Evaluating Ecosystem Pollution Indices of Heavy Metals in Microplastics in Surface Water, South-South, Nigeria

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Abstract
This study evaluates the ecosystem pollution indices of heavy metals in microplastics in surface water (MCPW) from the brackish water estuaries of Woji, Elelenwo, and Okujagu Creeks in Port Harcourt, Rivers State, Nigeria. The analysis, conducted in 2021, focuses on assessing the concentrations of heavy metals (Cd, Cu, Pb, Mn, Ni, Cr, Fe, Hg) in MCPW during dry and wet seasons, alongside the determinations of pollution indices: Pollution Load Index (PLI), Potential Ecological Risk Index (PERI), Geoaccumulation Index (Igeo), and Contamination Factor (CF). Results revealed significant seasonal variations, with higher heavy metal concentrations during the dry season, attributed to reduced dilution and increased runoff in the wet season. Copper (Cu) and nickel (Ni) exhibited moderate contamination, especially in the dry season, while other metals like cadmium (Cd), lead (Pb), and mercury (Hg) were either below detection limits or showed low contamination levels. The PLI and PERI values indicated minimal anthropogenic pollution, with low ecological risk, which was reinforced by the Geoaccumulation and Contamination Factor indices. The seasonal variations in heavy metal concentrations underscore the influence of hydrological dynamics on pollutant dispersion. Despite relatively low contamination, localized enrichment of Cu and Ni highlights the need for continued monitoring, especially considering potential urban runoff and industrial discharge. Overall, the results suggest that MCPW is under low pollution stress, though future land-use changes and human activities may impact the region's pollution trends.

Keywords: *ecosystem, pollution index, Geoaccumulation Index, PERI, anthropogenic pollution*

1. Introduction

The Niger Delta region of Nigeria is a globally significant ecosystem, known for its vast network of rivers, estuaries, and mangrove forests. This area, covering approximately 20,000 square kilometers, serves as the economic backbone of Nigeria due to its rich oil reserves and agricultural activities. However, the region is faced with severe environmental degradation, primarily driven by extensive oil exploration, industrial activities, and urbanization. Oil spills, gas flaring, deforestation, and industrial effluents have resulted in the contamination of aquatic environments, with detrimental consequences for local communities and biodiversity.

One of the most concerning forms of environmental pollution in the Niger Delta is the contamination of water and sediment systems by toxic heavy metals. These metals, such as cadmium (Cd), lead (Pb), mercury (Hg), copper (Cu), manganese (Mn), nickel (Ni), and chromium

(Cr), are introduced into the environment through industrial discharge, oil spills, and improper waste disposal (Nwankwoala et al., 2022; Oghenejoboh & Abiodun, 2018). Due to their persistent nature and ability to bioaccumulate, these metals pose significant risks to aquatic organisms, human health, and the overall ecosystem. Heavy metals can enter the food chain and lead to various health problems, including organ damage, neurological disorders, and cancers in both humans and wildlife.

In addition to heavy metals, microplastic pollution has emerged as a major environmental concern in the Niger Delta. Microplastics, tiny plastic particles less than 5mm in size, are found in vast quantities in the region's water bodies, often originating from plastic waste, oil-related activities, and urban run-off. These microplastics can adsorb and concentrate toxic substances from the surrounding water, including heavy metals. When ingested by aquatic organisms, they can contribute to the accumulation of these toxic substances in the food chain, potentially causing harm to both marine life and humans who rely on these ecosystems for sustenance (Isaac & Nwineewii, 2024). Despite the growing recognition of microplastic pollution globally, the interaction between microplastics and heavy metals in the sediments of the Niger Delta remains underexplored, highlighting a critical gap in current environmental research. Most studies have documented the contamination of sediments in the Niger Delta by heavy metals, with elevated concentrations often observed in areas with significant industrial activities, such as Port Harcourt and its surrounding areas. For example, studies by Olatunji et al. (2021) and Adebiyi & Oladipo (2019) found high concentrations of metals such as Pb, Cd, and Cr in the sediments of industrialized locations in the Niger Delta, which pose potential ecological and health risks. These studies typically focus on heavy metals but do not consider the combined effect of microplastics, which may exacerbate the risk posed by the metals. The co-contamination of sediments by heavy metals and microplastics in the Niger Delta remains an area requiring urgent scientific attention, as it could potentially amplify the ecological risks and pose new challenges for environmental management. This study aims to evaluate the pollution indices (Pollution Load Index -PLI), Geo) of heavy metals within microplastic-contaminated sediments from selected water bodies in Port Harcourt, Rivers State. Specifically, it will focus on Woji Creek, Elelenwo Creek, and Okujagu Creek, all of which are vital to the local ecosystem and are impacted by both industrial and domestic pollution.

2. Materials and Methods

2.1 Study Area

The study focuses on the brackish water estuaries of Woji, Elelenwo, and Okujagu Creeks in Port Harcourt, Rivers State, Nigeria (Figure 1). These creeks are part of the Sombreiro River system, which flows into the North Atlantic Ocean. The tidal influence of the Atlantic brings both freshwater and saltwater species into these creeks (Dibofori-Orji et al., 2019; Ibezim-Ezeani & Ihunwo, 2020). Woji Creek, located along the Bonny River estuary, borders the Port Harcourt-Trans-Amadi industrial area, which hosts various anthropogenic activities. Elelenwo Creek is surrounded by industrial sites such as an abattoir and oil servicing companies. Okujagu Creek, situated on the eastern edge of Port Harcourt, also receives significant pollution from industrial and domestic waste, with activities like dredging and oil bunkering impacting the environment. The shores of both Woji and Okujagu are lined with mangroves and Nypa palms, and the creeks are used for sand extraction, fishing, and boat transportation.

2.2 Sampling

Sediment samples were collected monthly from December 2020 to May 2021, during low tide events, at three stations located approximately 3 km apart along each creek. At each station, three sediment samples were taken from the top 10 cm of the sediment layer using two types of shovels: plastic and steel. These samples were collected approximately 1 meter from the shore to ensure consistency. The plastic and steel shovels were used to distinguish between samples for microplastics and metal analysis. After collection, the sediment samples were placed in well-labeled foil bags indicating the sampling point and time, then stored in ice chests at 4°C until they were transported to the laboratory for further analysis.

2.3 Metal Analysis in Microplastic in Water Samples

Microplastic samples were air-dried in the laboratory at room temperature, pulverized, and sieved through a 2 mm mesh to remove larger particles. A 2 g sample of microplastic-contaminated sediment (MCPQ) was placed into a 50 mL beaker and subjected to partial acid digestion according to the US EPA 3050B method (USEPA, 1996), as outlined by Isaac & Nwineewii (2024) and Vedolin et al. (2018). The digestion procedure involved adding 5 mL of concentrated nitric acid (HNO3), 3.0 mL of 30% hydrogen peroxide (H2O2), and 10 mL of hydrochloric acid (HCl) to the sample in the beaker. The mixture was heated at 90°C on a Corning PC-351 hot plate, under medium to low heat, until about 5 mL of concentrated extract remained. Once the sample cooled for approximately 30 minutes, it was filtered and transferred into a 50 mL volumetric flask, where it was made up to the 50 mL mark using distilled water.

Metal concentrations, including cadmium (Cd), copper (Cu), chromium (Cr), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and mercury (Hg), were determined using the GBC 908PBMT Flame Atomic Absorption Spectrophotometer (FAAS). Each sample was aspirated individually to quantify the metal levels. The concentrations were reported in mg/kg.

2.3 Ecosystem Pollution Indices

2.3.1 Pollution Load Index (PLi) and PERI (Pollution Load Index) Associated with MCPW

The Pollution Load Index (PLi) was used to assess the degree of contamination in MCPW based on the concentration of heavy metals. The index was calculated by comparing the concentration of each metal in the sediment sample to the corresponding background or baseline concentration.

$$PLi = \frac{\text{Cmeasured}}{\text{Cbackground}}$$

where:

- $C_{measured}$ is the measured concentration of a given metal (mg/kg), and
- $C_{background}$ is the natural background concentration (mg/kg) obtained from an uncontaminated reference site (Håkanson, 1980).

Pollution Load Index (PERI) was calculated the calculation as the ratio of the sum of pollutant concentrations to the sediment quality standards. This allows for the assessment of pollution in both dry and wet conditions by calculating the concentration of each pollutant and evaluating its impact on the ecosystem.

$$\text{PERI} = \frac{\sum \text{Cmetal}i}{\sum \text{Cstandard}i}$$

where:

- Cmetali is the concentration of metal iii in the sample, and
- Cstandardi is the reference standard for metal iii (Håkanson, 1980).

2.4 Geoaccumulation Index (Igeo) Associated with MCPW

The Geoaccumulation Index (Igeo) is a tool used to assess the degree of contamination of sediments by comparing current metal concentrations to pre-industrial levels.

$$\mathbf{Igeo} = \frac{\mathbf{log2}\mathrm{Cmeasured}}{1.5\mathbf{x}\ \mathbf{Cbackground}}$$

where:

- **C***measured* is the measured concentration of the metal,
- **C***background* is the natural background concentration, and
- The factor 1.5 accounts for natural variations in the environment (Müller, 1969).

Igeo values are interpreted according to established contamination classes ranging from unpolluted (Igeo ≤ 0) to extremely polluted (Igeo >3).

2.5 Contamination Factor (CF) Associated with MCPW

The Contamination Factor (CF) is used to determine the level of contamination of sediments by comparing the concentration of metals in the samples to the background concentrations. It is commonly used to evaluate the degree of contamination for individual metals.

$$\boldsymbol{CF} = \frac{\mathrm{Cmeasured}}{\mathrm{Cbackground}}$$

Where:

- Cmeasured is the measured concentration of the metal in the sediment sample.
- Cbackground is the background concentration of the metal.

The CF values are interpreted as follows:

- CF≤1: Low contamination
- 1<CF≤3: Moderate contamination
- 3<CF≤6: Considerable contamination
- CF>6: Very high contamination

These indices (PLi, Igeo, and CF) provide essential insights into the degree of contamination and the ecological risk posed by the presence of heavy metals in sediments, especially concerning their interaction with microplastics (MCPW).

3. Results and Discussion

3.1 Heavy Metals in MCPW

The results indicate significant seasonal variations in heavy metal concentrations in MCPW, with generally higher values observed during the dry season compared to the wet season. Isaac and Israel (2024) reported this trend earlier. This trend is likely due to reduced dilution effects in the dry season and increased surface runoff in the wet season, which could transport contaminants away from the sampling sites (Isaac & Israel, 2024; Obasi & Akudinobi, 2020).

Cadmium (Cd), Lead (Pb), and Copper (Cu)

Cadmium and lead were below detection limits in all samples, suggesting minimal anthropogenic contributions from these metals (Fig. 1). However, copper concentrations exceeded sediment quality guidelines (CHR: 30.24 mg/kg) during the dry season, particularly at Woji and Okujagu, but dropped significantly in the wet season (Fig. 1). This reduction could be attributed to increased mobilization and dilution (Olatunji et al., 2021).

Manganese (Mn), Nickel (Ni), Chromium (Cr), and Iron (Fe)

Manganese concentrations were highest at Woji during the dry season (133.22 mg/kg) and significantly lower in the wet season Fig. 2. Elevated Mn levels are associated with industrial discharges and weathering of parent rock materials (Adebiyi & Oladipo, 2019). Nickel and chromium exceeded the CHR guideline limits in some locations during the dry season, indicating potential contamination sources such as industrial effluents or metal corrosion (Nwankwoala et al., 2022). Iron concentrations were notably high in all locations, particularly in the dry season, suggesting natural lithogenic sources but possibly exacerbated by industrial activities.

Mercury (Hg) and Environmental Implications

Mercury was below detection limits in all samples, indicating minimal contamination risk. The variations observed in other heavy metals could pose ecological risks, especially for benthic organisms that bioaccumulate toxic elements. Previous studies in the Niger Delta have reported similar seasonal trends, reinforcing concerns about industrial pollution and urban runoff affecting sediment quality (Oghenejoboh & Abiodun, 2018).

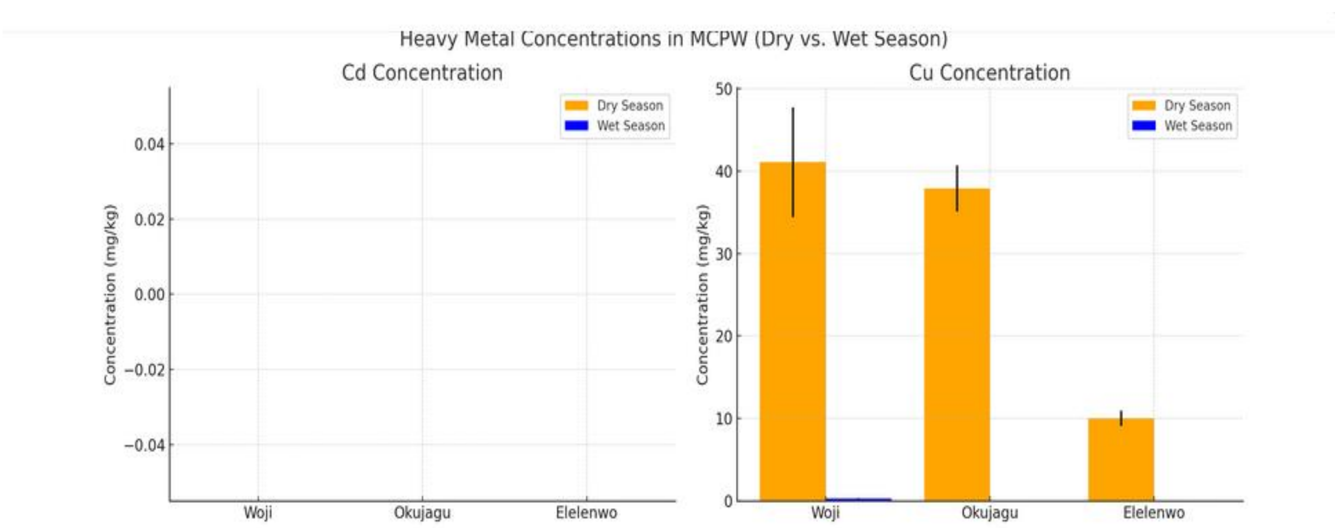

Fig. 1: Concentrations of heavy metals (Cd and Cu) in MCPW during dry and wet seasons

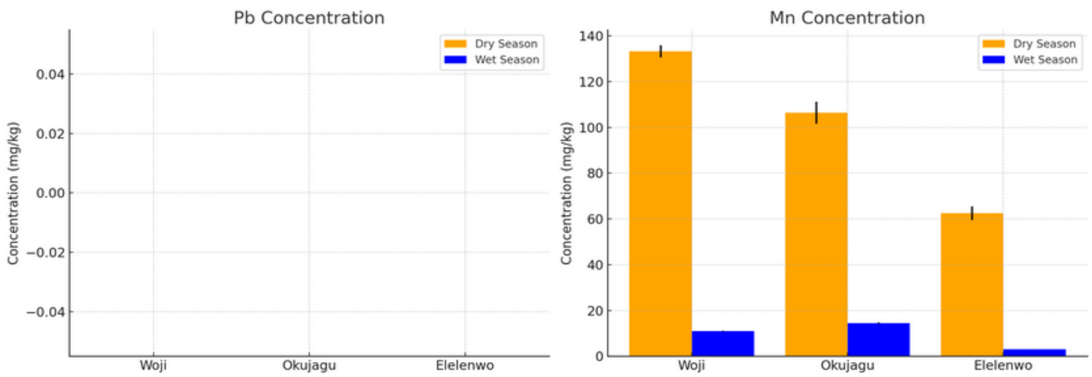

Fig. 2: Concentrations of heavy metals (Pb and Mn) in MCPW during dry and wet seasons

3.2 Pollution Load Index (PLI) and Potential Ecological Risk Index (PERI) associated with MCPW

Table 1presents the Pollution Load Index (PLI) and Potential Ecological Risk Index (PERI) for Woji, Okujagu, and Elelenwo in MCPW during both dry and wet seasons. The PLI values for all locations are significantly low, with values ranging from 0.0536 (Woji) to 0.0137 (Okujagu) in the dry season and from 0.0034 (Woji) to 0.0008 (Okujagu) in the wet season. These values indicate low levels of pollution, suggesting minimal anthropogenic contamination in the study area. However, the observed decrease in PLI during the wet season implies dilution effects due to increased rainfall and surface runoff (Kumar et al., 2021).

The PERI values further reinforce the low pollution levels, with the highest value recorded at Woji (18.11) in the dry season, which drops dramatically to 1.27 in the wet season. Similar trends are observed in Okujagu and Elelenwo. These findings align with studies by Wang et al. (2020) that showed seasonal variations in ecological risks due to hydrological changes affecting the mobility and bioavailability of pollutants. Compared to research in other urban water bodies, such as Chukwu et al. (2019), where PERI values exceeded 100 in industrial zones, MCPW exhibits significantly lower ecological risk levels.

Table 1: Pollution Load Index (PLI) and Potential Ecological Risk (PERI) in MCPW during dry and wet

Pollution Load Index (PLI)				
Location	**PLI (Dry)**	**PLI (Wet)**	**PERI (Dry)**	**PERI (Wet)**
Woji	0.0536	0.0034	18.11	1.27
Okujagu	0.0137	0.0008	14.62	1.11
Elelenwo	0.0367	0.0033	6.71	0.76

3.3 Geoaccumulation Index (Igeo) associated with MCPW

The Geoaccumulation Index (Igeo) values in Table 4 reveal that heavy metals such as Cd, Pb, and Fe have negative Igeo values across all locations, indicating unpolluted conditions. However, Cu and Ni show slightly positive values in the dry season, particularly at Woji (0.13 for Cu, 0.15 for Ni), indicating minimal enrichment but not at pollution levels. These findings are consistent with those of Ikpe et al. (2022), who found slight Cu enrichment in sediment samples from urban rivers in Nigeria.

During the wet season, there is a notable reduction in Igeo values, particularly for Cu, Mn, and Cr, suggesting that these metals experience dilution or are transported downstream due to increased surface runoff. A study by Li et al. (2021) in the Yangtze River basin also observed similar seasonal dilution effects on sediment-associated heavy metals. Compared to studies in heavily polluted regions such as the Niger Delta (Ogunfowokan et al., 2018), where Igeo values for Cu and Cr exceeded 3, the values in MCPW are significantly lower, reinforcing the relatively lower pollution burden of this waterway.

Table 2: Geoaccumulation Index (Igeo) in MCPW during dry and wet

Location	Igeo (Cd)	Igeo (Cu)	Igeo (Pb)	Igeo (Mn)	Igeo (Ni)	Igeo (Cr)	Igeo (Fe)	Igeo (Hg)
Geoaccumulation Index (Igeo)- Dry Season								
Woji	-8.81	0.13	-14.87	-3.26	0.15	-1.64	-1.99	-
Okujagu	-8.81	0.01	-14.87	-3.58	-0.26	-5.89	-2.48	-
Elelenwo	-8.81	-1.9	-14.87	-4.35	-1.27	-1.51	-2	-
Geoaccumulation Index (Igeo) -wet Season								
Woji	-8.81	-4.57	-14.87	-7.41	-3.47	-9.97	-6.23	-
Okujagu	-8.81	-7.43	-14.87	-7.01	-3.61	-9.97	-14.99	-
Elelenwo	-8.81	-7.43	-14.87	-9	-5.96	-4.5	-4.75	-

3.4 Contamination Factor (CF) associated with MCPW

Contamination Factor (CF) values are illustrated in Table 5, for heavy metals in MCPW. In the dry season, Cu exhibits the highest CF values, particularly at Woji (1.6424), indicating moderate contamination levels. Ni follows a similar trend, with Woji and Okujagu showing CF values above 1. The presence of moderate contamination in these locations may be linked to urban runoff, domestic effluents, or minor industrial discharges, as highlighted by Akinola et al. (2020) in their study of Lagos Lagoon. In contrast, Cd, Pb, and Fe exhibit extremely low CF values (<1), signifying no significant contamination. During the wet season, all CF values drop considerably, with Cu, Mn, and Cr reaching near-zero levels, reinforcing the idea that seasonal hydrological variations influence pollutant dispersion (Zhang et al., 2019).

These findings suggest that MCPW is currently under low pollution stress, with heavy metal contamination largely controlled by seasonal hydrological dynamics. The ecological risk remains minimal, but localized Cu and Ni enrichment warrant continuous monitoring. The drastic seasonal variations indicate that stormwater management and erosion control measures could further mitigate pollution risks. In comparison with previous studies in Nigeria and globally, MCPW appears less impacted by industrial pollution compared to other urban water bodies. However, future land use changes or increased anthropogenic activities may alter these trends, emphasizing the need for long-term environmental monitoring.

Table 3: Contamination Factor (CF) for MCPW during dry and wet

Location	CF (Cd)	CF (Cu)	CF (Pb)	CF (Mn)	CF (Ni)	CF (Cr)	CF (Fe)	CF (Hg)
Contamination Factor (CF) – dry season								
Woji	0.0033	1.6424	0.00005	0.1567	1.6615	0.3192	0.2981	0.01
Okujagu	0.0033	1.5152	0.00005	0.1251	1.2515	0.00002	0.1602	0.01
Elelenwo	0.0033	0.4012	0.00005	0.0735	0.6235	0.3612	0.2952	0.01
Contamination Factor (CF) – wet season								
Woji	0.0033	0.0132	0.00005	0.0129	0.1335	0.00002	0.0236	0.01
Okujagu	0.0033	0.00004	0.00005	0.017	0.119	0.00002	0.00006	0.01
Elelenwo	0.0033	0.00004	0.00005	0.0035	0.022	0.0362	0.0717	0.01

Conclusions and Recommendations

The study highlights the influence of seasonal changes on heavy metal concentrations in MCPW sediments. The elevated levels of Cu, Mn, Ni, and Fe during the dry season may indicate anthropogenic inputs, while the lower wet-season values suggest dilution effects. The MCPW exhibits low pollution levels, as indicated by significantly low PLI values, minimal ecological risk based on PERI, and negative Igeo values for most metals. However, slight enrichment of Cu and Ni was observed, particularly in Woji and Okujagu during the dry season, suggesting localized sources of contamination. The wet season showed a marked reduction in pollution indices, highlighting the influence of rainfall and runoff in dispersing contaminants. Compared to other urban water bodies, MCPW appears to have a lower pollution burden, though continued urbanization may alter this trend.

To ensure the sustainability of MCPW, regular environmental monitoring is recommended to track changes in pollution levels. Improved stormwater management strategies, such as biofiltration and enhanced drainage systems, should be implemented to control heavy metal runoff. Further studies should be conducted to identify specific pollution sources, particularly for Cu and Ni, to develop targeted mitigation measures. Public awareness campaigns on proper waste disposal, along with stricter enforcement of environmental regulations, will help minimize contamination risks. Additionally, integrating climate-adaptive water management strategies will enhance the resilience of MCPW against future pollution threats.

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