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Source Apportionment and Health Risk Analysis of Microplastics in Water and Sediment in Aluu River

Harrison, E
Department of Chemistry, Ignatius Ajuru University of Education, Rumuolemini, Port Harcourt. Rivers State, Nigeria

Nwoke, I. B
Department of Chemistry, Ignatius Ajuru University of Education, Rumuolemini, Port Harcourt. Rivers State, Nigeria
Email: imaobong67@gmail.com

Nwineewii, J. D.
Department of Chemistry, Ignatius Ajuru University of Education, Rumuolemini, Port Harcourt. Rivers State, Nigeria

Abstract:

Aquatic ecosystems in rapidly urbanizing regions are increasingly threatened by emerging contaminants such as microplastics which pose significant ecological and human health risks due to their persistence, bioaccumulation potential, and toxicity. Rivers serving as sources of domestic water, fishing, and agriculture are particularly vulnerable to these pollutants. This study aimed at the source apportionment, and potential ecological and human health risks of selected microplastics in surface water and sediment of the Aluu River. The specific objective were to quantify and characterize microplastic contamination, determine the sources of these contaminants and the health risks associated with exposure to microplastics. Surface water and sediment samples were collected from multiple locations along the Aluu River using standard sampling protocols. Microplastics were extracted, quantified, and polymer types identified using standard density separation and spectroscopic techniques. Source apportionment was conducted using principal component analysis (PCA), while ecological and human health risk assessments were performed using hazard quotient (HQ) and cancer risk (CR) models. Microplastic analysis identified five predominant polymers: polyvinyl chloride (PVC), polystyrene (PS), polyethylene (PE), polyurethane (PU), and polypropylene (PP) with higher cumulative concentrations in sediments (up to 26.96 µg/g) than in surface water. Risk assessment showed varying non-cancer hazard quotients (HQ) across all locations, with polyurethane and polyvinyl chloride contributing the most to potential health risks in both matrices. Cancer risk (CR) values for these polymers ranged from

5.3×10^{-5} to 1.42×10^{-4}, approaching or exceeding acceptable limits. The findings demonstrate significant contamination of the Aluu River by microplastics with sediment acting as a major sink for these pollutants. The dominance of high-risk polymers, coupled with elevated health risk indices, indicates potential long-term ecological degradation and serious public health concerns for populations dependent on the river. Continuous environmental monitoring, strict regulation of industrial discharges, improved waste management practices, and public awareness initiatives are strongly recommended

Keywords: Microplastics, Source Appointment, Health Risk, Sediment, Water.

Introduction

Freshwater ecosystems are among the most valuable natural resources on Earth, providing water for drinking, agriculture, industry, and ecological sustainability. Rivers serve as dynamic systems that transport nutrients, sediments, and organic matter while supporting diverse biological communities. However, increasing anthropogenic activities have significantly altered the quality of freshwater systems worldwide. One of the most emerging and persistent contaminants in aquatic environments is microplastics — small plastic particles typically less than 5 mm in size — which have become a major environmental concern in recent decades [1].

Microplastics originate from a variety of sources and are broadly classified as primary or secondary particles. Primary microplastics are intentionally manufactured at microscopic sizes for industrial and commercial applications such as cosmetics, personal care products, and synthetic textiles. Secondary microplastics are formed through the fragmentation of larger plastic debris due to physical, chemical, and biological weathering processes. These particles enter aquatic systems through urban runoff, wastewater discharge, improper waste management, industrial effluents, and atmospheric deposition. Because plastics are resistant to degradation, microplastics persist in the environment and accumulate in both water and sediment, where they can remain for extended periods [2].

The presence of microplastics in freshwater systems poses serious ecological and human health concerns. Aquatic organisms can ingest microplastics either directly or indirectly through the food chain, leading to physical injury, reduced feeding efficiency, and physiological stress. Microplastics also act as carriers of toxic substances such as heavy metals, persistent organic pollutants, and pathogenic microorganisms, enhancing their mobility and bioavailability in aquatic ecosystems. From a human health perspective, the ingestion of contaminated water or aquatic organisms may expose populations to chemical additives and adsorbed toxins associated with plastic particles. Although research on long-term human health impacts is still evolving, growing evidence suggests potential risks including inflammatory responses, endocrine disruption, and cellular damage [3].

Source apportionment is a critical component of microplastic research because identifying dominant pollution sources enables effective mitigation strategies. Understanding whether microplastics originate primarily from domestic waste, industrial activities, textile fibers, fishing gear, or urban runoff is essential for designing targeted environmental policies. In many developing countries, including Nigeria, inadequate waste management infrastructure and rapid urban expansion increase the likelihood of plastic leakage into rivers and other water bodies. Despite the global recognition of microplastic pollution, there remains a scarcity of localized studies that evaluate both environmental distribution and associated health risks in freshwater systems within Sub-Saharan Africa [4].

Aluu River is an important freshwater resource that supports domestic, agricultural, and economic activities in its surrounding communities. Like many rivers in rapidly urbanizing regions, it is exposed to multiple pollution pressures, including improper solid waste disposal, drainage runoff, and human activities along its banks. These pressures create favorable conditions for the accumulation of plastic debris and the subsequent formation of microplastics in water and sediments. However, scientific data on microplastic contamination in Aluu River are limited or nonexistent, creating a critical knowledge gap in environmental assessment and public health protection [5]

This study therefore focuses on the source apportionment and health risk analysis of microplastics in water and sediment in Aluu River. By identifying the types, abundance, distribution, and likely sources of microplastics, as well as evaluating their potential risks to human health, the research aims to generate baseline data necessary for environmental monitoring and policy development. The findings will contribute to a deeper understanding of freshwater microplastic pollution in Nigeria and support sustainable management strategies for the protection of aquatic ecosystems and community health.

Materials and Methods

Study area

The study was conducted in Aluu, a community located within Ikwerre Local Government Area of Rivers State in the South–South region of Nigeria. Geographically, Aluu lies at latitude 04°55′14.8″ North and longitude 06°55′07.7″ East, with an elevation of approximately 15.2 m above sea level. The area experiences a tropical climate marked by alternating wet and dry seasons, with an annual rainfall of about 240 cm, relative humidity exceeding 90%, and an average yearly temperature of around 27 °C. The inhabitants of Aluu are predominantly engaged in trading, farming, fishing, and hunting as their primary means of livelihood. The vegetation of the area is typical of a freshwater and mangrove environment, consisting of red and white mangrove species *(Rhizophora mangle* and *Avicennia spp.),* Nypa palm *(Nypa fruticans), Ipomoea aquatica, Nymphaea lotus, Mimosa pigra, Eichhornia natans,* water lily, and various aquatic ferns. Several human and economic activities occur within the study area, including agricultural transportation and dredging operations. The community cultivates a variety of crops such as cassava, maize, vegetables, and yam, among others.

Methods

Water sample collection

Water samples were collected using 1 L plastic bottles fitted with screw caps. The bottles had been pretreated by washing with detergent, soaking overnight in 10% (v/v) nitric acid (HNO_3), and thoroughly rinsing with deionised water. A total of ten samples were taken from different designated points along the Aluu River at a depth of approximately 30 cm below the water surface. Immediately after collection, the samples were stored in ice-packed containers and transported to the Integrated Science and Engineering Laboratory in Elekahia, Rivers State for analysis.

Sediment sample collection

Sediment samples were collected from the Aluu River at the same sampling points used for water collection. A total of ten sediment samples were obtained and stored in clean polythene bags. Following collection, the corresponding water samples were preserved in ice-packed containers and transported to the Integrated Science and Engineering Laboratory, Elekahia, Rivers State. The specific sampling locations and their spatial coordinates are presented in Table 3.1.

Table 1. Coordinates of Sample Area.

Location	Latitude	Longitude
Omouko River (L1)	4°16’66.0°N	6°34’57.5°E
	4°17’56.0°N	6°35’56.5°E
	4°17’19.0°N	6°35’53.5°E

Omuihuechi River (L2)	4°18’57.5°N	6°35’20.3°E
	4°17’54.8°N	6°37’20.8°E
	4°15’59.6°N	6°36’21.5°E
Omuchiolu River (L3)	4°14’41.0°N	6°33’19.5°E
	4°15’42.0°N	6°35’18.4°E
	4°16’41.1°N	6°36’17.3°E
	4°13’45.0°N	6°35’22.6°E

Extraction of microplastics

Surface water sample treatment-density separation

The method adopted in the extraction of microplastics from water was density floatation. The water samples were first oxidized using wet peroxide oxidation (WPO) to remove organic materials. The water samples were sieved through a 5mm sieve in order to ensure no particles greater than 5 mm was retained in the sample. Sieved water sample was washed in 500 mL beaker and 250 ml of sterile salt solution (NaCl) added to cause microplastics to float. The mixture was filtered directly with a glass fiber filter membrane (Whatman GF/D, 2.7 µm). The filter paper was dried at room temperature and stored in a glass petri dish for further identification.

Sediment sample treatment-density separation

The method adopted in the extract of microplastics from the sediment was Density floatation. An aliquot of 50 g air dried sediments from each site was weighted in a glass beaker and mixed with 200 mL of saturated sodium chloride solution (1.2 g L^{-1}). 5 mL of 30% H_2O_2 was added into the samples to degrade the organic matters until the foam disappeared. The supernatant of mixture was carefully transferred to a clean glass beaker after settling for 8 h. This procedure was repeated three times and all the supernatants were collected and combined as one sample. After settling for further 24 hours, the supernatant was filtered through a glass fiber filter membrane (Whatman GF/D, 2.7 µm). The filter paper was dried at room temperature and stored in a glass petri dish for further identification.

Identification of microplastics in water and sediment

Materials were examined with photo microscope (Olympus CX31RTSF) equipped with Olympus E330- ADU1.2X6K1338 camera at 40x magnification. Photographs of suspected particles were directly taken on the filters. Natural debris was separated from particles suspected to be microplastics during visual inspection according to the criteria enumerated by other workers.33-36 selected suspected particles were further identified with FTIR (Buck Scientific M530 USA). Spectra were in transmittance mode and ranged from 500 to 4000 cm^{-1}. Polymer types were identified by matching the wavelength data with those obtained from literatures. Laboratory materials used for sample preparation and extraction were rinsed with double distilled water and all liquids were filtered before use. Samples were covered when not in use and filters were carefully examined to prevent contamination by air-borne particles. Blank extraction was also run without the samples to ensure non-contamination.

Gas Chromatography-Mass Spectrometry

Gas Chromatography-Mass Spectrometry (GCMS) analysis was carried out using an Agilent 6890 gas chromatograph with a 5973 MS detector equipped with 30-m x 0.25-mm and 0.32-mm ID fused-silica capillary column chemically bonded with SE-54 (DB-5 or equivalent), and 1-µm film thickness (Agilent). The following temperature ramp was used: injector at 250°C, oven initially at 200°C, held for 1 min and heated to 230°C (1.5°C min-1, then held for 10min). Helium was used as the carrier gas at a flow rate of 1 mL min-1. The split ratio was 50:1, and the sample size was 2µL. The characterization and identification of the microplastics, from the sample was completed in the thermo Excalibur 2.1 0.114 acquisition software.

Carcinogenic risk assessment of MP

The carcinogenic risk potential through the surface water and sediment is estimated using incremental lifetime cancer risk (ILCR).

CDI in the following equation is the chronic daily intake of carcinogenic chemical materials (mg/kg/day). This index shows the mean daily dose of exposure to the carcinogenic materials in a lifetime:

$$\mathrm{ILCR} = \mathrm{CDI} \times \mathrm{CSF}. \qquad 1$$

The cumulative cancer risk as a result of exposure to multiple carcinogenic pollutants due to the consumption of water was assumed to be the sum of the individual pollutant increment risk and calculated using the following equation:

$$\sum \mathrm{ILCR} = \mathrm{ILCR}_1 + \mathrm{ILCR}_2 + \mathrm{ILCR}_3 + \cdots \mathrm{ILCR}_n. \qquad 2$$

In this equation, n is the individual carcinogenic of each pollutant in the bottled water or tap water. The level of acceptable cancer risk (ILCR) or for regulatory purposes is considered between 10^{-4} and 10^{-6}.

Table 2. Parameters for estimating human cancer risk.

Parameters	**Units**	**Values**	
		Ingestion	**Dermal absorption**
Pollutant concentration (C)	µg/L		
Daily average intake (DI)	L/day	2.2	
Skin surface area (SA)	cm^2		18000
Permeability coefficient (KP)	cm/hour		
Exposure Time (ET)	Hour/event		0.58
Exposure frequency (EF)	Day/years	365	350
Exposure duration (EP)	Year	70	30
Conversion factor (CF)	L/cm^3		0.001
Body weight (BW)	Kg	70	70
ABS	All	0.001	0.001
Average time (AT)	Days	25550	25550

Carcinogenic human health risk of MP

In estimating the level of exposure due to oral consumption of MP in the water the equation for estimated daily intake (EDI)for carcinogenic chemicals was calculated as follows;

$$\mathrm{ADD}\ \mathrm{mg/kg/day} = \frac{Cp \times IR \times EF \times ED}{BW \times AT} \qquad 2$$

where: Cp is the concentration of MP in water and sediment (mg/kg), IR is the ingestion rate (0.0312 for normal consumption in adult and 0.1424 kg/day for habitual consumers of water), EF is the exposure frequency (365 days/year), ED is the exposure duration over a lifetime; assumed as 70 years for both children and adult, BW body weight (70 kg for adults), and AT average lifetime (70 years × 365 days/year). EDI was calculated for 70 years exposure for adult as follows

$$\mathrm{ILCR} = \mathrm{CDI} \times \mathrm{CSF}.$$

where: CSF is cancer slope factor, also known as potency factor; 2.0 mg/kg/day for PCB congeners. The carcinogenic HQ was evaluated as follows:

$$\mathrm{HQ} = \frac{\mathrm{EDI}}{\mathrm{RfD}} \qquad 3$$

Results

Table 1. Concentration of polymers in microplastics of surface water samples.

Microplastic Polymers	**L1 Mean ± SD**	**L2 Mean ± SD**	**L3 Mean ± SD**
polyvinyl chloride (PVC)	3.19 ± 0.29	2.17 ± 0.23	3.03 ± 0.03
polystyrene (PS)	1.93 ± 0.25	3.27 ± 0.23	3.17 ±0.10
polyethylene (PE)	5.40 ± 1.00	4.17 ± 0.10	3.67 ± 1.03
polyurethane (PU)	2.43 ± 0.18	3.10 ± 1.10	2.13 ± 0.12
polypropylene (PP)	5.11 ± 0.11	2.57 ± 0.48	3.07 ± 0.58
Grand total concentration	18.06±1.83	15.28±2.14	15.07±1.86

N=10, L1-3=different locations within Aluu River.

Table 2. Concentration of microplastics in sediment samples.

Microplastic Polymers	**L1 Mean ± SD**	**L2 Mean ± SD**	**L3 Mean ± SD**
polyvinyl chloride (PVC)	7.51 ± 1.13	8.15 ± 0.91	9.23 ± 0.14
polystyrene (PS)	2.67 ± 0.54	1.03 ± 0.58	3.17 ± 0.15
polyethylene (PE)	5.13 ± 0.08	3.67 ± 0.53	4.00 ± 0.65
polyurethane (PU)	2.17 ± 0.05	4.01 ± 0.40	5.27 ± 0.53
polypropylene (PP)	3.37 ± 0.53	1.16 ± 0.73	5.29 ± 0.61
Grand total concentration	20.85± 2.33	18.02± 3.15	26.96± 2.68

N=10; L1-3 = different locations within the Aluu River.

Table 3. EDI Results of Microplastic Polymer in sediment.

Polymer	**EDI L1**	**EDI L2**	**EDI L3**
PVC	0.54	0.59	0.66
PS	0.19	0.07	0.23
PE	0.37	0.26	0.29
PU	0.16	0.29	0.38
PP	0.24	0.08	0.38

Table 4. Non-Cancer Risk (HQ) per Polymer in sediment.

Polymer	**HQ L1**	**HQ L2**	**HQ L3**
PVC	0.18	0.20	0.22
PS	0.04	0.01	0.05
PE	0.04	0.03	0.03
PU	0.08	0.15	0.19
PP	0.03	0.01	0.05

Table 5. Cancer Risk (CR) for PVC and PU of microplastic in sediment.

Polymer	**CR L1**	**CR L2**	**CR L3**

PVC	5.4 × 10^-5	5.9 × 10^-5	6.6 × 10^-5
PU	3.2 × 10^-5	5.8 × 10^-5	7.6 × 10^-5
Total	8.6 × 10^-5	1.17 × 10^-4	1.42

Table 6. EDI Results of microplastic polymer in water.

Polymer	L1 µg/kg/day	L2 µg/kg/day	L3 µg/kg/day
PVC	0.2294	0.1560	0.2179
PS	0.1388	0.2351	0.2279
PE	0.3883	0.2998	0.2639
PU	0.1747	0.2229	0.1531
PP	0.3674	0.1848	0.2207

Table 7. Non-Cancer Risk (Hazard Quotient - HQ) of surface water.

Polymer	L1	L2	L3
PVC	0.0765	0.0520	0.0726
PS	0.0278	0.0470	0.0456
PE	0.0388	0.0300	0.0264
PU	0.0873	0.1114	0.0766
PP	0.0525	0.0264	0.0315
Total	0.2829	0.1114	0.2527

Table 8. Cancer Risk (CR) of PVC and PU.

Polymer	L1	L2	L3
PVC	2.3×10^{-5}	1.6×10^{-5}	2.2×10^{-5}
PU	3.5×10^{-5}	4.5×10^{-5}	3.1
Total	5.8×10^{-5}	6.1×10^{-5}	5.3×10^{-5}

Table 9. PCA Loadings for Microplastics in Surface Water (Aluu River).

Polymer	PC1	PC2
Polyvinyl chloride (PVC)	0.451	0.438
Polystyrene (PS)	-0.510	0.230
Polyethylene (PE)	0.428	-0.492
Polyurethane (PU)	-0.283	-0.704
Polypropylene (PP)	0.523	-0.133
Total Variation	71.17%	28.83%

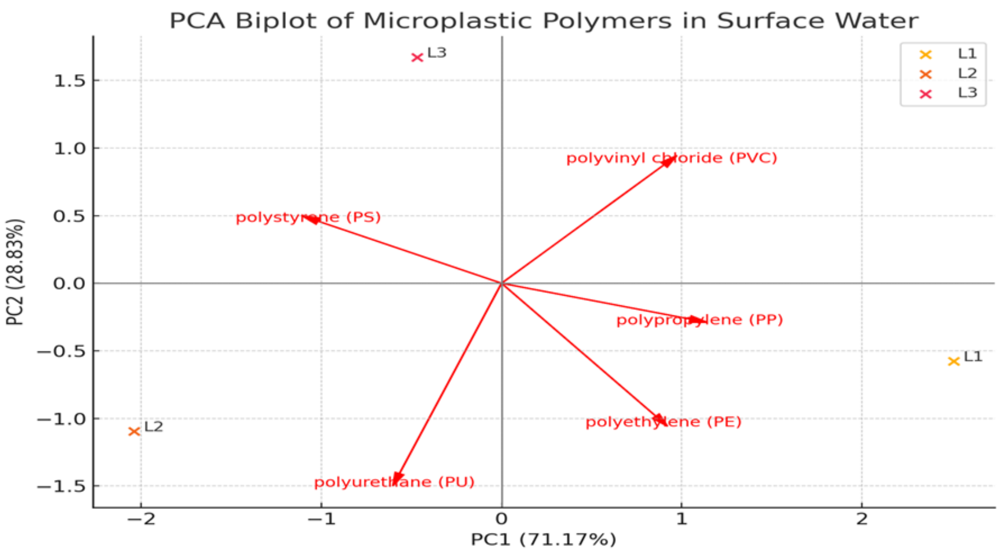

Figure 1. PCA biplot for microplastic concentrations in surface water**.**

Table 10. PCA Loadings for Microplastics in Sediment in Aluu River.

Polymer	**PC1**	**PC2**
Polyvinyl chloride (PVC)	0.590	0.086
Polystyrene (PS)	0.285	-0.595
Polyethylene (PE)	-0.314	-0.576
Polyurethane (PU)	0.552	0.252
Polypropylene (PP)	0.408	-0.493

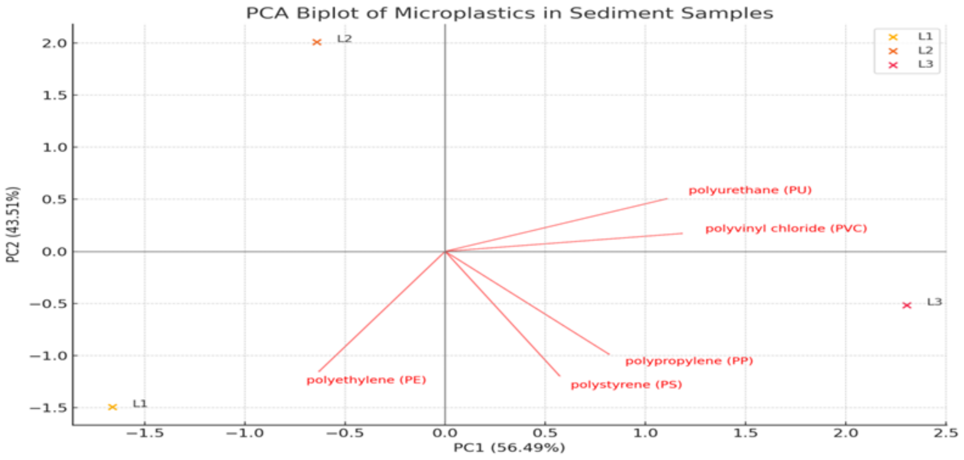

Figure 2. PCA biplot for microplastic concentrations in sediment.

Discussion

Concentration of microplastics in surface water

The analysis of microplastic polymer concentrations in surface water samples from the three study locations (L1–L3) reveals a varied distribution of synthetic polymer types, reflecting differential sources of plastic pollution in the aquatic environment. Among all samples, polyethylene (PE) showed the highest concentrations across the locations, particularly in L1 with 5.40 ± 1.00 µg/L, followed by 4.17 ± 0.10 µg/L in L2, and 3.67 ± 1.03 µg/L in L3. This trend is expected, as PE is one of the most widely used plastics in packaging materials and consumer products, which commonly enter the environment through domestic waste and runoff. Polypropylene (PP) also recorded significantly high levels, especially in L1 (5.11 ± 0.11 µg/L), aligning with its widespread use in disposable items such as food containers, bottle caps, and ropes. Notably, L1 consistently recorded the highest total polymer concentration at 18.06 ± 1.83 µg/L, suggesting it may be closer to urban or industrial activities contributing to microplastic pollution. L2 and L3 had slightly lower total concentrations, 15.28 ± 2.14 µg/L and 15.07 ± 1.86 µg/L, respectively, but still indicate significant microplastic presence.

Polystyrene (PS) was particularly dominant in L2 (3.27 ± 0.23 µg/L) and L3 (3.17 ± 0.10 µg/L), indicating potential input from packaging foam, disposable utensils, and insulation materials. This polymer type is prone to fragmentation and may persist in aquatic systems due to its low density and resistance to biodegradation. Polyvinyl chloride (PVC) showed relatively high levels in L1 (3.19 ± 0.29 µg/L) and L3 (3.03 ± 0.03 µg/L), reflecting possible contamination from construction materials, pipes, or synthetic leather products, which are common sources of PVC in the environment. Polyurethane (PU) concentrations varied across sites, with the highest concentration in L2 (3.10 ± 1.10 µg/L). PU is often used in foams, adhesives, and coatings, and its presence may indicate industrial or domestic effluents entering the water bodies. The variability in polymer concentrations across locations suggests that different human activities—ranging from domestic waste discharge to industrial operations—are influencing microplastic pollution profiles in surface waters.

The dominance of PE and PP across all sites emphasizes the urgent need for better plastic waste management practices. The presence of these polymers in aquatic ecosystems poses ecological threats to aquatic organisms through ingestion, chemical leaching, and trophic transfer, warranting continued monitoring and public awareness. The presence of microplastics in Aluu Rivers could be associated Urban runoff, wastewater treatment plant, industrial discharges, plastics debris breakdown and agricultural practices. In a similar research, Graham et al. (2024) reported 1.00 ± 0.71 – 69.75 ± 68.55 SD items.L^{-1} for microplastics in surface water of Orange-Senqu River basin. Wang et al. (2021) reported 10.00–27.50 n/L microplastics in seawaters of coastal areas in Zhuhai, China. Ololade et al. (2024) reported low value of microplastics (6.71 to 17.12 particle/L) for water obtained from southwestern Nigeria. The value of microplastics (139–303 particles/L) reported by Olarinmoye et al. (2020) for water obtained from a lagoon bordering the urban agglomeration of Lagos, Southwest Nigeria was above that of Omoku River.

Concentration of micro-plastics in sediment

The concentration of different types of microplastics found in sediment of Aluu River were illustrated in Table 2. The concentration of microplastics in sediment samples across three locations (L1, L2, and L3) shows significant variation in both total microplastic load and the types of polymer detected. Among the five polymers analyzed—polyvinyl chloride (PVC), polystyrene (PS), polyethylene (PE), polyurethane (PU), and polypropylene (PP)—PVC was the most dominant across all locations. Its concentration increased progressively from 7.51 ± 1.13 µg/g at L1 to 9.23 ± 0.14 µg/g at L3. This trend may reflect increasing industrial activity or improper disposal of PVC-containing materials such as pipes, packaging, and consumer goods, especially near L3. The widespread presence of PVC is consistent with other studies that have found it to be a persistent and common microplastic in urban and coastal sediments due to its durability and widespread use [6].

Polystyrene (PS), typically used in disposable packaging and foam products, was found in lower concentrations overall, with a notable dip at L2 (1.03 ± 0.58 µg/g) and an increase at L3 (3.17 ± 0.15 µg/g). This variability may be linked to localized waste management practices or the proximity to recreational or commercial areas where PS-based products are prevalent. In contrast, polyethylene

(PE) showed moderate and relatively stable levels across all sites, which is expected given its common usage in plastic bags and bottles. PE concentrations ranged from 3.67 ± 0.53 µg/g to 5.13 ± 0.08 µg/g, supporting previous findings that PE is frequently detected in aquatic sediments.

A significant increase in polyurethane (PU) and polypropylene (PP) at L3 (5.27 ± 0.53 µg/g and 5.29 ± 0.61 µg/g, respectively) suggests the influence of site-specific pollution sources. These polymers are widely used in furniture, insulation, and textiles (PU), as well as packaging and automotive components (PP). The lower concentrations at L1 and L2 may indicate either less industrial activity or more effective waste control in those areas. Similar patterns of PU and PP accumulation have been observed in areas near urban outflows and industrial discharge points [7].

The grand total concentration of microplastics highlights L3 as the most contaminated site (26.96 ± 2.68 µg/g), compared to L1 (20.85 ± 2.33 µg/g) and L2 (18.02 ± 3.15 µg/g). This spatial variation suggests a cumulative effect of pollution as sediments travel downstream or toward more developed regions. L2's higher standard deviation (SD = 3.15) may reflect more sporadic or seasonal pollution inputs. These findings underscore the urgent need for localized assessments of microplastic pollution to inform environmental policies and improve waste management strategies, particularly in vulnerable aquatic ecosystems.

Health risk of micro-plastics

The health risk analysis of microplastic polymers in sediment samples across the three study locations—L1, L2, and L3—provides critical insight into potential human exposure through the food chain. Among the polymers analysed, polyvinyl chloride (PVC) and polyurethane (PU) emerged as the primary contributors to health risks due to their relatively high concentrations and toxicological properties. Estimated Daily Intake (EDI) calculations reveal that L3 consistently exhibits higher intake values across most polymers, indicating elevated potential for human exposure in this area. For instance, the EDI for PVC in L3 reaches 0.66 µg/kg/day, the highest among all locations and polymers [6].

When evaluating non-cancer risks, measured by Hazard Quotients (HQ), all values remained below the threshold of 1. This indicates that current exposure levels are not likely to produce adverse health effects according to U.S. EPA standards (EPA, 1989). However, the cumulative HQ at L3 (0.54) is significantly higher than at L1 (0.37) and L2 (0.40), suggesting relatively increased potential for health concerns at this site, particularly from PVC and PU which individually contributed HQs of 0.22 and 0.19 respectively at L3. These findings align with previous research indicating microplastic exposure risks are site-dependent and influenced by local contamination levels [8].

The cancer risk assessment highlights more serious concerns. The Cancer Risk (CR) for both PVC and PU at L2 and L3 exceeds the U.S. EPA's acceptable lifetime cancer risk threshold of 1 × 10^-4. L3 records the highest combined CR at 1.42 × 10^-4, followed by L2 at 1.17 × 10^-4. This suggests a potentially unacceptable carcinogenic risk from chronic exposure to microplastic contaminants in seafood sourced from these areas. The elevated cancer risk primarily stems from the presence of PVC and PU, whose slope factors indicate a probable carcinogenic effect at sustained exposure levels. These findings support earlier assessment by the EPA which classify components of PVC and PU (such as vinyl chloride and isocyanates) as probable human carcinogens [9]. CR > 1 × 10^-4 at L2 and L3 indicates a potential carcinogenic concern due to cumulative exposure [6].

While non-cancer risks appear manageable at current exposure levels, the cancer risk assessments, particularly for L2 and L3, suggest the need for urgent intervention. Monitoring of microplastic contamination, public health guidance, and possibly restrictions on seafood consumption from high-risk areas are warranted to mitigate long-term health impacts [8].

The assessment of health risks from microplastic polymers in surface water samples across three locations (L1, L2, and L3) reveals notable variations in estimated exposure levels. The estimated daily intake values suggest that polyethylene (PE) and polypropylene (PP) contribute the highest ingestion rates across most sites, with PE at L1 peaking at 0.3883 µg/kg/day. These figures reflect likely ingestion through contaminated seafood, assuming a 10% transfer from water to organisms, as supported by conservative estimates in dietary exposure models [8]. While EDI values differ by site and polymer, overall exposure remains moderate compared to terrestrial toxicant thresholds.

The non-cancer risk, calculated using the Hazard Quotient (HQ) method, shows all values well below the benchmark of 1, indicating that current exposure levels are unlikely to pose non-carcinogenic health effects. Among all polymers, polyurethane (PU) shows the highest individual HQ at L2 (0.1114), attributable to its elevated concentration at this site. The total HQ values for all polymers combined are 0.2829 (L1), 0.2668 (L2), and 0.2527 (L3), with L1 reflecting the greatest non-cancer exposure potential. This pattern is consistent with studies indicating that urban and industrial activity often leads to site-specific microplastic contamination [10]. All HQ values remain well below 1, indicating no expected non-cancer health risks from these exposure levels.

The cancer risk (CR) assessment was conducted only for polyvinyl chloride (PVC) and polyurethane (PU), for which cancer slope factors are available. The combined CR values ranged from 5.3×10^{-5} to 6.1×10^{-5} across sites, all falling within the U.S. EPA's acceptable risk range of 1×10^{-6} to 1×10^{-4} [10]. Site L2 exhibited the highest cancer risk, primarily due to elevated PU levels. Although these figures indicate a low-level carcinogenic risk, their proximity to the upper limit of the EPA's threshold suggests the need for continued monitoring and public health awareness, particularly in communities reliant on freshwater seafood [11]. The non-cancer and cancer risks from surface water exposure remain within acceptable limits, the cumulative presence of multiple polymer types—especially PU and PVC—highlights the importance of integrated monitoring efforts.

Source Apportionment of Microplastic Polymers

The source apportionment of microplastic polymer in surface water of Aluu River are shown in Table 4.9. Principal Component Analysis (PCA) of microplastic concentrations in surface water from the Aluu River indicates that the first two principal components (PC1 and PC2) account for 71.17% and 28.83% of the total variance, respectively. Combined, they explain 100% of the dataset's variability, suggesting a robust interpretation of source contributions based on these two components. PC1, which explains the majority of the variance, is positively associated with polypropylene (PP) (0.523), polyvinyl chloride (PVC) (0.451), and polyethylene (PE) (0.428). These polymers are commonly used in packaging, piping, and containers, indicating that PC1 likely represents land-based or municipal sources, particularly from waste mismanagement, plastic litter, and drainage inputs.

On the other hand, PC2 loads most strongly with polyurethane (PU) (-0.704) and polyvinyl chloride (PVC) (0.438). This suggests a second pollution profile possibly linked to industrial inputs, as PU is frequently used in foams and construction materials, while PVC spans multiple industrial uses. The presence of negatively loaded polystyrene (PS) (-0.510 on PC1) and polyurethane (PU) indicates variability in pollution types—some possibly episodic or source-specific, such as from localized urban activities, insulation debris, or transport-related plastic waste [12].

The Principal Component Analysis (PCA) biplot for microplastic concentrations in surface water from the Aluu River reveals key insights into the sources and distribution of polymer types across different sampling sites (Figure 4.1). This biplot projects both the sampling locations (L1, L2, and L3) and microplastic polymer vectors (PVC, PE, PP, PS, and PU) onto a two-dimensional plane formed by Principal Components 1 and 2 (PC1 and PC2), which together explain 100% of the total variance—71.17% by PC1 and 28.83% by PC2. From the biplot, PC1 serves as the dominant axis, distinguishing between sites with high concentrations of common packaging materials such as polypropylene (PP), polyethylene (PE), and polyvinyl chloride (PVC). These polymers are known to originate from municipal solid waste and urban runoff due to their widespread use in consumer goods like bags, bottles, and container. The strong loading of these polymers on PC1, and the close projection of sites L1 and L3 in their direction, suggests these locations are highly influenced by domestic and urban plastic waste. This is consistent with previous studies which identify urban centers and residential settlements as primary sources of PE and PP in aquatic environments [12].

In contrast, PC2, while explaining less variance, emphasizes the contribution of polymers like polystyrene (PS) and polyurethane (PU). These materials are often used in industrial packaging, foam insulation, and consumer electronics. Their direction in the biplot aligns closely with site L2, indicating that this location may be receiving inputs from industrial or commercial activities. This observation supports findings by GESAMP, which notes that industrial zones often contribute specialized plastic pollutants to adjacent water bodies through stormwater discharge or improper waste management [13], [14], [15]. The orientation and length of the polymer vectors provide further insight into their influence across locations. For instance, PP and PE, which have long vectors extending along PC1, are the strongest discriminators of pollution patterns among the sites. This suggests that efforts to control microplastic contamination in the Aluu River should prioritize these polymers as key indicators of plastic waste influx [12],[16], [17].

Conclusion

The research focused on source apportionment and health risk analysis of microplastics in water and sediment in Aluu River. All sampled sites showed measurable concentrations of microplastics in both water (15.07–18.06 µg/L) and sediment (18.02–26.96 µg/kg), with polyethylene (PE), polypropylene (PP), and polyvinyl chloride (PVC) being dominant. PVC and PU exhibited the highest non-cancer and cancer risk values, especially in sediment samples. PU, in particular, had the highest cancer risk at L3 (7.6×10^{-5}), suggesting chronic exposure hazards.

Recommendations

It is recommended that:

1. Public education campaigns should focus on reducing plastic use, safe waste disposal, and the health risks of consuming contaminated water or fish.
2. Strengthen environmental regulations and enforce pollution control laws, particularly around petrochemical industries and urban settlements.

Contribution to Knowledge

1. This study provides the first integrated assessment of both microplastic polymers in water and sediment from the Aluu River.
2. The study emphasizes the synergistic effect of microplastics in aquatic ecosystems and their potential bioaccumulation.

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