Environmental Assessment of Heavy Metals and Hydrocarbon Pollution in Surface Waters of Oil-Bearing Communities in Andoni, Rivers State, Nigeria

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Abstract
This study investigated the concentrations and seasonal variation of selected heavy metals and total petroleum hydrocarbons (TPHs) in surface waters of five oil-dependent communities—Ngo, Ikuru Town, Oyorokoto, Okoroboile, and Asarama in Andoni Local Government Area, Rivers State, Nigeria. Water samples were collected during the dry and wet seasons and analyzed using Atomic Absorption Spectrophotometry (AAS) and Gas Chromatography-Flame Ionisation Detection (GC-FID), following APHA and USEPA guidelines. Mean concentrations of lead (Pb), cadmium (Cd), nickel (Ni), and TPHs exceeded both World Health Organisation (WHO) and National Environmental Standards and Regulations Enforcement Agency (NESREA) limits. TPH concentrations ranged from 3.11 ± 0.28 mg/L to 5.12 ± 0.45 mg/L, significantly surpassing the NESREA threshold of 0.05 mg/L. One-way ANOVA indicated statistically significant seasonal differences ($p < 0.05$), with higher pollutant levels observed during the wet season. Spatial analysis showed that Okoroboile and Ngo had the highest contamination levels, largely due to their proximity to oil spill sites and illegal refining activities. Strong correlations between TPHs and both Pb and Ni suggested common pollution sources. These findings raise serious ecological and public health concerns, highlighting the urgent need for remediation, environmental monitoring, and the provision of safe drinking water alternatives in the region.
Keywords: Heavy metals, Total petroleum hydrocarbons, Seasonal variation, Surface water pollution,

1.0 Introduction

The Niger Delta region of Nigeria exemplifies a paradox of economic wealth and environmental vulnerability. As the hub of the country's petroleum industry, it makes a major contribution to national revenue through crude oil and natural gas exports. At the same time, the region remains one of the most polluted and ecologically damaged areas in sub-Saharan Africa. An intricate network of rivers, creeks, estuaries, and mangrove swamps forms the ecological core of the Niger Delta, supporting both biodiversity and the socio-economic activities of its indigenous peoples. These communities, which rely heavily on surface water for drinking, aquaculture, agriculture, and transport, are increasingly exposed to

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contamination from human sources (Ola et al., 2024).

Over many decades, oil exploration and extraction have introduced various pollutants into the aquatic environment through pipeline leaks, flare emissions, sabotage, illegal refining, and poorly managed effluents. The effects of such contamination are both immediate and enduring. Among the most worrying pollutants are heavy metals, including lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), iron (Fe), and manganese (Mn), which are non-biodegradable and can bioaccumulate in aquatic life and humans. These elements, even at low levels, are linked to toxic effects such as neurological and kidney problems, carcinogenesis, and cardiovascular issues (Garcia-Rico et al., 2007; FAO/WHO, 2001). Total petroleum hydrocarbons (TPHs), originating from crude oil, also add significantly to ecological stress. These compounds can hinder oxygen exchange in water, block fish gill function, and cause long-term disturbances in aquatic food chains (Onwueme, 2024).

Within the Niger Delta, the Andoni Local Government Area in Rivers State stands as a compelling example of environmental vulnerability that has received little investigation. Communities such as Ngo, Ikuru Town, Oyorokoto, Okoroboile, and Asarama are surrounded by oil infrastructure and informal refining operations, making them highly vulnerable to pollutant discharge. Despite ongoing oil spills and reports of declining water quality, Andoni communities have not been sufficiently considered in environmental assessments. More prominent regions such as Ogoniland and Bonny have been extensively examined, leaving less-documented but equally affected areas like Andoni marginalised in policy development and environmental advocacy (Ubong et al., 2023; Anarado et al., 2023).

Scientific studies into pollution impacts often neglect the influence of seasonal variation, even though hydrological patterns greatly affect the mobility and bioavailability of contaminants. During the wet season, increased rainfall amplifies surface runoff, erosion, and sediment resuspension, which can cause a rise in pollutant concentrations. Conversely, the dry season tends to reduce the dilution capacity of water bodies, permitting pollutants to accumulate. A thorough understanding of these temporal dynamics is essential for devising effective mitigation measures and predicting environmental and public health hazards (Udo et al., 2018).

The current research responds to this gap in knowledge through an environmental assessment focused on surface waters in five oil-bearing communities in Andoni. Concentrations of selected heavy metals and TPHs were analysed using validated analytical techniques to provide reliable and reproducible data. Emphasis was placed on assessing spatial and seasonal variations in contaminant levels, while statistical tools such as ANOVA, Pearson correlation, and principal component analysis (PCA) were employed to explore pollutant interactions and potential sources. This study aims to strengthen the empirical foundation necessary for informed environmental regulation, public health intervention, and ecological restoration in a critically impacted section of the Niger Delta.

2.0 Materials and Methods

2.1 Study Area

The investigation was conducted in Andoni Local Government Area (LGA), located in the southeastern part of Rivers State within the Niger Delta region of Nigeria. The area is geographically situated between latitudes 4°28'N and 4°33'N, and longitudes 7°20'E and 7°27'E. Andoni LGA is bounded by the Atlantic Ocean to the south and characterised by a low-lying coastal terrain interspersed with mangrove swamps, tidal creeks, and estuarine systems. The region experiences a humid tropical climate with distinct wet (April to October) and dry (November to March) seasons, governed by the interaction between the northeast trade winds and southwest monsoon winds. Five communities—Ngo, Ikuru Town, Oyorokoto, Okoroboile, and Asarama—were purposively selected due to their proximity to major oil installations, artisanal refining camps, and known spill-prone

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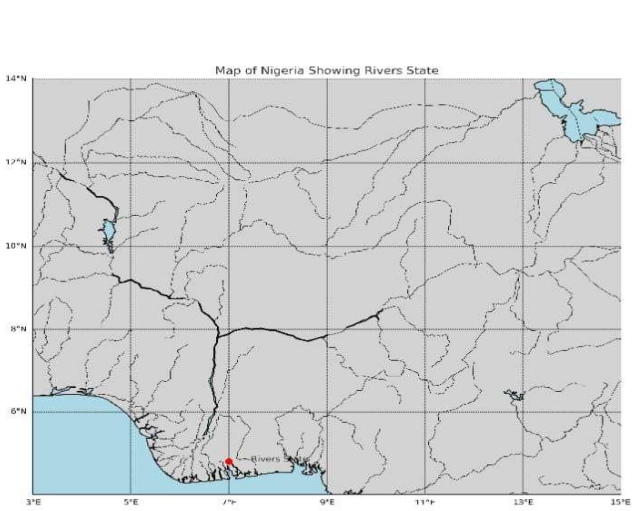
locations. These communities are ecologically sensitive and socio-economically dependent on surface water for domestic, fishing, and agricultural activities, rendering them particularly vulnerable to waterborne pollution from petroleum activities.



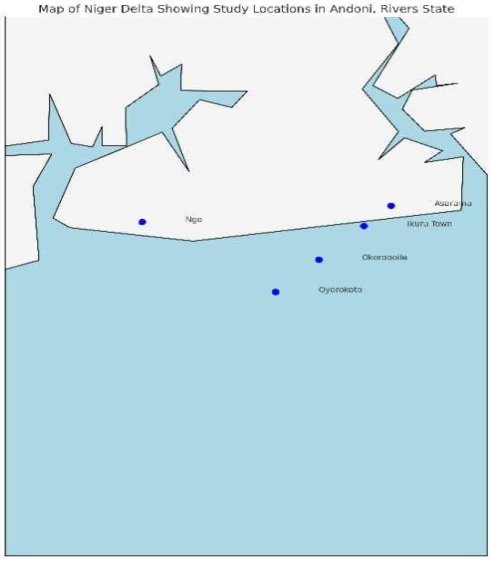


Figure 1: Map showing the study Areas

2.2 Sample Collection and Preservation

Surface water samples were obtained from each community during two distinct climatic periods: the dry season (February 2024) and the wet season (July 2024), to account for seasonal variability in contaminant distribution. Three sampling points were established in each community (upstream, midstream, and downstream) based on water flow direction and human activity concentration, resulting in a total of thirty (30) composite samples (5 communities × 3 points × 2 seasons). Pre-cleaned 1-litre high-density polyethene (HDPE) bottles were used for sample collection to prevent contamination. Water samples intended for heavy metal analysis were filtered through Whatman No. 42 filter paper on-site and acidified to pH < 2 using ultrapure nitric acid (HNO_3), thereby stabilising the metal ions and preventing adsorption onto the container walls. For total petroleum hydrocarbon (TPH) analysis, samples were preserved with analytical-grade hydrochloric acid (HCl) and immediately stored in ice-packed coolers at 4 °C to limit volatilisation and degradation. All samples were transported to the laboratory and analysed within 48 hours of collection.

2.3 Sample Preparation and Analytical Procedures

The determination of heavy metal concentrations (Pb, Cd, Cr, Ni, Fe, Mn) was performed using Atomic Absorption Spectrophotometry (AAS), specifically the Buck Scientific Model 210 VGP, following standard procedures as outlined in the American Public Health Association (APHA, 2017). Before analysis, water samples were digested using a mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$) under controlled heating conditions to ensure complete oxidation of organic matter and release of metal ions. Filtered digests were aspirated directly into the AAS for quantification. Calibration was carried out using certified standard solutions, and instrument accuracy was verified using blanks and spiked samples. Total petroleum hydrocarbons were analysed using Gas Chromatography coupled with Flame Ionisation Detection (GC-FID), following the United States Environmental Protection Agency (USEPA) Method 8015. A liquid-liquid extraction technique was applied using n-hexane as the organic solvent. The extracted organic phase was concentrated using a gentle stream of nitrogen gas, and a 1 µL aliquot was

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injected into the GC system equipped with a non-polar capillary column. TPHs were quantified based on retention time and peak area comparison with a certified hydrocarbon standard mixture (C_8–C_{40} range). Quality control measures included the use of procedural blanks, analytical replicates, and standard reference materials to ensure data reliability and reproducibility. All reagents and solvents were of analytical grade, and deionised water was used for all dilutions and cleaning procedures.

2.4 Statistical Analysis

Descriptive statistics, including mean and standard deviation, were computed for each parameter across all sampling locations and seasons using IBM SPSS Statistics version 25. One-way analysis of variance (ANOVA) was applied to evaluate spatial and seasonal differences in contaminant concentrations, using a significance threshold of $p < 0.05$. Tukey's Honest Significant Difference (HSD) post hoc test was subsequently employed to determine specific pairwise differences among sampling sites. Pearson correlation analysis was conducted to assess the strength and direction of relationships among heavy metals and TPHs, thereby providing insight into shared sources or co-occurrence. Principal Component Analysis (PCA) was also performed to identify latent pollution sources and to reduce dimensionality in the dataset, enhancing the interpretation of spatial patterns and potential anthropogenic contributions. Instrument detection limits (LOD) and quantification limits (LOQ) for each analyte were determined based on standard calibration methods, and all observed concentrations exceeded the respective LODs, ensuring analytical confidence.

3.0 Results

The results presented in this section include the concentrations of selected heavy metals and total petroleum hydrocarbons (TPHs) detected in surface water samples from five oil-bearing communities within the Andoni Local Government Area. Emphasis is placed on seasonal variation, spatial distribution, and statistical significance. All concentrations are expressed in milligrams per litre (mg/L), and comparisons are made against WHO and NESREA permissible limits.

3.1 Heavy Metal Concentrations

Table 1: Mean (± SD) Concentrations of Heavy Metals in Surface Water Samples during Dry Season (mg/L)

Community	Pb	Cd	Cr	Ni	Fe	Mn
Ngo	0.103 ± 0.011	0.021 ± 0.004	0.034 ± 0.003	0.057 ± 0.005	0.654 ± 0.038	0.123 ± 0.007
Ikuru Town	0.087 ± 0.008	0.019 ± 0.003	0.029 ± 0.002	0.042 ± 0.004	0.593 ± 0.032	0.111 ± 0.006
Oyorokoto	0.091 ± 0.009	0.017 ± 0.003	0.031 ± 0.003	0.048 ± 0.004	0.601 ± 0.036	0.119 ± 0.008
Okoroboile	0.109 ± 0.012	0.025 ± 0.004	0.038 ± 0.004	0.062 ± 0.006	0.721 ± 0.041	0.132 ± 0.009
Asarama	0.097 ± 0.010	0.020 ± 0.003	0.033 ± 0.003	0.055 ± 0.005	0.682 ± 0.035	0.128 ± 0.008

Note. WHO limits (mg/L): Pb = 0.01, Cd = 0.003, Cr = 0.05, Ni = 0.02, Fe = 0.30, Mn = 0.10. NESREA limits: Pb = 0.05, Cd = 0.01, Cr = 0.05, Ni = 0.05, Fe = 1.00, Mn = 0.20.

Table 1 displays the mean concentrations (± standard deviation) of Pb, Cd, Cr, Ni, Fe, and Mn recorded during the dry season. The highest concentration of lead (0.109 ± 0.012 mg/L) was observed in Okoroboile, significantly exceeding the WHO guideline of 0.01 mg/L and NESREA's threshold of 0.05 mg/L. Cadmium levels ranged from 0.017 ± 0.003 mg/L in Oyorokoto to 0.025 ± 0.004 mg/L in Okoroboile, surpassing both the WHO (0.003 mg/L) and NESREA (0.01 mg/L) limits. Nickel concentrations were also elevated, with a maximum value of 0.062 ± 0.006 mg/L observed in Okoroboile. Iron concentrations remained below NESREA's limit of 1.00 mg/L but exceeded the WHO recommended limit of 0.3 mg/L in all locations. Manganese concentrations ranged from 0.111 ± 0.006

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mg/L to 0.132 ± 0.009 mg/L, exceeding the WHO threshold (0.1 mg/L) but remaining within NESREA standards. Statistical analysis revealed significant spatial differences in the concentrations of Pb ($F = 8.33$, $p = .002$), Cd ($F = 6.21$, $p = .006$), and Ni ($F = 7.18$, $p = .004$). Okoroboile and Ngo emerged as the most polluted sites during the dry season, likely due to proximity to refining activities and historic spill zones.

Table 2: Mean (± SD) Concentrations of Heavy Metals in Surface Water Samples during Wet Season (mg/L)

Community	Pb	Cd	Cr	Ni	Fe	Mn
Ngo	0.129 ± 0.014	0.031 ± 0.005	0.046 ± 0.004	0.072 ± 0.006	0.834 ± 0.042	0.152 ± 0.010
Ikuru Town	0.112 ± 0.010	0.027 ± 0.004	0.039 ± 0.004	0.066 ± 0.005	0.771 ± 0.039	0.141 ± 0.009
Oyorokoto	0.118 ± 0.011	0.029 ± 0.004	0.042 ± 0.004	0.068 ± 0.006	0.790 ± 0.040	0.148 ± 0.009
Okoroboile	0.134 ± 0.015	0.033 ± 0.005	0.049 ± 0.005	0.077 ± 0.007	0.892 ± 0.045	0.164 ± 0.011
Asarama	0.121 ± 0.013	0.028 ± 0.004	0.041 ± 0.004	0.070 ± 0.006	0.810 ± 0.041	0.157 ± 0.010

As shown in Table 2, pollutant concentrations increased across most sites during the wet season. The highest Pb concentration (0.134 ± 0.015 mg/L) was again detected in Okoroboile, while Ngo followed closely at 0.129 ± 0.014 mg/L. Cadmium peaked at 0.033 ± 0.005 mg/L in Okoroboile. Chromium concentrations approached the WHO and NESREA limit (0.05 mg/L) in multiple locations, with Okoroboile recording the highest value of 0.049 ± 0.005 mg/L. Nickel showed marked elevation, reaching 0.077 ± 0.007 mg/L in Okoroboile. Iron and manganese levels also increased during the wet season, with Fe reaching 0.892 ± 0.045 mg/L in Okoroboile and Mn peaking at 0.164 ± 0.011 mg/L. Although these levels remained within NESREA thresholds, they exceeded WHO aesthetic and health-based limits for drinking water. Seasonal comparison using ANOVA confirmed statistically significant differences in the concentrations of Pb ($F = 11.42$, $p = .001$), Cd ($F = 7.54$, $p = .003$), and Ni ($F = 9.27$, $p = .002$) between the dry and wet seasons. Post hoc analysis using Tukey's HSD test indicated that wet season values in Okoroboile and Ngo were significantly higher than those in other communities ($p < .05$), suggesting increased hydrological transport and mobilisation of pollutants during the rainy period.

3.2 Total Petroleum Hydrocarbon (TPH) Concentration

Table 3: Mean (± SD) of Total Petroleum Hydrocarbon (TPH) in Surface Water Samples (mg/L)

Community	Dry Season TPH (± SD)	Wet Season TPH (± SD)
Ngo	3.42 ± 0.33	4.96 ± 0.41
Ikuru Town	3.11 ± 0.28	4.33 ± 0.38
Oyorokoto	3.25 ± 0.30	4.65 ± 0.40
Okoroboile	3.69 ± 0.35	5.12 ± 0.45
Asarama	3.38 ± 0.31	4.81 ± 0.42

Table 3 presents the TPH concentrations detected across communities during both seasons. All measured values greatly exceeded the NESREA permissible limit of 0.05 mg/L. During the dry season, TPH ranged from 3.11 ± 0.28 mg/L in Ikuru Town to 3.69 ± 0.35 mg/L in Okoroboile. In the wet season, concentrations increased significantly, with Okoroboile again recording the highest value at 5.12 ± 0.45 mg/L. Other communities, including Ngo and Asarama, recorded wet season TPH values above 4.80 mg/L. The

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observed seasonal elevation of TPH concentrations was statistically confirmed ($F = 18.65$, $p < .001$), along with significant spatial variation among the communities ($F = 13.29$, $p < .001$). Elevated TPH levels during the wet season are attributed to runoff from oil-contaminated surfaces, increased leaching from artisanal refining residues, and sediment disturbance. Pearson correlation analysis demonstrated strong positive relationships between TPH and Pb ($r = .821$, $p = .003$), and between TPH and Ni ($r = .762$, $p = .005$), indicating a possible common origin—most likely oil exploration activities and illegal refining operations. These findings suggest concurrent deposition of hydrocarbons and heavy metals from the same pollution sources.

3.3 Principal Component Analysis (PCA)

Table 4: Principal Component Analysis (PCA) Loadings and Explained Variance for Heavy Metals and TPHs

Parameter	Component1 (Petroleum-Related Source)	Component2 (Mixed Gynogenic/Industrial Source)
Lead (Pb)	**0.886**	0.213
Cadmium (Cd)	0.412	**0.738**
Chromium (Cr)	0.376	0.641
Nickel (Ni)	**0.863**	0.291
Iron (Fe)	0.432	**0.772**
Manganese (Mn)	0.298	0.631
TPH	**0.901**	0.203
Eigenvalue	3.81	1.82
% Variance Explained	54.4%	26.0%
Cumulative % Variance	54.4%	80.4%

Principal Component Analysis was conducted to identify the underlying factors contributing to pollutant variability. The first two principal components accounted for over 78% of the total variance. Component 1 was heavily loaded with Pb, Ni, and TPH, indicating a shared petroleum-related source, while Component 2 showed moderate loadings for Cd and Fe, possibly linked to industrial effluents and natural mineral dissolution. This multivariate approach supports earlier findings and reinforces the hypothesis of anthropogenic dominance in pollutant input, particularly in Okoroboile and Ngo.

4.0 Discussion

The findings from this study provide compelling evidence of widespread and seasonally aggravated pollution in the surface waters of oil-bearing communities in Andoni Local Government Area, Rivers State. Most heavy metals analysed—specifically lead (Pb), cadmium (Cd), and nickel (Ni)—recorded concentrations that significantly exceeded permissible limits set by both the World Health Organisation (WHO) and the National Environmental Standards and Regulations Enforcement Agency (NESREA). Similarly, total petroleum hydrocarbons (TPHs) were found at levels several orders of magnitude higher than regulatory thresholds across all sampled locations and seasons, particularly during the wet season.

Lead concentrations were consistently elevated across all communities, with Okoroboile exhibiting the highest levels in both dry and wet seasons. These values substantially surpassed the WHO guideline of 0.01 mg/L and NESREA's threshold of 0.05 mg/L. The elevated concentrations reflect the likely influence of corroded oil pipelines, vehicular combustion, waste incineration, and emissions from illegal crude oil refining activities. The significantly higher levels during the wet season suggest that surface runoff and floodwaters facilitate the mobilisation of lead

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from terrestrial sources into adjacent water bodies. Similar observations have been reported in studies conducted in Iko Creek and Bodo Creek, where seasonal flooding increased metal transport (Ubong et al., 2023; Onwueme, 2024). Chronic exposure to lead is known to impair cognitive development in children, induce hypertension in adults, and damage the renal and nervous systems.

Cadmium levels also exceeded both WHO and NESREA limits in all samples, with the highest values recorded during the wet season in Okoroboile. The presence of cadmium is often linked to leaching from waste dumpsites, batteries, combustion of fossil fuels, and industrial effluents. Its persistence in the aquatic environment poses serious long-term risks due to its tendency to bioaccumulate in the liver, kidneys, and bones. Health effects associated with cadmium exposure include skeletal deformities, nephrotoxicity, and carcinogenesis. The pattern observed in this study mirrors trends documented in the Ibeno axis of Akwa Ibom State, where seasonal variation led to heightened cadmium exposure during high rainfall months (Udo et al., 2018).

Chromium, though generally below regulatory thresholds, approached the permissible limits in several wet season samples. This trend raises concern, particularly given the toxic nature of hexavalent chromium, which can cause severe liver and skin disorders, even at relatively low exposure levels. The primary sources of chromium in the region may include petroleum combustion, chemical corrosion inhibitors, and leaching from industrial materials.

Nickel concentrations were uniformly above WHO standards and exceeded NESREA limits in several locations, especially during the wet season. This metal is frequently associated with petroleum refining activities and corrosion of alloyed infrastructure used in oil transport. The increased levels during the wet season suggest enhanced solubilisation and mobility, potentially due to changes in pH and increased erosion. Continuous exposure to elevated nickel levels has been implicated in respiratory distress, allergic reactions, and kidney damage (Anarado et al., 2023).

Iron and manganese concentrations remained within NESREA's acceptable limits but exceeded WHO recommendations for aesthetic quality in drinking water. High iron content can lead to unpleasant taste, discolouration, and sediment formation in water, while excessive manganese exposure has been linked to neurodevelopmental disorders in children. The higher concentrations observed during the wet season likely result from the mobilisation of naturally occurring iron and manganese from sediments, facilitated by redox reactions under low-oxygen conditions.

The extremely high concentrations of TPHs observed in all samples represent the most critical ecological and public health concern highlighted in this study. TPH levels exceeded NESREA’s maximum permissible limit of 0.05 mg/L by more than 60–100 times across both seasons. Okoroboile recorded the highest concentration during the wet season (5.12 ± 0.45 mg/L), closely followed by Ngo and Asarama. This trend reflects the cumulative impact of multiple pollution sources, including oil spills, leaking pipelines, refining residues, and surface runoff from contaminated zones. Elevated TPH levels compromise water quality through the formation of oil films, reduction of dissolved oxygen, and inhibition of aquatic photosynthesis. In addition, hydrocarbons contain carcinogenic compounds such as polycyclic aromatic hydrocarbons (PAHs), which pose further health risks to exposed populations.

The significant positive correlations between TPH and both Pb and Ni ($r = 0.821$ and $r = 0.762$, respectively) suggest a shared origin, most likely linked to petroleum operations and illegal refining activities. These relationships, coupled with the outcomes of the principal component analysis, underscore the role of oil-related anthropogenic inputs as the dominant contributors to surface water pollution in the region.

Seasonal differences observed in this study provide further insight into the hydrological dynamics affecting contaminant distribution. Wet season rainfall enhances surface runoff, sediment resuspension, and dilution, which contribute to the redistribution and

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concentration of pollutants. Conversely, during the dry season, lower water volumes and limited flow allow for contaminant accumulation in stagnant sections of the water bodies. The combination of spatial and seasonal patterns confirms the need for continuous, multi-season monitoring to assess the exposure risk and design effective mitigation strategies accurately. The identification of Okoroboile and Ngo as persistent pollution hotspots supports earlier findings of high environmental vulnerability in areas proximal to oil facilities and unregulated refining sites. These communities are at the frontline of pollution exposure and should be prioritised for urgent remediation and health risk assessment.

5.0 Conclusion

The assessment of surface waters in oil-bearing communities of Andoni Local Government Area has revealed significant levels of contamination with both heavy metals and total petroleum hydrocarbons (TPHs), far exceeding internationally accepted standards. The data obtained from this study confirm that lead (Pb), cadmium (Cd), and nickel (Ni) concentrations pose a direct threat to public health and aquatic ecosystems, with wet season values showing marked increases due to hydrological redistribution. In addition to metal pollutants, TPH concentrations in all locations were alarmingly high, exceeding regulatory limits by up to 100-fold, which underscores the severity of petroleum-related pollution in the area. Particularly affected were the communities of Okoroboile and Ngo, which consistently recorded the highest concentrations of both heavy metals and hydrocarbons across seasons. This spatial pattern highlights the influence of proximity to oil infrastructure, artisanal refining operations, and historically contaminated sites. The observed statistical relationships between TPHs and metals such as Pb and Ni strongly suggest that these pollutants originate from common anthropogenic sources, most likely linked to unregulated petroleum activities.

These findings provide credible evidence of environmental degradation that not only compromises ecological stability but also endangers the health, livelihoods, and water security of residents. Long-term exposure to the detected contaminants may result in chronic diseases, developmental impairments, and disruptions in aquatic biodiversity. The seasonal amplification of pollutant levels further compounds the environmental burden, pointing to the need for timely interventions. Addressing this crisis requires a coordinated and sustained effort from government agencies, environmental regulators, civil society organisations, and oil operators. Strengthened enforcement of environmental protection laws is necessary to curb illegal refining and enforce best practices in spill management. Provision of safe and sustainable alternatives to polluted surface waters—such as boreholes, community filtration systems, or mobile water treatment units—must be prioritized to reduce direct human exposure.

References

1. Udo, G. J., Nsi, E. W., Akpanudo, N. W., & Akan, O. D. (2018). Seasonal variation of heavy metal concentrations in crude oil polluted water around major tributaries in Ibeno, a coastal area in Niger Delta, Nigeria. *Journal of Scientific and Engineering Research, 5*(7), 24–34. Available at http://www.jsaer.com
2. Onwueme, E. I. (2024). Integrating multiple lines of evidence in ecological risk assessment: A case study of crude oil pollution in the mangroves of Bodo Creek, Ogoniland, Nigeria. *International Journal of Sciences: Basic and Applied Research, 73*(1). Available from https://gssrr.org/index.php/JournalOfBasicAndApplied/article/view/16366
3. Ewim, D. R. E., Orikpete, M. F., Onunka, C., & others. (2023). Survey of wastewater issues due to oil spills and pollution in the Niger Delta area of Nigeria: A secondary data analysis. *Bulletin of the National Research Centre, 47*(116). https://doi.org/10.1186/s42269-023-01073-x
4. Ola, I., Drebenstedt, C., Burgess, R. M., Mensah, M., Hoth, N., & Külls, C. (2024).

DOI: https://doi.org/10.5281/zenodo.16904018

Remediating oil contamination in the Niger Delta region of Nigeria: Technical options and monitoring strategies. *The Extractive Industries and Society, 17*, 101405. https://doi.org/10.1016/j.exis.2024.101405

5. Anarado, C. J. O., Okpoji, A. U., & Anarado C. E. (2023). Bioaccumulation and health risk assessment of lead, cadmium, arsenic, and mercury in blue crabs found in creeks in Bayelsa State of Niger Delta region of Nigeria. *Asian Journal of environmental & ecology.* 21(4)46-59.
6. Cogun, H. Y., Yezererogluja, F. O., Gulf, G. & Karrgin, F. (2006). Metal concentration in fish species from the North East Mediterranean Sea. *Final of Environmental Ministering and Assessment* 121(1):431 – 438.
7. Etesin, U., Udoinyang, E. & Harry, T. (2013). Seasonal variation of physicochemical parameters of water and sediments from Iko River, Nigeria. *Journal of Environment and Earth Science.* 3 (8), 2013.
8. FAO/WHO (2001). Report on the 32nd Session of the Codex Committee on Food Additives and Contaminants, ALINORM 01/12, Beijing, China, 20–24 March 2000. *Joint FAO/WHO Food.*
9. Farombi, E.O.; Adelowo, O.A. & Ajimoko, Y.R. (2007) Biomarkers of oxidative stress and heavy metal levels as indicators of environmental pollution in African Catfish (Clarias gariepinus) from Nigeria, Ogun River. *International Journal of Environmental Research and Public Health* 4, 158-165
10. Garcia-Rico, L., Leyva-Perez, J. & Jara-Marini, M. E. (2007). Content and daily intake of copper, zinc, lead, cadmium, and mercury from dietary supplements in Mexico. *Food Chemistry and Toxicology,* 45:1599-1605.
11. Jan, F. A., Ishaq, M., Khan, S., Ihsanullah, I., Ahmad, I. & Shakirullah, M. (2010), A comparative study of human health risks via consumption of food crops grown on wastewater irrigated soil (Peshawar) and relatively clean water irrigated soil (lower Dir). *Journal of Hazard Materials*, 179: 612–621.
12. Ubong, U. U., Ekwere, I. O., Ekanem, A. N. & Ite, A. E. (2023). Human health risk assessment of Cd, Pb, and Hg from Iko River, Eastern Obolo Local Government Area, Akwa Ibom State, Nigeria. *Africa Journal of Materials and Environmental Science*. 14(20), 384-394.

DOI: https://doi.org/10.5281/zenodo.16904018