.6	1	0.4	0.52	1.56	4.3	26	0.3	1.67	1056.67	15805	
Station C	0.01	8.6	1	0.1	0.58	0.7	4.4	29	0.3	8.7	3.33	50	

Results NPI values≤= 1: Low minute quantity to significantly cause water degradation; NP1 values > 1: indicates presence of parameters significantly cause water degradation

Table 7 The result of the Potential Ecological Risk Index (PERI) Values

Study Stations	Class	PER1 value	Ecological Risk
A	1	195.76	Moderate Ecological risk
B	1	177.02	Moderate Ecological risk
C	3	431.08	Severe Ecological Risk
CLASSIFICATION			
Class	PERI		Ecological Risk
0	<110		Low risk
1	<110≤RI<200		Moderate risk
2	200≤RI<400		Considerable Ecological Risk
3	>400		Severe Ecological Risk

Compliance with ethical standards

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Disclosure of conflict of interest

The author affirms no competing interest.

Statement of ethical approval

The present research work does not contain any studies performed on animals/humans' subjects by any of the authors.

Statement of informed consent

This study does not contain any information about any individual.

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