Organic Contamination in Water and Sediment of Opokuma Community, Kolokuma/Opokuma Local Government Area, Bayelsa State, Niger Delta, Nigeria

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Abstract

This study assessed the levels of organic contamination and selected physicochemical parameters in water and sediment samples from the Opokuma community in Kolokuma/Opokuma Local Government Area, Bayelsa State, Niger Delta, Nigeria. Ten sampling stations were established along a creek at approximately 100 m intervals, and both water and sediment samples were collected and analyzed using standard laboratory procedures. The parameters determined included pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total petroleum hydrocarbons (TPH), total hydrocarbon content (THC), and iron (Fe). The mean pH values were 5.12 ± 0.09 for water and 6.41 ± 0.52 for sediment, indicating slightly acidic conditions. Dissolved oxygen concentrations were 3.05 ± 0.32 mg/L in water and 2.73 ± 0.31 mg/L in sediment, which are below the recommended limit of 5 mg/L. Biochemical oxygen demand values were 59.48 ± 6.26 mg/L in water and 83.60 ± 9.60 mg/L in sediment, while chemical oxygen demand values were 104.55 ± 20.79 mg/L in water and 199.13 ± 41.29 mg/L in sediment, indicating significant organic pollution. The concentrations of total hydrocarbon content were 1.61 ± 0.46 mg/L in water and 2.68 ± 0.68 mg/L in sediment, whereas total petroleum hydrocarbon concentrations were 0.62 ± 0.76 mg/L in water and 0.91 ± 0.81 mg/L in sediment. Iron concentrations were 1.63 ± 0.42 mg/L in water and 0.96 ± 0.55 mg/L in sediment, exceeding recommended limits. Total organic carbon values were 3.26 ± 0.61 mg/L in water and 2.97 ± 0.35 mg/L in sediment. Statistical analysis showed significant differences ($p < 0.05$) between water and sediment samples for pH, DO, BOD, THC, and Fe. The results indicate organic and hydrocarbon contamination in the study area, emphasizing the need for continuous monitoring and environmental management.

Keywords: *Organic contamination; physicochemical parameters; petroleum hydrocarbons; water quality; sediment quality; Niger Delta*

INTRODUCTION

Aquatic ecosystems worldwide are increasingly threatened by contamination resulting from both natural processes and anthropogenic activities. In many developing regions, particularly those characterized by extensive oil exploration and industrial activities, contamination of water bodies and sediments has become a major environmental concern. Sediments and surface waters often serve as sinks for pollutants such as organic matter, petroleum hydrocarbons, and heavy metals, which may accumulate over time and disrupt aquatic ecosystem functioning (Alloway, 2013; Varol, 2011).

Sediments originate from the weathering and erosion of parent rocks and soils that are transported by rivers and streams and eventually deposited in aquatic environments. During transportation, sediments may adsorb organic substances and contaminants originating from agricultural runoff, industrial effluents, sewage discharge, and petroleum exploration activities (Förstner and Wittmann, 1983). These contaminants can persist in sediments for extended periods and may later be remobilized into the water column, thereby influencing water quality and posing ecological risks (Chapman, 2007).

Organic contamination indicators such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total petroleum hydrocarbons (TPH), and total hydrocarbon content (THC) are widely used to evaluate pollution levels in aquatic environments. Elevated concentrations of these parameters generally indicate high organic loading and increased microbial activity, which can lead to oxygen depletion and negatively affect aquatic organisms (APHA, 2017; Wetzel, 2001).

In petroleum-producing regions such as the Niger Delta, contamination of water bodies and sediments is frequently associated with oil exploration, pipeline leaks, illegal refining activities, and improper waste disposal. These activities release petroleum hydrocarbons and other organic contaminants into surrounding ecosystems, where they may accumulate in sediments and pose long-term environmental threats (Nriagu *et al.*, 2016; Izah and Srivastav, 2019; Osuji and Adesiyan, 2005).

Hydrocarbon pollution in aquatic systems can significantly disrupt ecological balance by affecting benthic organisms, fish populations, and microbial communities. Prolonged exposure to petroleum-derived contaminants may result in reduced biodiversity, toxicity to aquatic organisms, and bioaccumulation in the food chain, thereby posing potential health risks to humans who depend on these aquatic resources (Adeniji *et al.*, 2017; UNEP, 2011).

The Niger Delta region of Nigeria is particularly vulnerable to environmental degradation due to its intense oil exploration and production activities. Frequent oil spills and artisanal refining operations have contributed to increased hydrocarbon contamination in surface waters, sediments, and surrounding soils. Consequently, monitoring the physicochemical characteristics and organic contamination levels of water and sediment is essential for environmental management and pollution control in the region (Iwegbue *et al.*, 2013).

Despite numerous environmental assessments conducted across the Niger Delta, limited information exists regarding the comparative levels of organic contaminants in both water and sediment within the Opokuma community of Kolokuma/Opokuma Local Government Area. Therefore, this study aimed to evaluate selected physicochemical parameters and organic contamination indicators in water and sediment samples from the Opokuma aquatic environment in order to determine the level of pollution and potential ecological risks associated with these contaminants.

MATERIALS AND METHODS

Study Area

The study was conducted in the Opokuma community, located in Kolokuma/Opokuma Local Government Area of Bayelsa State in the Niger Delta region of Nigeria. The study area lies approximately between latitude 4.95°N and longitude 6.23°E and is characterized by low-lying swampy terrain dominated by mangrove vegetation and numerous creeks that form tributaries of the Nun River. The region experiences a humid tropical climate with average temperatures ranging from 26–30°C and annual rainfall between 2500 and 4000 mm, with two distinct seasons: the

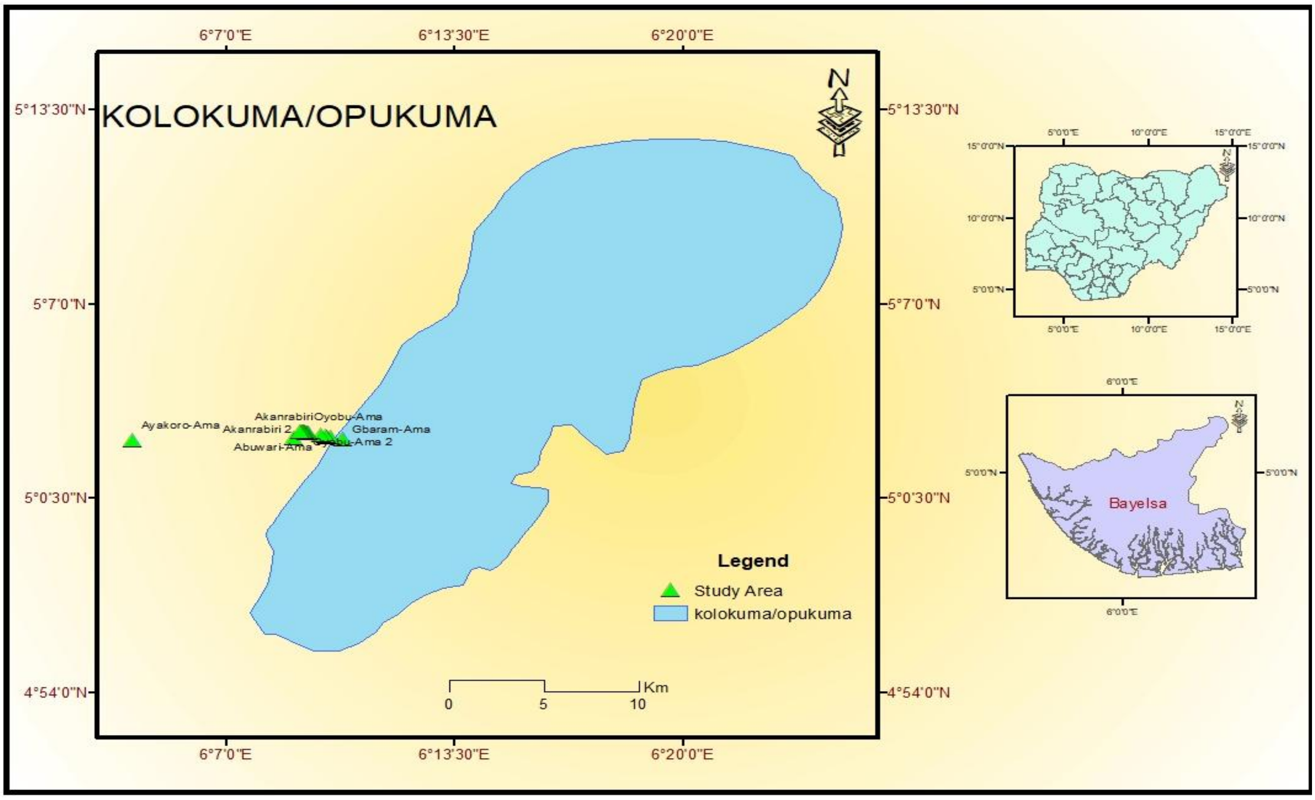

Fig. 1: Map showing the sampling locations in Opokuma community, Bayelsa State, Nigeria.

rainy season (March–October) and the dry season (November–February). The hydrological and ecological characteristics of the Niger Delta make the region particularly vulnerable to contamination from petroleum exploration and other anthropogenic activities (Nwankwoala and Angaya, 2017; UNEP, 2011).

Sample Collection

A total of ten sampling stations were established along the creek at approximately 100 m intervals to ensure adequate spatial coverage of the study area (Fig. 1). At each sampling station, both water and sediment samples were collected for physicochemical analysis. Water samples were collected at a depth of approximately 1 m below the surface using clean plastic sampling bottles, while sediment samples were collected at the same depth using sediment sampling tools and placed in labelled sampling bags. Prior to sample collection, the containers were rinsed with creek water to avoid contamination and sampling errors. The samples were properly labelled and transported to the laboratory for analysis following standard environmental sampling procedures (APHA, 2017; ASTM, 2014).

Laboratory Analysis

Laboratory analyses were carried out at the Central Research Equipment Laboratory (CREL), Niger Delta University, Wilberforce Island, Bayelsa State. The physicochemical parameters determined in this study included pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total petroleum hydrocarbon (TPH), total hydrocarbon content (THC), and iron (Fe). Standard analytical procedures recommended for water and sediment quality assessment were adopted to ensure accuracy and reliability of the results (APHA, 2017; Hach, 2015).

Determination of pH

The pH of sediment samples was determined using the electrometric method. Approximately 20 g of air-dried sediment was weighed into a beaker and mixed with 40 mL of distilled water to form a suspension. The mixture was stirred thoroughly and allowed to stand for 30 minutes before measurement. The pH meter was calibrated using standard buffer solutions of pH 4.0 and pH 9.0, after which the electrode was inserted into the suspension to obtain a stable reading. The procedure followed standard methods for soil and water pH determination (APHA, 2017; Radojevic and Bashkin, 2006).

Determination of Chemical Oxygen Demand (COD)

Chemical oxygen demand was determined using the dichromate reflux titration method, which measures the amount of oxygen required to chemically oxidize organic matter in the sample. In this procedure, potassium dichromate was used as the oxidizing agent in the presence of concentrated sulfuric acid and silver sulfate catalyst. After refluxing the sample mixture, the excess dichromate was titrated with ferrous ammonium sulfate using ferroin indicator. The COD value was calculated based on the difference between blank and sample titration values (APHA, 2017; Sawyer *et al.*, 2003).

Determination of Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD_5) was determined using the five-day incubation method. Approximately 2 g of the sediment sample was dissolved in dilution water and transferred into 125 mL BOD bottles. The initial dissolved oxygen (DO_0) was measured, after which the bottles were incubated in the dark at 20°C for five days. After incubation, the final dissolved oxygen (DO_5) was measured. The BOD was calculated as the difference between the initial and final dissolved oxygen concentrations (APHA, 2017; Metcalf and Eddy, 2014).

Determination of Total Organic Carbon (TOC)

Total organic carbon in sediment samples was determined using the dichromate oxidation method. In this method, potassium dichromate and concentrated sulfuric acid were added to the sediment sample to oxidize organic carbon. After the reaction, the remaining dichromate was titrated with ferrous sulfate solution using ferroin indicator. The amount of organic carbon present in the sample was calculated from the titre values obtained (Nelson and Sommers, 1996; Schumacher, 2002).

Determination of Total Petroleum Hydrocarbon (TPH)

Total petroleum hydrocarbons were determined using a solvent extraction method. Water samples were extracted with dichloromethane in a separating funnel and shaken vigorously to allow hydrocarbon extraction into the organic phase. The organic layer was separated, dried with anhydrous sodium sulfate, and concentrated before gravimetric determination of petroleum hydrocarbons. This method is widely used for determining hydrocarbon contamination in environmental samples (USEPA, 2007; Wang and Fingas, 2003).

Determination of Total Hydrocarbon Content (THC)

Total hydrocarbon content was determined using n-hexane extraction followed by gravimetric analysis. The water sample was acidified with sulfuric acid and extracted with n-hexane using a separating funnel. The organic extract was refluxed and concentrated before evaporation of the solvent. The residue obtained after drying was weighed, and the THC concentration was calculated from the difference between the final and initial flask weights (ASTM, 2014; Wang and Fingas, 2003).

Data Analysis

The data obtained from the physicochemical analysis of water and sediment samples were analyzed using descriptive statistics and multivariate statistical techniques. Descriptive statistics, including mean and standard deviation (Mean ± SD), were used to summarize the measured parameters. An independent sample t-test was applied to determine significant differences between water and sediment samples at $p < 0.05$. Pearson correlation analysis was used to evaluate relationships among the physicochemical parameters. In addition, Principal Component Analysis (PCA) and cluster

Table 1: Mean ± standard deviation of physicochemical parameters in water and sediment samples.

Parameter	Water (Mean ± SD)	Sediment (Mean ± SD)	WHO Limit
pH	5.12 ± 0.09[a]	6.41 ± 0.52[b]	6.5–8.5
DO (mg/L)	3.05 ± 0.32[a]	2.73 ± 0.31[b]	≥5
BOD (mg/L)	59.48 ± 6.26[a]	83.60 ± 9.60[b]	5
THC (mg/L)	1.61 ± 0.46[a]	2.68 ± 0.68[b]	0.01–0.3
TPH (mg/L)	0.62 ± 0.76[a]	0.91 ± 0.81[b]	0.3
Fe (mg/L)	1.63 ± 0.42[a]	0.96 ± 0.55[b]	0.01–0.3
TOC (mg/L)	3.26 ± 0.61[a]	2.97 ± 0.35[b]	7
COD (mg/L)	104.55 ± 20.79[a]	199.13 ± 41.29[b]	150

Note: Values with different superscripts indicate significant difference ($p < 0.05$).

analysis were employed to identify possible pollution sources and group sampling stations based on similarities in contamination levels. The Water Quality Index (WQI) was also calculated to assess the overall quality of the water samples. All analyses were conducted at a 95% confidence level ($p < 0.05$).

RESULTS

Table 1 shows the mean ± standard deviation of the physicochemical parameters in water and sediment samples. The mean pH values were 5.12 ± 0.09 for water and 6.41 ± 0.52 for sediment, indicating slightly acidic conditions in the water. Dissolved oxygen (DO) values were 3.05 ± 0.32 mg/L in water and 2.73 ± 0.31 mg/L in sediment, which are below the recommended limit of 5 mg/L, suggesting oxygen depletion. Biochemical oxygen demand (BOD) values were 59.48 ± 6.26 mg/L in water and 83.60 ± 9.60 mg/L in sediment, exceeding the WHO limit of 5 mg/L. Total hydrocarbon content (THC) values were 1.61 ± 0.46 mg/L in water and 2.68 ± 0.68 mg/L in sediment, which are above the permissible limit of 0.01–0.30 mg/L. Total petroleum hydrocarbon (TPH) concentrations were 0.62 ± 0.76 mg/L in water and 0.91 ± 0.81 mg/L in sediment, exceeding the recommended limit of 0.3 mg/L. Iron concentrations were 1.63 ± 0.42 mg/L in water and 0.96 ± 0.55 mg/L in sediment, both above the permissible limit of 0.3 mg/L for drinking water. Total organic carbon (TOC) values were 3.26 ± 0.61 mg/L in water and 2.97 ± 0.35 mg/L in sediment. Chemical oxygen demand (COD) values were 104.55 ± 20.79 mg/L in water and 199.13 ± 41.29 mg/L in sediment, with sediment values exceeding the WHO limit of 150 mg/L. The superscripts in the table indicate significant differences ($p < 0.05$) between water and sediment samples.

Table 2 presents the results of the independent sample t-test comparing water and sediment samples. Significant differences ($p < 0.05$) were observed for pH ($t = -7.678$, $p < 0.001$), DO ($t = 2.254$, $p = 0.037$), BOD ($t = -6.651$, $p < 0.001$), THC ($t = -4.106$, $p = 0.0007$), and Fe ($t = 3.065$, $p = 0.0067$). These results indicate that these parameters differ significantly between water and sediment samples. However, TPH ($t = -0.826$, $p = 0.420$) and TOC ($t = 1.322$, $p = 0.203$) showed no significant difference ($p > 0.05$) between the two sample types.

Table 2: Independent sample t-test (water vs sediment).

Parameter	t-value	p-value	Interpretation
pH	-7.678	<0.001	Significant
DO	2.254	0.037	Significant
BOD	-6.651	<0.001	Significant
THC	-4.106	0.0007	Significant
TPH	-0.826	0.420	Not significant
Fe	3.065	0.0067	Significant
TOC	1.322	0.203	Not significant

Table 3 shows the Pearson correlation relationships among physicochemical parameters in water samples. A positive correlation ($r = 1.00$) was observed between DO and BOD, indicating a positive relationship between oxygen concentration and organic matter decomposition. A relatively positive correlation was also observed between THC and TOC ($r = 0.65$), suggesting that hydrocarbons contribute significantly to the organic carbon content of the water. A moderate negative correlation was observed between pH and Fe ($r = -0.51$), indicating that lower pH conditions may increase iron solubility in water.

Table 4 presents the results of principal component analysis. The first three principal components explained 78.9% of the total variance in the dataset. PC1 explained 39.4% of the variance and was mainly associated with THC, TOC, and BOD, indicating hydrocarbon and organic pollution sources. PC2 explained 23.2% of the variance and was associated with DO and BOD, representing oxygen dynamics. PC3 explained

Table 3: Pearson correlation matrix (water samples).

Parameter	pH	DO	BOD	THC	TPH	Fe	TOC
pH	1.00	-0.25	-0.25	-0.14	-0.13	-0.51	0.04
DO	-0.25	1.00	1.00	0.39	-0.31	-0.07	0.38
BOD	-0.25	1.00	1.00	0.38	-0.30	-0.07	0.37
THC	-0.14	0.39	0.38	1.00	-0.06	-0.24	0.65
TPH	-0.13	-0.31	-0.30	-0.06	1.00	-0.23	-0.12
Fe	-0.51	-0.07	-0.07	-0.24	-0.23	1.00	-0.16
TOC	0.04	0.38	0.37	0.65	-0.12	-0.16	1.00

Table 4: Principal component analysis (PCA).

Component	Variance Explained
PC1	39.4%
PC2	23.2%
PC3	16.3%

Table 5: Cluster analysis that grouped the 10 sampling stations into three pollution groups.

Cluster	Stations	Pollution Level
Cluster 1	Stations 2, 8, 9	High contamination
Cluster 2	Stations 5, 6	Moderate contamination
Cluster 3	Stations 1,3,4,7,10	Low contamination

Table 6: Water quality index (WQI).

WQI Range	Water Quality
0 – 25	Excellent
26 – 50	Good
51 – 75	Poor
76 – 100	Very Poor
>100	Unsuitable

16.3% of the variance and was associated with Fe and pH, indicating metal-related influences.

Table 5 presents the results of cluster analysis, which grouped the sampling stations into three pollution clusters. Cluster 1 (stations 2, 8, and 9) represented areas with high contamination levels, while Cluster 2 (stations 5 and 6) showed moderate contamination levels. Cluster 3 (stations 1, 3, 4, 7, and 10) represented areas with lower contamination levels, indicating spatial variation in pollution across the study area.

Table 6 presents the classification of water quality based on the Water Quality Index. The classification ranges from excellent (0–25) to unsuitable for drinking (>100). Based on the measured physicochemical parameters such as BOD, THC, COD, and Fe, the water quality in the study area falls within the poor to very poor category, indicating that the water is not suitable for drinking without treatment.

DISCUSSION

The present study evaluated the levels of organic contamination and selected physicochemical parameters in water and sediment samples collected from the Opukuma community in Kolokuma/Opokuma Local Government Area of Bayelsa State, Niger Delta, Nigeria. The results revealed varying levels of contamination in both environmental media, with sediments generally showing higher accumulation of pollutants compared to the overlying water column. This observation supports the widely accepted view that sediments act as sinks for contaminants in aquatic environments due to their ability to adsorb and accumulate organic matter and hydrocarbons (Förstner and Wittmann, 1983; Varol *et al.*, 2020).

The pH values recorded in the study area were 5.12 ± 0.09 for water and 6.41 ± 0.52 for sediment, indicating slightly acidic conditions in the water column. Acidic conditions in aquatic environments are often associated with the decomposition of organic matter, industrial discharges, and petroleum contamination (Wetzel, 2001). Similar slightly acidic conditions have been reported in other aquatic environments in the Niger Delta region, where hydrocarbon contamination and anthropogenic activities influence water chemistry (Iwegbue *et al.*, 2013). The statistically significant difference observed between water and sediment pH values suggests that sediments may buffer pH changes through mineral interactions and organic matter accumulation.

Dissolved oxygen concentrations recorded in this study were 3.05 ± 0.32 mg/L in water and 2.73 ± 0.31 mg/L in sediment, which are below the recommended limit of 5 mg/L required for sustaining healthy aquatic ecosystems. Low dissolved oxygen concentrations are usually associated with high levels of organic matter decomposition and microbial respiration (Wetzel, 2001; Saha *et al.*, 2021). Similar findings have been reported in polluted aquatic systems where organic waste inputs increase biological activity and oxygen consumption (Chapman, 2007). The low dissolved oxygen levels observed in this study, therefore, indicate possible organic pollution and may pose risks to aquatic organisms that require adequate oxygen levels for survival.

The biochemical oxygen demand (BOD) values recorded in the study were 59.48 ± 6.26 mg/L for water and 83.60 ± 9.60 mg/L for sediment, which are far above the WHO recommended limit of 5 mg/L. Elevated BOD values are typically indicative of high organic pollution levels and increased microbial decomposition of organic materials (APHA, 2017). The higher BOD values observed in sediments compared to water samples suggest that organic matter accumulates within sediment matrices where microbial degradation processes occur. Similar elevated BOD levels have been reported in aquatic environments affected by oil exploration and industrial discharge in the Niger Delta (Osuji and Adesiyan, 2005).

Hydrocarbon contamination was evident in the study area based on the elevated concentrations of total hydrocarbon content (THC) and total petroleum hydrocarbons (TPH) recorded in both water and sediment samples. The mean THC values were 1.61 ± 0.46 mg/L in water and 2.68 ± 0.68 mg/L in sediment, which exceed the recommended environmental limits. Hydrocarbon contamination is common in petroleum-producing regions such as the Niger Delta, where oil spills, pipeline leaks, and illegal refining activities introduce petroleum products into surrounding ecosystems (UNEP, 2011; Edeh *et al.*, 2020). The higher concentration of hydrocarbons in sediment samples observed in this study is consistent with previous findings that sediments tend to accumulate hydrophobic organic compounds due to adsorption onto particulate matter (Wang and Fingas, 2003).

Total petroleum hydrocarbon concentrations recorded in the study were 0.62 ± 0.76 mg/L in water and 0.91 ± 0.81 mg/L in sediment, both exceeding the recommended limit of 0.3 mg/L. Although the difference between water and sediment concentrations was not statistically significant, the elevated values indicate the presence of petroleum contamination within the aquatic environment. Similar hydrocarbon contamination levels have been reported in other studies conducted in the Niger Delta region, where petroleum exploration activities significantly influence water and sediment quality (Nriagu *et al.*, 2016).

Iron concentrations recorded in this study were 1.63 ± 0.42 mg/L in water and 0.96 ± 0.55 mg/L in sediment, exceeding the WHO permissible limit of 0.3 mg/L for drinking water. Elevated iron levels in aquatic systems may originate from both natural and anthropogenic sources, including weathering of iron-bearing minerals, industrial discharges, and petroleum-related activities (Alloway, 2013). High iron concentrations can affect water quality by altering taste, color, and turbidity, and may also impact aquatic organisms when present in excessive amounts.

Total organic carbon (TOC) concentrations recorded in the study were 3.26 ± 0.61 mg/L in water and 2.97 ± 0.35 mg/L in sediment, indicating the presence of organic matter within the aquatic system. Organic carbon is an important indicator of organic pollution in aquatic environments and may originate from natural processes such as plant decomposition as well as anthropogenic inputs including sewage discharge and petroleum contamination (Nelson and Sommers, 1996). The moderate TOC values observed in this study suggest that organic matter inputs are present but may vary across sampling locations.

Chemical oxygen demand (COD) values recorded in the study were 104.55 ± 20.79 mg/L in water and 199.13 ± 41.29 mg/L in sediment, with sediment values exceeding the WHO recommended limit of 150 mg/L. High COD values indicate the presence of oxidizable organic pollutants in aquatic systems and are commonly associated with industrial waste discharge, petroleum contamination, and organic matter accumulation (Sawyer *et al.*, 2003). The higher COD levels observed in sediments further support the role of sediments as reservoirs for organic contaminants in aquatic ecosystems.

The results of the statistical analyses further provided insight into the relationships between the measured parameters. The Pearson correlation analysis revealed a positive correlation between dissolved oxygen and biochemical oxygen demand, indicating that organic matter decomposition significantly influences oxygen dynamics in the study area. Additionally, the positive correlation observed between THC and TOC suggests that hydrocarbons contribute to the overall organic carbon content of the aquatic system. These findings are consistent with previous studies that have reported strong relationships between hydrocarbon contamination and organic carbon levels in polluted aquatic environments (Wang and Fingas, 2003).

Principal component analysis indicated that hydrocarbon pollution and organic matter decomposition were the dominant factors influencing water quality in the study area, accounting for the majority of the total variance in the dataset. This observation further confirms the influence of petroleum-related activities on environmental quality in the Niger Delta region. Similarly, cluster analysis grouped the sampling stations into different contamination categories, indicating spatial variation in pollution levels within the study area.

The Water Quality Index classification further indicated that the water quality in the study area falls within the poor to very poor category, suggesting that the water may not be suitable for domestic use without adequate treatment (Tyagi *et al.*, 2020). This finding highlights the need for effective environmental monitoring and pollution control measures in the study area to protect aquatic ecosystems and safeguard public health.

CONCLUSION

This study assessed the levels of organic contamination and selected physicochemical parameters in water and sediment samples from Opukuma community in Kolokuma/Opokuma Local Government Area, Bayelsa State. The results revealed elevated concentrations of several parameters, including BOD, THC, TPH, Fe, and COD, with many values exceeding recommended environmental limits. Sediment samples generally recorded higher concentrations of contaminants compared to water samples, indicating that sediments serve as reservoirs for organic pollutants and hydrocarbons in the aquatic environment. The statistical analyses further indicated significant differences between water and sediment for several parameters, while correlation and multivariate analyses suggested that hydrocarbon pollution and organic matter decomposition are the major factors influencing water quality in the study area. Overall, the findings indicate that the aquatic environment in Opukuma is impacted by organic and petroleum-related contamination.

Recommendations

Regular monitoring of water and sediment quality should be conducted, and stricter environmental regulations should be enforced to control oil spills, illegal refining, and waste discharge. Environmental remediation and public awareness programs should also be implemented to protect and sustain the aquatic ecosystem.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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