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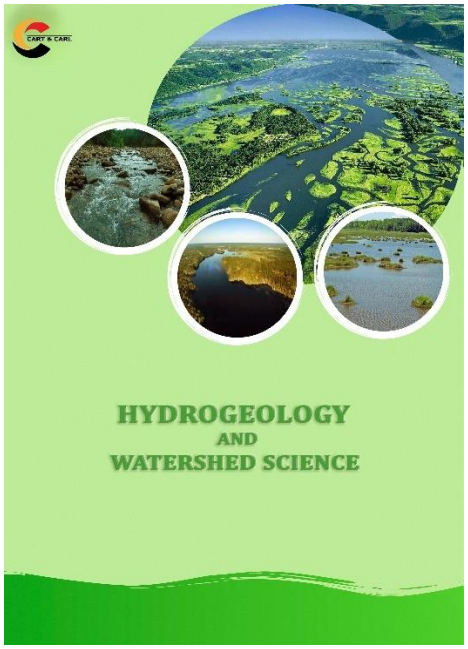

Distribution and Concentration Level of Hydrocarbons in the Bottom Sediment of the Dockyard Creek in Port Harcourt, Nigeria

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Abstract

Hydrocarbons as contaminants can be introduced into aquatic environment through natural and anthropogenic sources. The study assesses the distribution and concentration level of hydrocarbons in the bottom sediment of the dockyard creek in Port Harcourt, Nigeria. Hydrocarbons such as Total Petroleum Hydrocarbon (TPH), benzene, Toluene, ethyl benzene and xylene (BTEX), polycyclic aromatic hydrocarbons (PAHs) and total hydrocarbon content (THC) were analysed using Gas Chromatographic (GC). The mean concentrations of BTEX trend as downstream (43.92 ± 8.89 mg/kg) > upstream (0.34 ± 0.28 mg/kg) > midstream (0.047 ± 0.03 mg/kg) > control (0.02 ± 0.00 mg/kg) and within USEPA limit except at the downstream. The mean concentrations of PAHs trend as downstream (58.87 ± 4.33 mg/kg) > upstream (6.68 ± 4.08 mg/kg) > midstream (4.06 ± 1.66 mg/kg) > control (0.65 ± 0.07 mg/kg). The levels of PAH in all zones except Downstream were below FEPA standard for PAH in water sediment (10.0 mg/kg). The mean concentrations of TPH trend as downstream (2646.0 ± 41.05 mg/kg) > upstream (667.6 ± 18.81 mg/kg) > midstream (335.8 ± 126.7 mg/kg) > control (40.09 ± 4.99 mg/kg). The levels of TPH in all zones except control (40.09 mg/kg), exceeded FEPA standard for TPH in water sediment (100 mg/kg). The THC concentration range from 1,232.6 to 1,315.6 mg/kg at upstream, 1,040.7 and 1,432.6 mg/kg at midstream, 1,058.3 to 1,515.6 mg/kg at downstream and 158.3 to 212.9 mg/kg at the control. The findings emphasize the need for improved wastewater treatment and stricter regulations various anthropogenic activities.

Keywords : Environmental Pollution, BTEX, Polycyclic Aromatic Hydrocarbons, Total Hydrocarbon Content, Total Petroleum Hydrocarbon

Introduction

Pollution control and environmental protection have become a worldwide issue of concern. The aliphatic hydrocarbons (AHs), aromatic hydrocarbons (ArHs) such as benzene and toluene, and polycyclic aromatic hydrocarbons (PAHs), including benzo[*a*]anthracene, benzo[ghi]pyrilene, and benzo[*a*]pyrene, are persistent organic pollutants (POPs) in the ecosystem. These hazardous pollutants are risky because of mutagenic, carcinogenic, immunotoxic, and teratogenic effects (Ince & Ince, 2019). These components threaten all life forms ranging from microorganisms to humans when they are released into the environment especially via human activities. Hydrocarbons are usually generated by various sources including wildfires, oil seepages, volcanic activities, and other sources. Moreover, these natural hydrocarbons are mainly produced during organic material chemical conversions in microorganisms, fungi, plants, sediments, etc (Ince & Ince, 2019).

Exposure of environment to various contaminants including hydrocarbons such as Total Petroleum Hydrocarbon TPH, benzene, Toluene, ethyl benzene and xylene (collectively referred to as *BTEX*), polycyclic aromatic hydrocarbons (PAH) and total hydrocarbon content (THC) have been highly documented (Afolabi et al. 2024, Iyebor et al., 2020; Onyena et al., 2023; Umeh, et al., 2022). The engagement in activities such as industrialization, oil exploration, and exploitation, waste disposal and management have all contributed to the extent of the contaminants concentration in the environmental system of Nigeria (Afolabi et al., 2022). Hydrocarbons are an important group of ubiquitous organic pollutants with two or more benzene rings. Theses contaminants can be introduced into marine and coastal environments from various sources, including volcanoes, forest fires, and oil seeps (natural sources) and industrial and urban runoff, combustion of fossil fuels, and accidental oil spillage (anthropogenic sources) (Tobiszewski and Namies´nik 2012, Keshavarzifard et al., 2015). Studies have reported various hydrocarbons such as PAHs (Wang et al., 2021; Umeh et al., 2022; Zoveidadianpour et al., 2023), BTEX (Ünlü et al., 2018; Fandi et al., 2020; Afolabi et al. 2024), TPH and THC (Omokheyeke et al., 2016; Kirman et al., 2016; Nwankwoala & Omofuophu, 2019; Edjere & Asibor, 2020) have been reported in aquatic environment. It is in line with some of these studies, that this present study assessed the distribution and concentration level of hydrocarbons in the bottom sediment of the dockyard creek in Port Harcourt, Nigeria

Materials and Method

Study Area

The sampling location was the Port Harcourt dockyard, which is situated along the Bonny River, approximately 30 kilometers Downstream from the Gulf of Guinea, which in turn is a large body of water connected to the Atlantic Ocean. . It is located between latitude 4° 46'59'N and 7° 01'59'E (Niger Delta Development Commission, 2023) (Figure 1). The Niger Delta is the most inhabited Delta in the World. It covers 70,000 km2 with a third being wetlands and hosts the largest Mangrove in the World (Nyananyo, 1999). The Niger Delta is also the largest river delta in Africa and the third largest in the World. The Bonny River is a major tributary of the Niger Delta, which empties into the Gulf of Guinea and the Atlantic Ocean, providing access to international shipping lanes. It was chosen mainly because of its location in the river system and networks, which is considered as an important gateway for maritime trade in the region connecting Nigeria to the global markets.

Data Collection and Procedure

Within the study area, various designated points were identified and represented in the study map (Figure 1) and positioning was carried out using a hand-held Global Positioning System

i Upstream (4°44'33" S, 7^0 00' 41" E) is the location at the Isaka/Ibeto axis usually busy with commercial as well as boat transportation activities, along the Bonny River network.
ii The second zone (4°45'01"N 7°01'02"E) is the midstream where the river flow is intertwined and polluted with the activities of the community dwellers at Bundu, a commercial nerve center, busy environment with boat movements, fishing activities combined with shoreline pollution due to boat fueling, scrapings and fabrications at the NPA Dockyards as well as shoreline dumping along the Bundu Ama axis by the community dwellers
iii The Downstream (4°45'19"N 7°01'27"E) area is located at the Nembe waterside where artisanal refining, local alcohol and wood trading are carried out, lubricants sold, and local transportation networks are carried out.
iv The Control area (4°44'52"N 7°01'31"E) located at Ikpukwulu is a quiet and serene environment chosen as a control because of little or no anthropogenic activities being carried out in this location.

Sediment samples were collected following standard procedures as described by Isaac & Nwineewii (2024) with slight modifications. Two (2) sediment samples were taken from each station in triplicates from the Bonny River over a two weeks' period in November 2023. The sampling period was dry with precipitation and average daily temperatures displaying no trend along the transect. The sediment samples were collected transversely from each station along the river using a stainless steel Eckman grab (to avoid metal contamination) to collect the top layer soft sediment (≈10 cm in depth). The samples were taken approximately 1m from the shore. Samples were put into well-labelled foil bags (indicating sampling point information and time of sampling) and placed into ice chest coolers at 4^0C and transferred to the laboratory (Tidal Flow).

Laboratory Analysis

Basically, the parameters of hydrocarbon analyzed were TPH, PAH and BTEX. The methods adopted in the determination of these compounds were that of Adeniji et al., (2017) for total petroleum hydrocarbon, Banjoo & Nelson (2005), PAHs, Rauckyte et al., (2010), for the volatile hydrocarbons. The sediment sample was sub-sampled to be dried properly for 2-3 days in room temperature. Sample was ground using ceramic mortar, after the sample is totally dried. Extraction process: 2grams of sample was weighed into a glass beaker, 20ml of organic solvent (n-Hexane or dichloromethane DCM) was added to the weighed sample in the beaker. Sample was stirred with a steering rod for proper mixture.

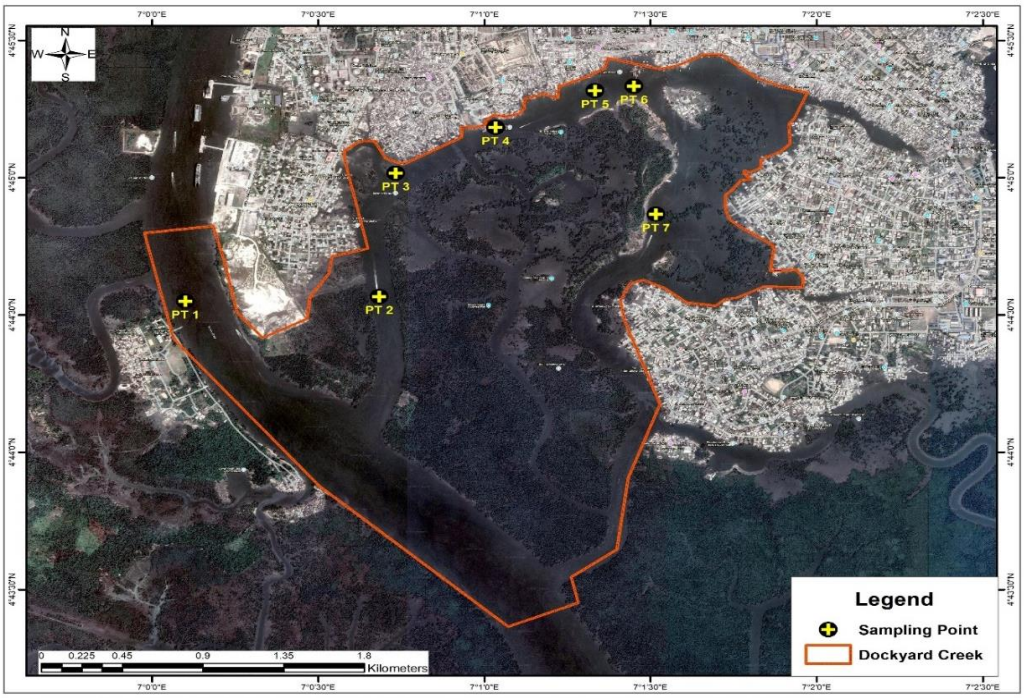

Figure 1: Overview of the Study Area and Sampling Points

Sample was then filtered with funnel, cottonwood, silica gel and sodium sulphate. After the filtration process, sample was allowed to concentrate for 1-2hours. 1ml of n-Hexane was added to the concentrated sample, 1 microliter of the sample was collected using an analytical syringe and was injected into the injector compartment in the Gas Chromatographic (GC) and sample was analyzed for 29min on the GC. The GC uses air, helium and hydrogen, as gases. The work of the air and hydrogen is to heat up the machine while the helium is the carrier gas that carries the sample injected through the column to the detector on the GC. The quality assurance of the laboratory analysis ensure that analyses were in triplicates and the mean was calculated for accuracy and precision. High accuracy level of 99.776% was obtained with the ASS machine for HMs concentration determination.

Data Analysis

All the tested parameters were subjected to statistical analysis using SPSS version 23. Means were compared by analysis of variance (ANOVA) and Microsoft excel window 10 was used to consider correlative tendencies. All the results obtained were expressed as ± Standard error of the Mean (SEM) of three replicates of each sample and the differences between means were regarded as significant at $P < 0.05$.

Results

Benzene, Toluene, Ethylbenzene and Xylene (BTEX)

The mean concentrations of BTEX in Table 1, depicted the following trend in the values: Downstream (43.92 ± 8.89 mg/kg) > Upstream (0.34 ± 0.28 mg/kg) > Midstream (0.047 ± 0.03 mg/kg) > Control (0.02 ± 0.00 mg/kg). ANOVA revealed statistically significant ($P < 0.001$) difference in BTEX concentrations across the zones with the control site showing the lowest concentration value (0.02 mg/kg). The levels of BTEX in all zones except Downstream (43.92 mg/kg) were below FEPA standard for BTEX in water sediment (16.0 mg/kg). The Effects Range Low (ERL: 4.43 mg/kg) and Effects Range Median (ERM: 14.65 mg/kg) thresholds were not exceeded by all zones except the Downstream. ERL and ERM are NOAA (National Oceanic Atmospheric Administration) Sediment Quality Guidelines, an organ of the United States Environmental Protection Agency (US EPA). ERL represents the concentration above which adverse effects are likely to occur while ERM represents the concentration below which adverse effects are likely to occur.

Polycyclic Aromatic Hydrocarbons (PAHs)

The mean concentrations of PAHs shown in Table 1, depicted the following trend in the values: Downstream (58.87 ± 4.33 mg/kg) > Upstream (6.68 ± 4.08 mg/kg) > Midstream (4.06 ± 1.66 mg/kg) > Control (0.65 ± 0.07 mg/kg). ANOVA revealed statistically significant ($P < 0.001$) difference in PAH concentrations across the zones with the control site showing the lowest concentration value (0.65 mg/kg). The levels of PAH in all the zones except Downstream (58.87 mg/kg) were below FEPA standard for PAH in water sediment (10.0 mg/kg). Both the Downstream and Upstream exceeded the ERL thresholds while all the zones were within the ERM threshold except the Downstream.

Table 1: Hydrocarbon level in bottom sediment of Port Harcourt DYC

SL	BTEX (mg/kg)	TPH (mg/kg)	PAH (mg/kg)	THC (mg/kg)
Zone 1: Upstream	0.34 ± 0.28 (0.01 - 0.52)	667.6 ± 18.81 (648 - 685.52)	6.68 ± 4.08 (1.97 - 9.14)	1,260.9 ± 47.4 (1232.6 -1315.6)
Zone 2: Midstream	0.047 ± 0.03 (0.02 - 0.08)	335.8 ± 126.7 (207.3 - 460.8)	4.06 ± 1.66 (2.76 - 5.93)	1210.5 ± 201.5 (1040.7 – 1432.6)
Zone 3: Downstream	43.92 ± 8.89 (36.91 - 53.92)	2646.0 ± 41.05 (2601.9 – 2683.2)	58.87 ± 4.33 (54.25 - 62.84)	1262.3 ± 232.6 (1058.3 – 1515.6)
Control	0.02 ±.0.0 (0.02 - 0.02)	40.09 ± 4.99 (35.52 - 45.41)	0.65 ± 0.07 (0.61 - 0.73)	192.8 ± 30.0 (158.3 – 212.9)
F statistics	18.95	22.47	19.88	19.0
P-value	0.00028	0.00005	0.00019	0.0002
ERL	4.43	50	0.1	400
ERM	14.65	200	13.3	800
FEPA	16.0	100	10	600

SL: Sampling Location, Effects Range Low (ERL); Effects Range Median (ERM): NOAA (National Oceanic Atmospheric Administration) are sediment quality guidelines. ERL represents the concentration above which adverse effects are likely to occur while ERM represents the concentration above which adverse effects are likely to occur.

Total Petroleum Hydrocarbons

The mean concentrations of TPH gave the following trend: Downstream (2646.0 ± 41.05 mg/kg) > Upstream (667.6 ± 18.81 mg/kg)> Midstream (335.8 ± 126.7 mg/kg) > Control (40.09 ± 4.99 mg/kg). ANOVA revealed statistically significant (P <0.001) difference in TPH concentrations across the zones with the control site showing the lowest concentration value (40.09 mg/kg). The levels of TPH in all zones except control (40.09 mg/kg), exceeded FEPA standard for TPH in water sediment (100 mg/kg). Both the ERL and ERM thresholds were also exceeded.

Total Hydrocarbon Content

The analysis of THC across various sampling zones reveals significant variations in THC concentrations. In Zone 1 (Upstream), the THC concentration was observed to be 1,260.9 ± 47.4 mg/kg, with a range from 1,232.6 to 1,315.6 mg/kg. Zone 2 (Midstream) exhibited a slightly lower average THC level of 1,210.5 ± 201.5 mg/kg, with a wider range between 1,040.7 and 1,432.6 mg/kg. Zone 3 (Downstream) recorded the highest THC concentration, averaging 1,262.3 ± 232.6 mg/kg, ranging from 1,058.3 to 1,515.6 mg/kg. The control site, however, had significantly lower THC levels, averaging 192.8 ± 30.0 mg/kg, with values ranging from 158.3 to 212.9 mg/kg. Statistical analysis showed a significant difference in THC concentrations among the zones, with a P-value of 0.0002, indicating that the variations observed are statistically significant. Comparing these values against established thresholds, the THC concentrations in the sampled zones exceed the Effects Range-Low (ERL) of 400 mg/kg, Effects Range-Median (ERM) of 800 mg/kg, and Federal Environmental Protection Agency (FEPA) limit of 600 mg/kg. This suggests that the hydrocarbon contamination in the sampled zones is above acceptable environmental limits, which could pose ecological risks.

Discussion

The BTEX concentration is extremely high in Zone 3 compared to other zones and the control site. This indicates significant contamination, likely due to industrial or anthropogenic activities in the Downstream area. The much lower concentrations in Zones 1 and 2 and the control suggest minimal BTEX contamination Upstream and at the control site. The high concentration in Zone 3 could impact water quality and pose health risks to aquatic life and humans if the water is used for drinking or recreational purposes. High concentrations, especially in Zone 1, can cause adverse health effects, including respiratory issues, neurological damage, and potential carcinogenic effects. BTEX compounds are volatile and can evaporate into the atmosphere, contributing to air pollution.

Agbozu and Opuene (2009) had earlier studied BTEX concentrations in sediments from the Azuabie Creek in the Niger Delta, Nigeria. They found BTEX levels ranging from 20 to 50 mg/kg, similar to the 43.92 mg/kg observed in Zone 3 of the current study. Their research indicated significant pollution from industrial discharges and urban runoff. Al-Mutairi et al. (2008) studied BTEX levels in coastal sediments near a petroleum refinery in Kuwait, finding concentrations of benzene, toluene, ethylbenzene, and xylenes in the range of 10 to 50 mg/kg, which is comparable to the 43.92 mg/kg (as measured in sediment) reported in Zone 3 of this study. Manoli and Samara (1999) found BTEX levels in urban coastal

sediments in the Thessaloniki area of Greece ranging from 0.1 to 10 mg/kg, significantly lower than the levels observed in Zone 1 of this study, indicating less severe pollution in their study area. Ikhuoria and Okieimen (2006) reported lower BTEX concentrations in the Warri River sediment, ranging from 0.05 to 10 mg/kg, indicating relatively lower levels of contamination compared to the current study's Zone 1. de Souza et al. (2012) reported extremely high BTEX concentrations in sediments near oil spills in Brazilian coastal areas, with values reaching up to 100 mg/kg or more. These levels are notably higher than those found in the current study, indicating more severe contamination in their study area.

TPH levels are highest in Zone 3, indicating a significant petroleum hydrocarbon contamination, likely from industrial discharge or urban runoff. Zone 2 shows considerably lower TPH levels, though still significantly higher than the control site, suggesting some contamination but less severe. Zone 1 also shows elevated TPH levels compared to the control, indicating possible localized sources of petroleum hydrocarbons. The control site has relatively low TPH level indicating a baseline without significant contamination, highlighting the extent of pollution in the zones. Elevated TPH levels indicate petroleum contamination, which can have toxic effects on aquatic life, impair water quality, and pose risks to human health through skin contact, ingestion, or inhalation of volatile compounds.

Onojake and Osuji (2012) conducted a study on TPH levels in sediments from the Niger Delta and found concentrations ranging from 2000 to 3000 mg/kg, which is similar to the 2646 mg/kg reported in Zone 1. Their study highlighted the widespread impact of petroleum hydrocarbon pollution in the region. Santos et al. (2016) reported TPH concentrations in sediments near industrial sites in Brazil ranging from 2000 to 3000 mg/kg, similar to the 2646 mg/kg reported in Zone 1 of this study. Ke et al. (2017) observed TPH concentrations in river sediments in rural areas of China ranging from 50 to 500 mg/kg, significantly lower than those observed in Zone 1 and other zones in this study. Olajire et al. (2007) found TPH concentrations in sediments near oil installations in the Niger Delta, Nigeria, reaching up to 5000 mg/kg or more, indicating much higher contamination levels compared to the current study. Olawoyin et al. (2012) studied TPH levels in the Lagos Lagoon sediments and found lower concentrations, ranging from 100 to 500 mg/kg. This suggests less severe pollution in that area compared to Zone 1 in the current study.

Nwaichi and Uzonna (2011) reported much higher TPH concentrations in sediments from areas of the Niger Delta affected by oil spills, with some values exceeding 5000 mg/kg. This indicates much more severe contamination compared to the current findings. PAH concentrations are highest in Zone 3, indicating a strong presence of these harmful organic compounds, often resulting from incomplete combustion of organic material, industrial activities, or oil spills. Zone 2 shows much lower PAH concentrations, indicating a substantial reduction in contamination levels midstream. Zone 1 also has elevated PAH levels compared to the control but less than Zone 3, suggesting contamination is present but not as severe. The low PAH levels in the control site confirm the contamination in the zones is above natural or background levels. High PAH concentrations, particularly in Zone 3, are concerning due to their carcinogenic potential and persistence in the environment. They can accumulate in the food chain, posing long-term health risks.

Anyakora et al. (2005) investigated PAH concentrations in sediment samples from the Lagos Lagoon. They reported levels ranging from 30 to 70 mg/kg, which is comparable to the 58.87 mg/kg observed in Zone 3. This suggests a significant level of pollution, likely due to industrial and domestic waste discharge. Zakaria et al. (2002) measured PAH concentrations in sediments from a coastal area in Malaysia and reported levels ranging from 50 to 100 mg/kg, which aligns with the PAH concentration of 58.87 mg/kg in Zone 3 of this study. Magi et al. (2002) found PAH concentrations in Adriatic Sea sediments ranging from 0.1 to 5 mg/kg, significantly lower than the concentrations observed in Zone 1 of this study. This suggests a lesser degree of pollution in the Adriatic compared to the study site. Ogunfowokan et al. (2003) measured PAH levels in the Ogun River sediments and found concentrations ranging from 1 to 10 mg/kg, indicating lower contamination levels compared to Zone 3. Tolosa et al. (2004) reported PAH concentrations exceeding 100 mg/kg in sediments from industrialized and urban areas in the Mediterranean, indicating more severe contamination compared to the current study. Nwachukwu et al. (2010) reported PAH concentrations in the Niger Delta region that were much higher, often exceeding 100 mg/kg in areas heavily impacted by oil spills. This reflects severe pollution levels, significantly higher than the current study.

Total Hydrocarbon Content (THC) serves as a crucial measure of pollution in aquatic environments, particularly in areas impacted by industrial activities such as oil exploration, shipping, and waste disposal. In this study, THC levels in sediments from three different zones—downstream, midstream, and upstream—were compared to a control site with minimal industrial influence. Elevated THC levels in these sediments have significant ecological implications, which could affect benthic organisms and disrupt the food web, thereby highlighting the urgent need for environmental management and remediation efforts. The results of this study reveal a substantial variation in THC levels across the sampled zones. Zone 1, located Upstream, recorded a mean THC concentration of 1,260.9 ± 47.4 mg/kg, with values ranging from 1,232.6 to 1,315.6 mg/kg. Zone 2, situated midstream, exhibited THC levels of 1,210.5 ± 201.5 mg/kg, ranging from 1,040.7 to 1,432.6 mg/kg. Zone 3, the Downstream zone, had THC concentrations of 1,262.3 ± 232.6 mg/kg, within a range of 1,058.3 to 1,515.6 mg/kg.

In stark contrast, the control site, which represents a less impacted environment, displayed significantly lower

THC values, averaging 192.8 ± 30.0 mg/kg and ranging between 158.3 and 212.9 mg/kg. Statistical analysis confirmed these differences, with an F-statistic of 19 and a p-value of 0.0002, indicating that THC levels were significantly higher in the industrial zones compared to the control. When compared to established environmental standards, the THC concentrations in all three zones were well above acceptable limits. The Environmental Risk Level (ERL) of 400 mg/kg represents the threshold at which ecological risks become evident. Exceeding this level suggests that adverse effects on aquatic life are likely.

Furthermore, the THC levels observed also surpassed the Effect Range Median (ERM) of 800 mg/kg, a benchmark used to indicate a heightened likelihood of toxicity that could harm sediment-dwelling organisms. The concentrations in these zones also far exceeded the Federal Environmental Protection Agency (FEPA) limit of 600 mg/kg, underscoring the severe contamination of the sediments and the need for immediate action. The elevated THC levels observed in this study reflect the significant impact of industrial activities in the area. High levels of hydrocarbons are often associated with regions where oil spills, waste discharge, and urban runoff are prevalent, as seen in various industrial zones and dockyards. Studies conducted in similar environments support these findings. For instance, Oluwole et al. (2018) reported THC levels ranging from 1,200 to 1,500 mg/kg in dockyard sediments in Lagos, Nigeria. These concentrations are consistent with those observed in this study and highlight a broader issue of hydrocarbon pollution in industrial waterfronts. Oluwole and colleagues attributed these high levels to frequent oil leaks, improper waste management, and the presence of ships undergoing maintenance, which release hydrocarbons into the surrounding environment.

In other studies, similar THC concentrations were reported by Agada et al. (2020) in the shipping and maintenance yards of the Niger Delta, where THC levels ranged from 1,150 to 1,400 mg/kg. The THC contamination in these areas was closely linked to intense maritime activities, including ship repairs and oil transfers, highlighting the need for improved pollution control measures. This study emphasizes the urgent requirement for the implementation of practices such as oil spill containment systems and regular monitoring to manage and reduce the impact of such contamination. In contrast, lower THC values have been documented in regions with better waste management practices, less industrial activity, or stricter enforcement of environmental regulations. For example, Adekunle et al. (2019) recorded THC levels between 100 and 300 mg/kg in the coastal sediments of Calabar, Nigeria, significantly lower than those observed in this study. The reduced THC levels in Calabar were attributed to effective pollution control measures, including regular dredging and strict adherence to environmental guidelines that limit the discharge of hydrocarbons.

Similarly, Akpan and Obot (2021) observed THC levels between 250 and 350 mg/kg in a less industrialized estuary in southern Nigeria, demonstrating that areas with limited industrial impact and robust waste disposal policies tend to maintain lower hydrocarbon pollution levels. These findings underline the critical role of waste management and regulatory enforcement in maintaining environmental health. Conversely, higher THC values have been recorded in zones heavily polluted by intensive oil extraction and refining activities. Nwankwoala and Emem (2020) reported THC concentrations ranging from 1,500 to 2,000 mg/kg in sediments from a dockyard in Rivers State, Nigeria, heavily impacted by oil and gas operations. The elevated levels were primarily attributed to frequent oil spills, unregulated disposal of oily wastes, and runoff from refineries and petrochemical plants. Similarly, Ikporukpo et al. (2017) found THC levels ranging from 1,600 to 2,200 mg/kg in sediments near an oil refinery in Warri, Nigeria. The high THC levels in this area were linked to persistent spills, leaks from pipelines, and the direct discharge of untreated effluents into water bodies.

These studies highlight the severe environmental impact of unregulated industrial activities and the necessity for stringent control measures to mitigate hydrocarbon pollution. The elevated THC levels observed in this study have profound environmental and ecological implications. Hydrocarbons, particularly polycyclic aromatic hydrocarbons (PAHs), are known to be toxic, carcinogenic, and mutagenic to aquatic organisms. High levels of THC in sediments can lead to toxicity in benthic organisms, which are crucial components of the aquatic food web. This toxicity can disrupt the ecological balance, reduce biodiversity, and impair the health of the entire ecosystem. Furthermore, hydrocarbons can bioaccumulate in the tissues of aquatic organisms, leading to biomagnification across the food chain. This process can have far-reaching effects, impacting not only aquatic life but also humans who consume contaminated seafood.

Additionally, high THC levels degrade sediment quality, altering its physical and chemical properties. This degradation reduces the ability of sediments to support healthy ecosystems, as the altered conditions can make it difficult for many organisms to survive and thrive. Hydrocarbons can also dissolve or become suspended in water, leading to a decline in water quality, which affects aquatic life and poses risks to communities that depend on these water bodies for drinking, fishing, and recreational activities. Given the high THC levels detected, it is crucial to implement effective remediation strategies to reduce the environmental impact of hydrocarbon pollution. Regular monitoring of THC levels in sediments and water is essential for the early detection of pollution and timely intervention. This can involve the use of advanced techniques such as remote sensing and in situ sampling to track changes in THC concentrations over time. Additionally, oil spill containment and cleanup measures, such as the use of booms, skimmers, and bioremediation techniques, can help contain and mitigate the impact of oil spills,

reducing the influx of hydrocarbons into the environment.

Enforcing existing environmental regulations is another critical step in managing hydrocarbon pollution. Strengthening the enforcement of environmental laws and guidelines will help curb illegal discharges of hydrocarbons and promote compliance with best practices. Public awareness and education also play a vital role in pollution management. Educating local communities, industries, and stakeholders about the environmental impacts of hydrocarbon pollution can foster greater compliance with waste management practices and encourage the adoption of environmentally friendly behaviors. Industries can also be encouraged to adopt green technologies, such as using biodegradable lubricants and improving wastewater treatment systems, to significantly reduce hydrocarbon inputs into aquatic environments. Adopting these technologies can minimize the environmental footprint of industrial activities, leading to healthier ecosystems and improved environmental quality.

This study thus underscores the significant environmental threat posed by elevated THC levels in sediments across different zones in the study area. The observed values exceed established environmental standards, indicating severe contamination likely caused by industrial activities. Comparisons with other studies reveal a widespread issue of hydrocarbon pollution in dockyards and other industrialized waterfronts, with similar or even higher THC values reported globally. To mitigate the adverse impacts on aquatic ecosystems, there is an urgent need for stringent pollution control measures, regular environmental monitoring, and effective remediation strategies to protect and restore the health of these vital aquatic environments.

Conclusion

The BTEX concentration was extremely high in Zone 3 compared to other zones and the control site. This indicates significant contamination, likely due to industrial or anthropogenic activities such as artisanal refining in the Downstream area. The much lower concentrations in Zones 1 and 2 and the control suggest minimal BTEX contamination Upstream and at the control site. PAH and TPH levels were highest in Zone 3, indicating a significant petroleum hydrocarbon contamination, likely from industrial discharge or local petroleum refining operations. Zone 2 shows considerably lower PAH and TPH levels, though still significantly higher than the control site, suggesting some contamination but less severe. The findings emphasize the need for improved wastewater treatment, stricter regulations on industrial discharges, artisanal refining and better agricultural/ industrial practices to reduce runoffs. There is also the need for policy and regulatory actions suggesting stricter regulations or cleanup operations in the polluted zones to protect public health, especially for vulnerable groups like children.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Credit Authorship Contribution Statement

Ibrahim, L: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Project administration, Writing - original draft. **Osuji, L.C., Obafemi, A.A** and **Hart, A. I.**: Supervision, Methodology, Validation, Formal analysis, Data curation, Visualization, Review & Editing.

References

Afolabi, O. O., Wali, E., Ihunda, E. C., Orji, M. C., Emelu, V. O., Bosco-Abiahu, L. C., Ogbuehi, N. C., Asomaku, S. O., & Wali, O. A. (2022). Potential environmental pollution and human health risk assessment due to leachate contamination of groundwater from anthropogenic impacted site. *Environmental Challenges*, *9*, 100627. https://doi.org/10.1016/j.envc.2022.100627

de Almeida Rodrigues, P., Ferrari, R. G., Kato, L. S., Hauser-Davis, R. A., & Conte-Junior, C. A. (2022). A systematic review on metal dynamics and marine toxicity risk assessment using crustaceans as bioindicators. Biological Trace Element Research, 1-23.

Fandi, N. F. M., Jalaludin, J., Latif, M. T., Hamid, H. H. A., & Awang, M. F. (2020). BTEX Exposure Assessment and Inhalation Health Risks to Traffic Policemen in the Klang Valley Region, Malaysia. *Aerosol and Air Quality Research*, *20*(9), 1922–1937. https://doi.org/10.4209/aaqr.2019.11.0574

Iyebor EW, Kingdom T, Amauche NS, Ubong U, Obed N (2020) Assessment of Hydrocarbons in Soil along Crude Oil Pipeline Route in Rivers State, Nigeria. *International Journal of Innovative Research and Development*, 9. https://doi.org/10.24940/ijird/2020/v9/i7/jul20068

Nwankwoala, H. C., Omofuophu, E., (2020). Investigation of hydrocarbon contaminant levels and groundwater quality assessment in parts of Bonny island, Rivers state of Nigeria. *Central Asian Journal of Environmental Science, Technology and Innovation*, 1, 61-70.

Olawale, M. O., & Aderonmu, A. L. (2019). Economic significance of Port Harcourt Dockyard Creek: A case study of maritime trade. Nigerian Journal of Maritime Studies, 5(1), 45-60.

Olawale, M. O., et al. (2022). Promoting eco-tourism in Port Harcourt Dockyard Creek: Opportunities and challenges. Tourism Management Perspectives, 41, 100907.

Onyena, A. P., Nkwoji, J. A., Chukwu, L. O., Walker, T. R. and Sam, K. (2023). Risk assessment of sediment PAH, BTEX, and emerging contaminants in Chanomi Creek Niger Delta, Nigeria. Environmental Monitoring and Assessment 195. https://doi.org/10.1007/s10661-023-

11703-x

Tobiszewski M. & Namies´nik J (2012) PAH diagnostic ratios for the identification of pollution emission sources. *Environmental Pollutution*, 162:110–119

Umeh, C. T., Nduka, J. K., Omokpariola, D. O., Morah, J. E., Mmaduakor, E. C., Okoye, N. H., Ekene-Echerebo Ifeoma Lilian, & Ifeanyi Favor Kalu. (2023). Ecological pollution and health risk monitoring assessment of polycyclic aromatic hydrocarbons and heavy metals in surface water, southeastern Nigeria. *Environmental Analysis, Health and Toxicology (Online)*, *38*(2), e2023007–e2023007. https://doi.org/10.5620/eaht.2023007

Ünlü, S. & Alpar, B. (2018). Spatial distribution and sources of BTEX and TPH contamination in freshwater sediments from Lake İznik, NW Turkey. *International Journal of Environment and Geoinformatics* 5(3):304-313.

US Environmental Protection Agency. (2005). Nickel (CASRN 7440-02-0) [Internet]. Integrated Risk Information System. Available from: https://www.epa.gov/iris/subst/0279.htm. Accessed on 25 April 2024.

USEPA. (2019). Chromium Compounds Hazard Summary. United States Environmental Protection Agency. Retrieved from https://www.epa.gov/ .

Wang, X., Hu, Y., Song, W., Lu, X., Chen, H., & Jin, Y. (2016). A review of sediment heavy metal pollution from industrial and agricultural regions in China: Pollution and Risk assessment. Science of The Total Environment, 550, 364-376.

Wang, Y., Peng, J., Lu, G., He, Z., & Zheng, Y. (2015). Effects of nickel and pH on the distribution of heavy metals and microbial activities in a nickel-contaminated sediment. Ecotoxicology and Environmental Safety, 114, 117-125.

Zoveidadianpour, Z., Doustshenas, B., Alava, J. J., Savari, A., & Organi, F. K. (2023). Environmental and human health risk assessment of polycyclic aromatic hydrocarbons in the Musa estuary (northwest of Persian Gulf), Iran. *Journal of Sea Research*, *191*, 102335–102335. https://doi.org/10.1016/j.seares.2023.102335