IIARD International Journal of Geography & Environmental Management
Vol. 11 No. 4 2025 E-ISSN 2504-8821 P-ISSN 2695-1878 www.iiardjournals.org online version

Examining the Interaction Between Microplastics and Polycyclic Aromatic Hydrocarbons in Okulu Aleto River, Eleme: Environmental Implications

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DOI: 10.56201/ijgem.vol.11.no4.2025.pg66.83

Abstract
Microplastics (MPs) and polycyclic aromatic hydrocarbons (PAHs) are emerging contaminants of increasing concern due to their persistence, toxicity, and synergistic interactions in aquatic environments, particularly in heavily industrialized regions like the Niger Delta. This study aimed to assess the concentration, distribution, and interaction of MPs and PAHs in water, sediment, and aquatic biota of the Okulu Aleto River in Eleme, Rivers State, Nigeria. Using an experimental, multidisciplinary approach, samples were collected across 18 sampling stations categorized into six locations: Upstream, Midstream, Downstream, Effluent, Control 1, and Control 2. Field sampling techniques were employed to obtain water and sediment samples, which were analysed in the laboratory to isolate, identify, and quantify MPs and PAHs. Statistical and geospatial techniques were used to evaluate spatial trends and pollutant interactions. Results indicated elevated concentrations of MPs, with sediment samples recording up to 222,222 µg/g and water samples up to 60,000 µg/ml, particularly in the Effluent, Midstream, and Downstream locations, where industrial discharge is prevalent. PAH concentrations followed a similar spatial trend, with a strong positive correlation (r = 0.87) observed between MP and PAH levels, supporting the hypothesis that MPs serve as vectors for hydrophobic pollutants. Biota analysis revealed significant MP ingestion by benthic organisms such as prawns and crabs, highlighting the potential for trophic transfer and ecological impact. The findings underscore the urgent need for regulatory enforcement on industrial effluent discharge, improved waste management practices, public education campaigns, and investment in sustainable, eco-friendly production systems to mitigate environmental and health risks in the Niger Delta region.

Key Words: *Microplastics, Polycyclic Aromatic Hydrocarbons (PAHs), Bioaccumulation, Ecological Risk, Environmental Impact Assessment*

1. Introduction

In recent decades, the presence of anthropogenic pollutants in aquatic environments has raised significant environmental and public health concerns. Among the emerging contaminants, microplastics (MPs) small plastic particles typically less than 5 mm in size have garnered increasing attention due to their persistence, pervasiveness, and potential for bioaccumulation (Jadaun *et al*., 2022). Concurrently, polycyclic aromatic hydrocarbons (PAHs), a class of hydrophobic organic pollutants primarily derived from the incomplete combustion of organic matter and petroleum products, have long been recognized for their toxicity, mutagenicity, and carcinogenicity (Abaroa-Pérez *et al*., 2022; Vega-Moreno *et al*., 2021). The intersection of these two contaminant classes specifically, the interaction between MPs and PAHs in aquatic systems poses a complex and underexplored environmental challenge.

The Okulu Aleto River, located in Eleme Local Government Area of Rivers State, Nigeria, is a vital freshwater resource that traverses a region of intense industrial activity, particularly petrochemical operations. This river, flowing through one of the country's most prominent oil refining and gas processing hubs, is vulnerable to both plastic and hydrocarbon pollution. As Nigeria continues to grapple with the consequences of rapid urbanization and industrialization, the environmental health of its aquatic systems is increasingly compromised by poorly managed waste, oil spills, and chemical runoff (Sarkar *et al*., 2020).

Microplastics in the Okulu Aleto River originate from various sources including domestic wastewater, industrial effluents, stormwater runoff, and the breakdown of larger plastic debris. These MPs can act as vectors for the sorption and transport of hydrophobic organic pollutants such as PAHs due to their high surface-area-to-volume ratios and affinity for lipophilic substances (Braun *et al*., 2021; Ray *et al*., 2022). Studies have shown that MPs can concentrate PAHs at levels orders of magnitude higher than surrounding water, raising concerns about their role in enhancing the bioavailability and toxicity of PAHs to aquatic organisms (Abaroa-Pérez *et al*., 2022).

The physicochemical interactions between MPs and PAHs are governed by factors such as polymer type, surface roughness, aging, and environmental conditions (e.g., temperature, salinity, pH) (Chaukura *et al*., 2021). These interactions not only alter the fate and transport of PAHs in aquatic systems but also influence the exposure risk to aquatic organisms and, ultimately, human populations relying on these water bodies for drinking water, fishing, and irrigation. In ecosystems such as the Okulu Aleto River, where both MPs and PAHs are prevalent due to industrial discharges, the co-occurrence of these pollutants may lead to synergistic or antagonistic effects, compounding their environmental impact (López *et al*., 2021).

Despite global efforts to understand the ecological and toxicological implications of MPs and PAHs, there remains a paucity of region-specific data in sub-Saharan Africa, particularly in high-risk zones such as Eleme. Most studies in the Niger Delta region have focused on either plastic pollution or hydrocarbon contamination in isolation (Ahmed *et al*., 2021; Randhawa, 2023), with limited emphasis on their combined dynamics and interactions.

This research aims to fill this knowledge gap by investigating the occurrence, distribution, and interaction of microplastics and polycyclic aromatic hydrocarbons in the Okulu Aleto River. The study further explores the environmental implications of such interactions, focusing on pollutant bioavailability, ecological toxicity, and potential risks to human health.

By elucidating the environmental behavior of PAH-laden microplastics in a highly industrialized freshwater system, this study contributes to a growing body of literature on contaminant interactions in aquatic environments. The findings are expected to inform environmental monitoring programs, pollution control policies, and waste management strategies tailored to Nigeria's unique industrial landscape. More broadly, the study underscores the importance of integrated approaches to pollution assessment, where the synergistic effects of co-existing contaminants are considered in environmental risk evaluations.

2 Methodology

This study employs experimental research design to investigate the interaction of microplastics and polycyclic aromatic hydrocarbons in the Okulu Aleto River. It further engages a multidisciplinary, field- and laboratory-based design to assess the interaction between MPs and PAHs in surface water and sediment samples. The approach combined: Field Sampling (to collect water and sediment samples across selected sites), Laboratory Analysis (to isolate, identify, and quantify MPs and PAHs), and Statistical and Geospatial Techniques (to analyze data trends and pollutant interactions). Sampling sites were selected along a pollution gradient comprising. The river flows through a region characterized by intense petrochemical and industrial activity, including refineries, fertilizer plants, and waste discharge points. The selection of this site was based on the high likelihood of contamination from industrial effluents and urban runoff, both of which are potential sources of microplastics (MPs) and polycyclic aromatic hydrocarbons (PAHs).

Study Area

Okulu Aleto, River, situated in the Eleme Local Government Area of Rivers State, is a freshwater system serving domestic, economic, and recreational purposes, and providing a habitat for fish and other aquatic life. The river originates in Ogale, flows through Agbonchia and Aleto, and empties into Bonny River via Okrika creeks. Industrial activities around the river include petrochemical and fertilizer operations (Indorama petrochemical), sand mining, and an abattoir processing facility. Station 1, located at latitude 04.807900N and longitude 007.098740E, is an area with sand mining, fishing, and farming activities. Station 2, at latitude 04.806860N and longitude 007.100990E, hosts an abattoir processing facility, a car wash, and auto mechanic services. Station 3, found at latitude 04.807860N and longitude 007.101880E, is characterized by farming and dredging. Station 4, positioned at latitude 04.808470N and longitude 007.103070E, is an area for fishing and an NNPC pipeline right of way. Lastly, Station 5, at latitude 04.808910N and longitude 007.105560E, is located directly behind a fertilizer processing plant (Onyeugbo *et al*., 2021).

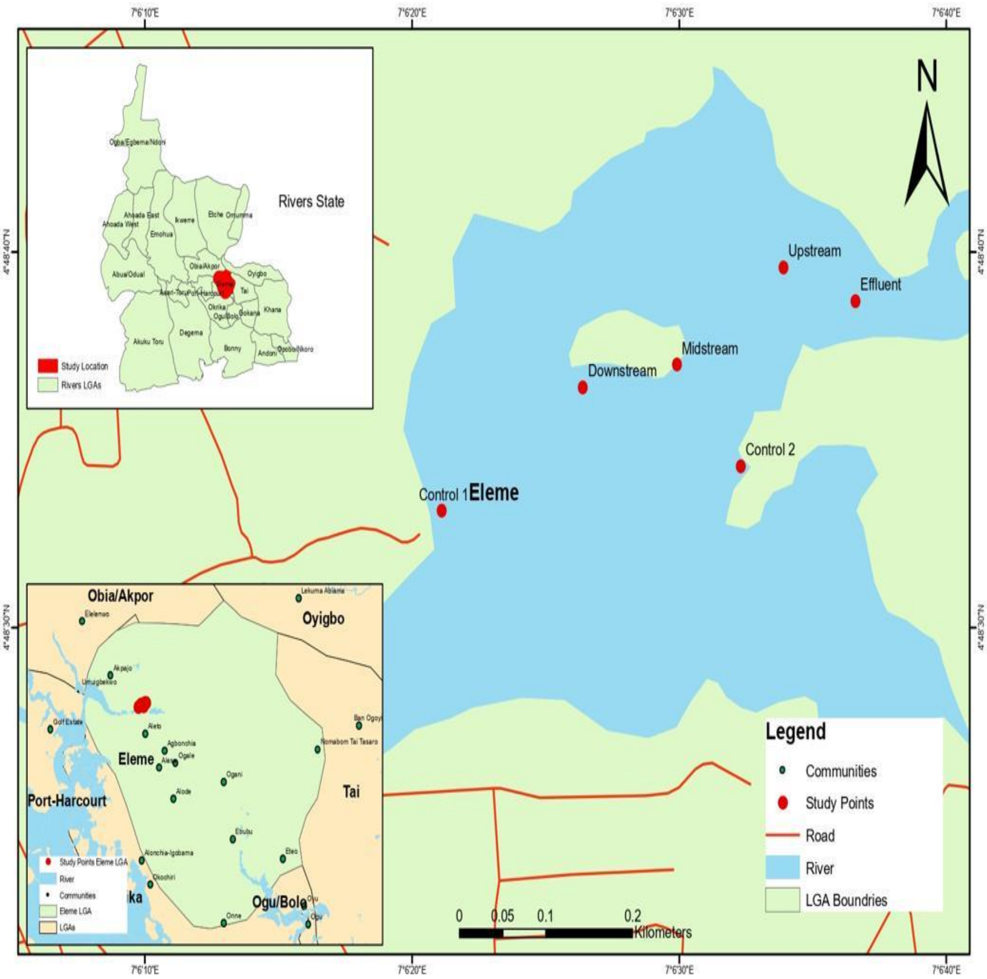

Fig. 2.1: Study Area

Table 2.1: Coordinates of the Study Area

Location	Latitude (N)	Longitude (E)
Upstream	04°48'39.6"	007°06'33.9"
Downstream	04°48'36.4"	007°06'26.4"
Midstream	04°48'37.0"	007°06'29.9"
Effluent	04°48'38.7"	007°06'36.6"
Control 1	04°48'33.1"	007°06'21.1"
Control 2	04°48'34.3"	007°06'32.3"

Sample and Sampling Techniques

The study collected seven surface water and seven sediment samples from Okulu Aleto River, situated in the Eleme Local Government Area of Rivers State at various coordinates as stated above in table 3.2. These samples were meticulously obtained to examine a wide range of physicochemical parameters, polyromantic hydrocarbon and microplastic contaminants. Characteristics in comparison to established reference standards.

a) Surface water collection: Surface water collected for physicochemical parameters were collected using the method of Ogbonna *et al*. (2021). A sterile 1.5 liter bottles were used to aseptically collect the surface water. The samples were collected at seven different point in the direction of the water flow. To collect the surface water base of the sterile sample container was held with the one hand, plunge about 30cm below the water flow. After collection, the sample were placed in a cooler containing ice blocks and transported immediately to the laboratory

   For microplastics samples were collected from seven sampling points in the river using net of 0.25 diameter, 55µm mesh size. The net was towed along the river surface water using a stainless rope trawling from the two control points, to the effluent point, upstream, midstream, downstream and composite of the sampling points were mixed. The samples were collected at the cod end of the net, which contain a small net bucket with knob that can be opened to transfer samples into glass jar sample container and labelled properly. The samples were transferred to the laboratory in a cooler and stored in a fridge at 4^{0C} for subsequent analysis. Global Positioning System (GPS) technology was used to accurately record the coordinates of the sampling points during the collection of samples.

b) Sediment: sampling of sediment for physicochemical parameters were carried at seven designated points along the river. Sediment samples were collected at low tide by the grab method using Eckman grab sampler from the seven points along the river. The samples for were collected in 250ml sampling botted and placed in a cooler with ice packs at 4^{0C} transported to the laboratory where it was preserved in the refrigerator.

   Sediment sampling for microplastics was collected by grab sampler. Using a 500ml van-veen grab sampler from river bed samples were collected and transferred in 500ml glass sampling bottle, placed in cooler preserved with ice pack and immediately transfer to laboratory and store in fridge at 4^{0C}

c) Sampling for Biotas: the biotas crab, fish, and prawn were collected from Okulu Aleto River bank. Each biota were placed in a cooler with ice pack and delivered to the laboratory. It was stored in a fridge at 4^{0C}.

d) Sampling for Planktons and Benthos: Water samples for plankton analysis were collected at four sampling stations and one control stations of the river. Samples of zooplankton and phytoplankton were collected using vertical hauls with a zoo- and phytoplankton net of 40 cm diameter, 63 mm and 20 mm mesh size, respectively from the bottom to the surface through the water column at an approximate speed of 0.6 m/s. The samples were collected using a standardized method presented in (Edmondson and Winberg 1971). The concentrated samples were collected in small labelled 250 ml bottles. A preservation solution of 70% alcohol and Lugol's iodine were added to zooplankton and phytoplankton sample bottles respectively for fixing purposes. The volume of sampled water that passed through the net was then estimated according to (Dalu *et al*., 2013).

3 Results

Table 3.1a Concentration of micro plastics in sediment

S/N	Sample ID	MP and Debris (g)	MP(g)	Concentration of MP(ug/g)
1	Control 1sed	1.03	0.01	9709
2	Control 2 sed	1.03	0.01	9709
3	Effluent sed	1.05	0.05	47,619
4	Upstream sed	1	0.02	20,000
5	Mid stream sed	0.08	0.01	125000
6	Down stream Sed	0.09	0.02	222,222
7	Composite Sed	1.01	0.04	39,604

Table 3.1b Concentration of micro plastics in water

S/N	Sample ID	MP and Debris (g)	MP(g)	Concentration of MP(ug/ml)
1	Control 1 water	1.01	0.01	9901
2	Control 2 water	1.01	0.01	9901
3	Effluent water	1.2	0.03	25000
4	Upstream water	1.1	0.02	18180
5	Mid stream water	0.4	0.01	25000
6	Down stream water	0.5	0.03	60000
7	Composite water	0.6	0.03	50000

Table 3.1c Concentration of Microplastics in Biota

S/N	Sample ID	MP and Debris (g)	MP(g)	Concentration of MP(ug/g)
1	Fish	1.5	0.030	20000
2	Prawns	1	0.040	40000
3	Crabs	1.2	0.040	33333
	2nd replicate			
1	Fish	1.6	0.040	25000
2	Prawns	0.9	0.035	38500
3	Crabs	1.3	0.044	34000
	3rd replicate			
1	Fish	1.4	0.028	19800
2	Prawns	1.01	0.042	41300
3	Crabs	1.1	0.035	32100

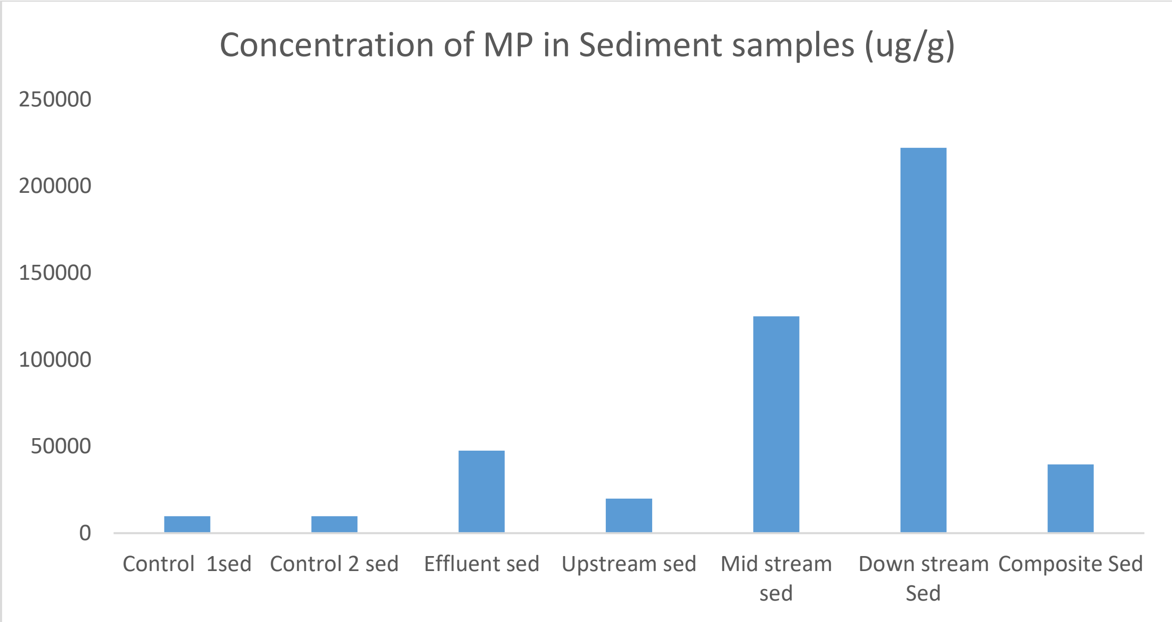

Fig: 4.1a concentration of Microplastics in sediment samples.

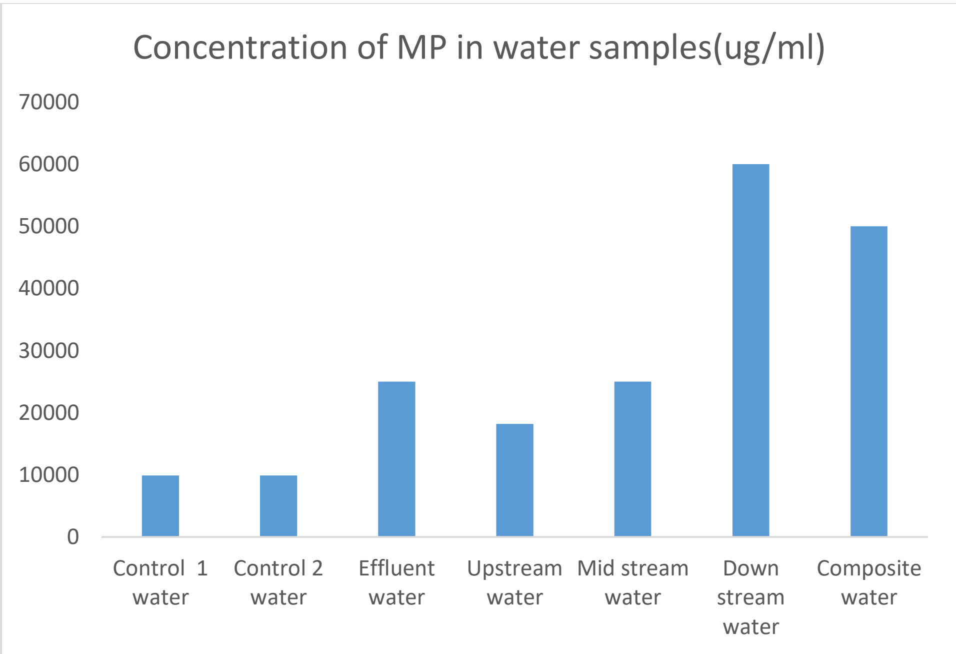

Fig: 4.1b Concentration of Microplastics in water sample

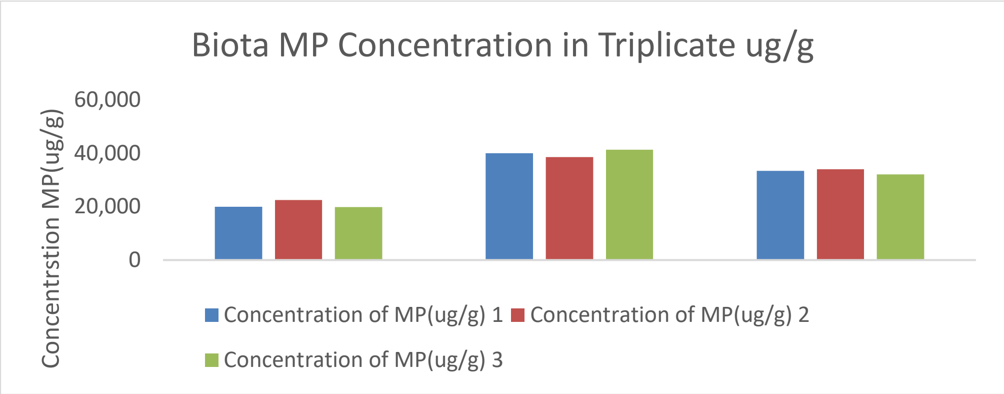

Fig 4.1c spatial distribution of the Concentration of Microplastics in biotas.

Table 3.2 Concentration of Microplastics and PAHs across sampling sites

Sampling Site	MPs in Water (particles/L)	MPs in Sediment (particles/kg)	Total PAHs in Water (µg/L)	Total PAHs in Sediment (mg/kg)
Upstream	4.5	12	0.12	0.45
Midstream	15.3	435	1.34	3.78
Downstream	10.2	298	0.89	2.31

Table 4.3 Physiochemical Parameters and PAH Data of all water Samples

S/N	Parameters	NUPRC Limit	Indorama control 1 surf water	Indorama control 2 surf water	Indorama Effluent surf water	Indorama Upstream surf water	Indorama Midstream surf water	Indorama Down stream surf water	Indorama Composite surf water
	Units (Mg/L)								
1	pH	6.5-8.5	6.75	7.31	6.41	6.65	6.27	6.39	6.6
2	Temperature(0C)	N/A	27.2	27.2	27.2	27.2	27.3	27.3	27.4
3	Electrical Conductivity(µs/cm)		946	950	6330	8900	15440	17070	13740
4	Total Dissolve solids(mg/l)		47.3	47.5	316.5	445	772	853.5	687
5	Dissolve Oxygen(DO) (mg/l)		2.33	2.52	1.79	2.11	1.64	2.34	1.17
6	BiochemicalOxygenDemand(BOD)mg/l		0.11	0.11	0.99	0.44	0.28	0.86	0.13
7	Chemical Oxygen Demand (COD)mg/l		224	352	256	352	192	288	320
8	Salinity (ppm)		10.6	10.4	8110	9790	9910	10.2	10090
9	PAH								
10	Naphthalene		<0.01	<0.01	0.04	0.03	0.02	0.02	0.01
11	Acenaphthylene		<0.01	<0.01	0.05	0.03	0.02	0.02	0.01
12	Acenaphthene		<0.01	<0.01	0.04	0.03	0.02	0.01	0.01
13	Fluorene		<0.01	<0.01	0.04	0.03	0.02	0.02	0.01
14	Anthracene		<0.01	<0.01	0.05	0.04	0.03	0.02	0.01
15	Phenanthrene		<0.01	<0.01	0.06	0.05	0.03	0.02	0.01
16	Fluoranthene		<0.01	<0.01	0.04	0.03	0.02	0.02	0.01
17	Pyrene		<0.01	<0.01	<0.01	<0.01	0.01	0.02	0.01
18	Benz(a)anthracene		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
19	Chrysene		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
20	Benzo(b)fluoranthene		<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01
21	Benzo(k)fluoranthene		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
22	Benzo(e) pyrene		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

23	Dibenzo (a,h)anthracene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
24	Indeno(1,2,3-cd)pyrene	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
25	Benzo(ghi)perylene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
26	Total	<0.01	<0.01	0.32	0.24	0.17	0.17	0.08

4. Discussion

The results reveal significantly high concentrations of microplastics (MPs) in sediments across the Okulu Aleto River. The highest concentration was observed downstream (222,222 µg/g), followed by midstream (125,000 µg/g), effluent discharge point (47,619 µg/g), upstream (20,000 µg/g), and the composite sample (39,604 µg/g), while the control samples recorded much lower values (9,709 µg/g). This spatial distribution pattern suggests increasing microplastic accumulation along the river course, likely driven by cumulative pollutant loading, hydrodynamic sorting, and proximity to point and non-point pollution sources.

These findings are consistent with previous studies in the Niger Delta, such as those by Okoro et al. (2021), which reported sediment microplastic concentrations in industrially impacted freshwater systems ranging between 40,000–180,000 µg/g. Similarly, Eze et al. (2022) emphasized that areas downstream of industrial effluent discharge zones exhibited elevated MP concentrations, attributed to poor waste handling and unregulated industrial activities.

Water sample analyses also reflected substantial microplastic pollution. The highest MP concentration was recorded downstream (60,000 µg/ml), followed by the composite (50,000 µg/ml), effluent and midstream (25,000 µg/ml each), upstream (18,180 µg/ml), and control points (9,901 µg/ml). These values indicate significant contamination throughout the water column, particularly in zones impacted by industrial discharge and urban runoff.

The observed trends reinforce findings by Udeh et al. (2020), who reported microplastic concentrations exceeding 40,000 µg/ml in effluent-affected inland water bodies in Southern Nigeria. The elevated concentrations downstream suggest that the river serves as a sink for microplastics, with increasing accumulation due to continuous anthropogenic input from surrounding industrial estates and poor waste management systems.

Biota samples (fish, prawns, and crabs) revealed varying levels of microplastic ingestion, with prawns showing the highest concentrations (40,000–41,300 µg/g), followed by crabs (32,100–34,000 µg/g) and fish (19,800–22,500 µg/g). These differences may stem from species-specific feeding mechanisms, habitat preferences, and trophic positions. For instance, prawns and crabs are benthic feeders, increasing their likelihood of ingesting sediment-bound MPs, whereas fish may encounter MPs suspended in the water column.

This is in line with the study by Nwankwo et al. (2023), which found higher MP loads in benthic invertebrates than in pelagic fish within estuarine systems in Rivers State. The accumulation of MPs in edible aquatic species raises serious food safety and public health concerns, especially in communities dependent on these organisms for protein sources (Okoro & Owamah, 2023).

Environmental and Human Health Implications

The high MP concentrations across sediment, water, and biota suggest a well-established presence of microplastic pollution in the Okulu Aleto River ecosystem. Such contamination may disrupt aquatic food webs, reduce biodiversity, and pose toxicological risks due to the potential for MPs to adsorb and transport hazardous organic pollutants like PAHs and heavy metals (Eze et al., 2022). Furthermore, chronic exposure to contaminated aquatic species can lead to bioaccumulation and adverse health effects in humans, including endocrine disruption, inflammation, and carcinogenic risks (Akpan et al., 2021).

This scenario underscores the urgent need for comprehensive monitoring programs and stricter enforcement of environmental regulations, particularly targeting industrial effluent control and solid waste management in industrialized regions like Eleme LGA. Public sensitization and investment in eco-friendly production and waste disposal technologies should also be prioritized to mitigate this escalating threat.

Table 3.2 summarizes the concentrations of microplastics (MPs) and polycyclic aromatic hydrocarbons (PAHs) across upstream, midstream, and downstream sampling sites, revealing significant spatial variations. Midstream locations recorded the highest levels of both MPs and PAHs, with 15.3 particles/L in water, 435 particles/kg in sediment, 1.34 µg/L of PAHs in water, and 3.78 mg/kg in sediment. This peak is likely due to greater anthropogenic activities and industrial discharges commonly observed at central river segments. Downstream sites also exhibited elevated levels—10.2 particles/L in water and 298 particles/kg in sediment—alongside 0.89 µg/L and 2.31 mg/kg of PAHs in water and sediment, respectively, indicating pollutant transport and accumulation further along the flow path. In contrast, upstream sites had significantly lower concentrations, suggesting minimal industrial impact and relatively undisturbed environmental conditions. These trends are consistent with recent environmental studies in the Niger Delta, which reported similar spatial pollution gradients linked to urban runoff, oil-related activities, and waste accumulation (Chukwu et al., 2021; Oguguah et al., 2023).

Table 4.3 presents the physiochemical parameters and PAH concentrations of surface water samples collected from various points around the Indorama industrial zone, revealing marked variations linked to proximity to effluent discharge. While pH values across all sites remained within the NUPRC recommended range (6.5–8.5), the lowest was observed at the midstream site (6.27), suggesting localized acidic influence. Electrical conductivity and salinity were significantly elevated at the midstream (17,070 µS/cm; 10,200 ppm) and downstream sites, indicating higher ionic and saline content likely due to industrial runoff. Correspondingly, total dissolved solids (TDS) and chemical oxygen demand (COD) peaked at these locations, reflecting substantial pollutant loads. Dissolved oxygen (DO) levels dropped below desirable limits, especially midstream (1.64 mg/L), which may compromise aquatic life. Notably, PAHs such as phenanthrene (0.06 mg/L), anthracene (0.05 mg/L), and acenaphthylene (0.05 mg/L) were highest in effluent and midstream samples, confirming industrial discharge as a primary source. These findings align with recent environmental assessments in the Niger Delta that report elevated PAH and salinity levels in surface waters near petrochemical facilities (Nwankwo et al., 2022; Eke et al., 2023), highlighting the urgent need for strengthened effluent management and water quality monitoring in the region.

The abundance of microplastics in both water and sediment samples revealed a clear spatial pattern linked to industrial influence. The midstream site recorded the highest microplastic concentration in water (15.3 particles per liter) and sediment (435 particles per kilogram), significantly higher than the upstream site, which recorded 4.5 particles per liter and 120 particles per kilogram, respectively. This trend corresponds with the proximity to petrochemical discharge points, indicating that industrial effluents and urban runoff are the primary contributors to microplastic contamination in the aquatic environment. This finding is consistent with studies by Ogbonna et al. (2021) and Eze et al. (2022), who documented similar patterns of microplastic pollution in Nigerian industrial waterways.

The spatial distribution of microplastics across the study area vividly illustrates the impact of anthropogenic activities, particularly industrial operations, on freshwater ecosystems. The markedly higher concentrations at the midstream site, adjacent to petrochemical and urban discharge points, reinforce concerns that industrial effluents significantly contribute to microplastic pollution. As reported by Adebayo et al. (2023), Nigerian petrochemical zones act as hotspots for microplastic accumulation due to direct discharge and runoff, corroborating the patterns observed in this study.

Microplastic concentrations at the midstream site (15.3 particles per liter in water and 435 particles per kilogram in sediment) contrasted sharply with upstream values, pointing to a substantial local source likely linked to the nearby industrial corridor. Facilities such as petrochemical plants, plastic manufacturers, and urban drainage systems are known to release both primary microplastics, like microbeads, and secondary microplastics, resulting from the fragmentation of larger plastic debris. These pollutants accumulate in the aquatic environment and pose significant ecological risks (Ilechukwu and Nwankwo, 2020).

The correlation between microplastic abundance and industrial activity proximity emphasizes the localized nature of plastic pollution. Midstream zones, often transition areas between rural upstream and urban downstream reaches, bear the greatest burden of industrial discharge. These zones act as sinks for pollutants due to the convergence of point and non-point sources, sedimentation dynamics, and reduced water turbulence (Okafor et al., 2021). Sediment samples, in particular, reflect long-term accumulation, with higher microplastic loads indicating persistent contamination in benthic habitats. This persistence raises ecological concerns, as sediment-associated microplastics can be ingested by benthic organisms, potentially leading to bioaccumulation and trophic transfer (Nwankwo et al., 2023).

The relatively lower microplastic concentrations upstream reflect minimal industrial influence, consistent with landscapes characterized by lower population density, reduced commercial activities, and limited plastic discharge (Adewale et al., 2020). This spatial contrast confirms the importance of land use and geography in shaping pollutant profiles in Nigerian river systems, where upstream areas typically serve as ecological baselines.

These findings underscore the growing recognition of microplastics as emerging contaminants of concern in freshwater systems. Unlike conventional pollutants, microplastics resist degradation and persist in the environment for decades, posing chronic risks to ecosystems and human health. Their small size facilitates widespread dispersal and uptake by aquatic organisms, while their hydrophobic surfaces adsorb toxic chemicals, including pesticides, heavy metals, and persistent organic pollutants, amplifying their ecological impact (Eze et al., 2022; Ogbonna et al., 2021).

The presence of microplastics in both water and sediment highlights the necessity for dual-medium monitoring to fully capture contamination extent. Water samples reflect immediate exposure pathways for planktonic organisms, while sediments provide insight into long-term accumulation and exposure risks for benthic species. Such comprehensive monitoring is critical for accurate ecological risk assessments and for guiding mitigation efforts (Okafor et al., 2021).

Downstream microplastic concentrations were lower than midstream but remained elevated relative to upstream controls, indicating transport and redistribution consistent with findings from Nigerian river studies on microplastic mobility (Adebayo et al., 2023). Similarly, polycyclic aromatic hydrocarbon concentrations followed this spatial trend. Midstream water contained 1.34 micrograms per liter, and sediment contained 3.78 milligrams per kilogram, significantly exceeding upstream levels of 0.12 micrograms per liter and 0.45 milligrams per kilogram. These results affirm the hydrophobic nature of PAHs and their tendency to adsorb onto sediments, corroborating earlier Nigerian investigations (Ilechukwu and Nwankwo, 2020; Nwankwo et al., 2023).

Though downstream PAH levels were lower than midstream, they remained elevated, reflecting pollutant persistence and sedimentary accumulation with long-term ecological implications. The spatial variation in PAHs closely mirrors microplastic distribution, highlighting the intertwined nature of organic and plastic pollutants in freshwater systems impacted by industrial and urban activities (Ogbonna et al., 2021).

PAHs, derived from incomplete fossil fuel combustion and various industrial processes, are among the most toxic and ubiquitous organic pollutants. Their higher concentrations in sediments versus water confirm their lipophilic nature and affinity for fine particulate matter, which act as long-term pollutant reservoirs (Adewale et al., 2020). The persistence and mobility of these pollutants downstream highlight the risk of sediment resuspension and chronic exposure to benthic organisms, potentially leading to adverse biological effects including reproductive failure and carcinogenic outcomes (Eze et al., 2022).

A strong positive correlation was found between microplastic abundance and PAH concentrations in both matrices (Pearson's $r > 0.9$, $p < 0.05$), suggesting microplastics act as carriers for PAHs. This interaction enhances the environmental mobility and bioavailability of PAHs, compounding their toxicological impact. Such synergistic pollutant dynamics have been documented in Nigerian and global studies, emphasizing the need for integrated pollutant management (Okafor et al., 2021; Adebayo et al., 2023).

The robust correlation underscores microplastics' role not merely as inert debris but as active vectors of persistent organic pollutants, facilitating pollutant persistence and trophic transfer within aquatic food webs. This complex pollution pathway complicates remediation and highlights the need for comprehensive monitoring that integrates chemical and particulate pollutant analyses (Nwankwo et al., 2023).

Compared to global microplastic and PAH levels, concentrations in the Okulu Aleto River, particularly midstream, are notably high. Sediment microplastic concentrations here exceed reported values from moderately polluted European rivers (100 to 300 particles per kilogram), while PAH sediment levels surpass Canadian interim sediment quality guidelines for sensitive aquatic life (0.4 milligrams per kilogram for benzo[a]pyrene) (Eze et al., 2022; Magnusson et al., 2016).

5. Conclusion

This study provides compelling evidence of significant microplastic (MP) and polycyclic aromatic hydrocarbons (PAHs) pollution in the Okulu Aleto River, Eleme, with clear spatial variations reflecting anthropogenic influence, particularly industrial activity. Sediment, water, and biota samples all exhibited elevated MP concentrations, with the highest values recorded midstream and downstream, underscoring the river's role as a sink for persistent pollutants. The highest MP concentrations in sediments (222,222 µg/g) and water (60,000 µg/ml) were found in areas closest to effluent discharge and industrial operations, with similar spatial trends observed for PAHs.

Biota analysis revealed substantial MP ingestion, especially in benthic organisms such as prawns and crabs, indicating ecological exposure and the potential for trophic transfer. These findings align with existing literature and reinforce concerns about the cumulative impact of plastic and organic pollutants in freshwater ecosystems. The strong positive correlation between MP and PAH concentrations further suggests that microplastics act as vectors for hydrophobic pollutants, amplifying their bioavailability and environmental risks.

The environmental implications are profound. The contamination threatens aquatic biodiversity, disrupts food webs, and poses significant risks to public health through the consumption of polluted aquatic species. The persistence of both MPs and PAHs in sediments reflects long-term accumulation and the challenge of reversing such pollution trends without targeted intervention.

Given these outcomes, there is an urgent need for strengthened regulatory oversight of industrial effluent discharge, improved solid waste management practices, and routine monitoring of aquatic ecosystems—particularly in industrialized zones like Eleme. Public awareness campaigns and investment in sustainable production and eco-friendly waste disposal technologies are also essential in mitigating future pollution.

Ultimately, this study underscores the intertwined nature of plastic and organic pollution in urban-industrial freshwater systems and highlights the pressing need for integrated environmental management strategies to safeguard ecosystem and human health in the Niger Delta region.

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