Journal of Science, Engineering
And Technology Yabatech
2026, Vol. 3, Issue 1 Cite as:
https://doi.org/10.65805/ddy5mp3c4a71

OPEN ACCESS

Research Article

Distribution and Health Risk Assessment of Microplastics in fishes, water and sediment from Nigerian Inland Rivers during the Rainy Season

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Article History

Submitted: March 09, 2026 Accepted: April 20, 2026 Published: July 10, 2026

Abstract

This study investigates the distribution, characteristics, and potential human health risks of microplastics (MPs) in water, sediments, and fish from seven Nigerian inland rivers during the rainy season of 2023. MP abundance was significantly influenced by seasonal hydrology, with higher concentrations observed in fish (up to 58 ± 0.58 particles/g in River Benue) and water (up to 48 ± 8.12 particles/50 mL in River Argungu) compared to dry season levels, attributable to enhanced runoff and mobilization of land-based plastics. Sediments showed reduced MP levels during the rainy season due to resuspension and downstream transport. Fibres dominated in fish (48.5%) and sediments (49.3%), while fragments prevailed in water (60.3%). Fifteen polymer types were identified via FTIR, with polystyrene exhibiting bioaccumulation in fish (27.8% in gills to 52.4% in guts), polypropylene prevalent across compartments, and ethylene vinyl acetate dominant in water (68%). Principal component analysis revealed distinct compartmental associations, with fish and sediments clustering together, indicating transfer pathways. Estimated daily intake (EDI) through fish and water consumption was low, with fish as the primary exposure route and River Benue posing the highest risk. Although EDI values were substantially below global estimates, the role of MPs as vectors for chemical contaminants underscores potential long-term health concerns. These findings highlight the exacerbating effect of the rainy season on MP pollution in Nigerian freshwater systems and emphasize the need for targeted mitigation strategies.

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Keywords

Microplastics; Nigerian inland rivers; Rainy season; Fish bioaccumulation; Polymer composition; Estimated daily intake; Health risk assessment; Seasonal variation; Runoff; Sediments

Introduction

Plastic particles smaller than 5 millimeters are called microplastics (MPs) and they have become one of the most widely distributed environmental contaminants in aquatic ecosystems worldwide. The sources of MPs include the fragmentation of larger pieces of plastic and the direct release of primary MPs, with additional sources being anthropogenic (manmade), such as through wastewater discharge, urban runoff, and agricultural runoff (Sunny et al., 2025). Freshwater ecosystems (i.e., rivers and lakes) provide significant pathways for the transport of MPs from land-based sources to oceanic sources, and thus, freshwater systems often contain greater concentrations of MPs than the gyres of oceans do because they are closer to pollution sources like these (Hossain et al., 2025). Collectively, rivers are estimated to export thousands of metric tons of MPs to the oceans each year, and this annual export of MPs to the oceans is exacerbated seasonally, particularly during rainy seasons when there is increased runoff of MPs into rivers and streams (Strokal et al., 2023).

In many developing countries, mainly in Africa, urban areas are growing faster than most regions of the world (Selhausen, 2020); this phenomenon is accompanied by a lack of appropriate systems to properly handle waste (both solid and liquid), and an increase in plastics and other manmade materials into the environment. The result has been an increase in microplastic (MPs) contamination within inland waterways that can cause harm to animal species (biodiversity), provide poor quality ecosystem services, and negatively affect people (Enyoh et al. 2023).

Nigeria is one of the largest contributors to the global problem of plastic waste mismanagement. Rivers in Nigeria (e.g., the Niger, Benue, Ogun, etc.) are some of the most polluted in the world and contain microplastics (MP) that are the same type and at concentrations similar to or higher than what have been detected in other developed areas (e.g., industrialized nations) (Li et al., 2026). For example, a comprehensive study across all six geopolitical zones in Nigeria during the dry season found that there was widespread contamination of fish, sediment, and water with MPs from seven major inland rivers (Rivers Yauri, Benue, Argungu, Jamare, Ogun, Ethiope, and Orashi), and that fibrous material was the primary constituent found in both water and fish samples, with polyethylene terephthalate (PET), polypropylene (PP), and polyethylene (PE) appearing in fish, PE/PA/Nylon, polyvinyl alcohol (PVA), and polyvinyl chloride (PVC) appearing in water, and PA/Nylon, polyurethane (PUR), PVC, and PET appearing in sediments (Doherty et al. 2024). This work identified the impacts that anthropogenic activities at the local level have on how prevalent these materials are throughout the environment, but reporting an estimated daily intake of MPs that was relatively low for these same areas, emphasized the need for comparative studies on a seasonal basis to determine seasonal changes in hydrodynamics due to precipitation.

In Nigeria, the rainy season provides an opportunity for the influx of microparticles (MPs) through increased rainfall, surface runoff, river discharge, and sediment re-suspension. As a result, it is predicted that a large number of MPs will enter the water column, altering their spatial and temporal distribution (Enyoh et al., 2021). Fish found in these rivers, which are an important source of protein for millions, will ingest and filter MPs, resulting in accession of MPs by fish and potential trophic transfer and bioaccumulation (Barboza et al., 2020). Human populations that consume the fish also will differ, with much of the risk arising from the ingestion of seafood. Many MPs contain additives and/or adsorbed/unintended chemicals that may pose serious health risks (Verla et al., 2019; Enyoh et al, 2023; Borgatta, and Breider, 2024). Currently, there is a scarcity of studies quantifying these risks and their health effects in inland waters of Nigeria.

This study will build upon the baseline data established during the dry season (Doherty et al., 2024) and examine the distribution, abundance, polymer types, and physical characteristics of MPs in water, sediment, and fish collected from seven Nigerian inland rivers during the rainy season. In addition, the underreported potential health impacts due to daily estimated fish and water consumption will be assessed. By designing this phase of the research to consider seasonal differences, the results will be useful to assist the development of targeted mitigation strategies, and to advance sustainable management of freshwater resources in a high-risk region.

Materials and methods

2.1. Study area

The study sites encompass seven rivers across Nigeria, as depicted in the map (Figure 1). In the northern region, these include River Yauri (a segment of the Niger River flowing through Yauri town), River Benue, River Argungu, and River Jamare. The southern sites comprise River Ogun, River Ethiope, and River Orashi. The Niger

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River, of which River Yauri forms part, spans approximately 4,180 km in length with a drainage basin covering 2,117,700 km² and extends across ten countries, including connections to Guinea via Mali and Niger (Misau et al., 2012). Downstream from Jebba, Nigeria, it traverses a broad, shallow valley 8–16 km wide, receiving the Kaduna River tributary about 110 km further, which supplies roughly one-quarter of its annual volume below their confluence. Near Lokoja, the river curves southward and converges with its primary tributary, the wider River Benue, creating a lake-like expanse of about two miles featuring islands and sandbanks. Yauri, located in Kebbi State, northwestern Nigeria, hosts one of the country's historic small emirates (Misau et al., 2012). The broader Niger Basin represents 7.5% of Africa's landmass. River Argungu, situated in Argungun town, Kebbi State, supports local economies through agriculture (including tobacco, peanuts, rice, millet, wheat, sorghum, cotton) and livestock rearing (cattle, goats, sheep), alongside providing irrigation and sustenance for the renowned annual fishing festival. The Jama'are River (also called Jamare or Bunga in its upper reaches) originates in the highlands near Jos, Plateau State, and flows northeastward through Bauchi and Yobe States before merging with the Hadejia River to create the Yobe River (Abdulrahman et al., 2022). The Hadejia-Jama'are Basin serves as a vital Sahelian biodiversity hotspot, with the Hadejia-Nguru wetlands—fed by these rivers—forming a critical habitat for avian species (Abdulrahman et al., 2022). In southwestern Nigeria, River Ogun spans a basin of roughly 23,000 km² and traverses multiple local government areas (including Ibarapa, Iseyin, Abeokuta, Owode, Ikorodu, and Ifo) before emptying into the Lagos Lagoon. It faces ongoing pollution challenges from commercial and anthropogenic activities. River Ethiope, located in Abraka, Delta State, is characterized by its swift flow (0.80–1.0 m/s), clear greenish hue, and freshwater quality. Historically a primary drinking source for riparian communities, it now primarily supports recreation like swimming and picnicking. Extensive dredging of its pristine white sand for construction has increased suspended solids, diminished visibility, and altered its crystalline appearance. Inflows from the Orime River further modify its color to a duller green and lower its pH. The Orashi River (alternatively Urashi or Ulasi), a tributary in the lower Niger Basin feeding Oguta Lake in southeastern Nigeria, stretches about 250 km and lies 183 m above sea level (Prince et al., 2013; Anazoo et al., 2003). Originating from areas like Dikenafai in Imo State, it courses through communities in Imo, Anambra, Rivers, and Bayelsa States before reaching the Atlantic. Local populations in places such as South Ideato, Mmahu, Abacheke (Egbema), Ogba, Ahoada, and Oguta rely on it for drinking, washing, and diverse domestic needs. Recognized as an ecosystem of national significance, Orashi sustains livelihoods, biodiversity, clean water provision, and recreational opportunities (Prince et al., 2013).

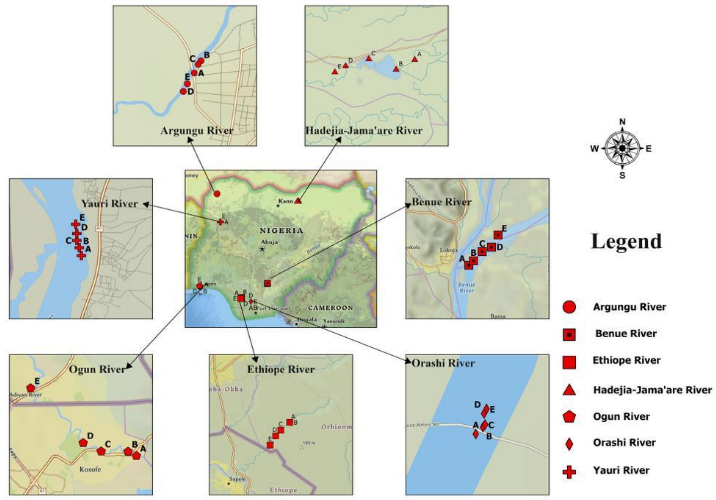


Figure 1: Map of the study Areas in Nigeria

2.2. Sample Collection

Fish specimens were captured by local fishermen at five designated locations across the seven selected rivers and immediately preserved in 70% ethanol. At the same sampling stations, surface water and sediment samples were collected. Water and sediment samples were composited on-site, properly preserved, and transported to the laboratory within 24 hours of collection, arriving the following day for processing. All sampling activities were conducted during the rainy season of 2023.

2.3. Microplastic Extraction from Samples

2.3.1. Fish

Prior to dissection, the total length (cm) and body weight (g) of each fish were measured and recorded. The gastrointestinal tract (GIT) was excised, weighed, and subjected to chemical digestion using a 10% potassium hydroxide (KOH) solution at 40°C for 12 hours (Li et al., 2015, 2016). The resulting digestate was vacuum-filtered through a 20 µm pore-size, 47 mm diameter membrane filter (Millipore, NY2004700) using a Buchner funnel connected to a pump. The retained filter membrane was transferred to a clean, covered Petri dish for subsequent microscopic examination.

2.3.2. River Water

A 50 mL aliquot of each water sample was sequentially vacuum-filtered using a suction pump and cellulose-based filter paper. Following filtration, retained particles were air-dried, visually isolated, and enumerated under an AmScope Trinocular Stereo Zoom Microscope (SM-1TY-144-18M3) equipped with an 18.0 MP digital camera. Microplastic abundance was expressed as particles per 50 mL (Bosker et al., 2018).

2.3.3. Sediment

One kilogram of air-dried sediment from each site was processed for density separation using a saturated sodium chloride (NaCl) solution. Samples were agitated on an orbital shaker at 300 rpm for 15 minutes, repeated three times. The combined supernatants were passed through a 1 mm stainless steel sieve lined with filter paper. Retained material was thoroughly rinsed with distilled water, dried, and examined for microplastics using the same AmScope Trinocular Stereo Zoom Microscope (SM-1TY-144-18M3) with an 18.0 MP digital camera.

2.4. Observation and Identification of Microplastics

Suspected microplastic particles were examined and confirmed under the AmScope Trinocular Stereo Zoom Microscope (SM-1TY-144-18M3) equipped with an 18.0 MP digital camera. Particles were classified according to shape (fibre, fragment, film), colour (black, blue, red, white, yellow, green, purple), and size. Size measurements were performed using a calibrated eyepiece graticule and categorised into six classes: ≤0.5, 0.5–1, 1–2, 2–3, 3–4, and 4–5 mm (Abidli et al., 2017). Digital photographs were captured for documentation. Polymer composition was determined using attenuated total reflectance-Fourier transform infrared spectroscopy (ATR-FTIR) on a Nicolet Nexus 470 instrument (Thermo, USA) operated with Omnic software. Spectra were acquired in the 650–4000 cm^{-1} range at 4 cm^{-1} resolution, with frequent background corrections using air spectra to minimise errors (Qiu et al., 2016).

2.5. Risk Assessment Modelling

Human exposure to microplastics via oral ingestion represents a key pathway from contaminated fish and drinking water. The quantity-based estimated daily intake (EDI) was therefore calculated for both adults and children using the following equation (Enyoh et al., 2022a):

$$EDIq = (P_i \times R_i) / B_w \quad (1)$$

where EDI_q is the estimated daily intake (MP particles/g-day for fish or MP particles/mL-day for water); P_i is the mean microplastic concentration in fish (MP particles/g) or water (MP particles/L); R_i is the ingestion rate in Nigeria (fish: 20.8 g/day; water: 2.2 L or 2200 mL/day for adults and 1.8 L or 1800 mL/day for children); and B_w is the average body weight (70,000 g for adults; 15,000 g for children).

2.6. Statistical Analysis

Results were expressed as mean ± standard deviation (SD). Percentages and frequencies of microplastic occurrence across species and the overall sampled population were calculated using OriginLab Pro software (Origin Software, USA). Principal component analysis (PCA) and hierarchical cluster analysis (HCA) were employed to explore potential sources of microplastics and inter-river relationships, also performed using OriginLab Pro.

Results

3.1. Distribution of MPs

The figure 2 displays the abundance of MPs (measured as MP particles/mL for water, and MP particles/g for fish and sediments) across different river sites during the wet/rainy season. During the rainy season, River Benue recorded the highest MP concentrations in fish (58 ± 0.58 MP particles/g), which was more than double the dry season value (28.33 ± 3.51 MP particles/g) (Doherty et al, 2024). Other rivers, including Ogun, Ethiope, Orashi, Yauri, and Jamare, showed moderate rainy season values (10–33 MP particles/g), which were generally higher than their dry season equivalents (Doherty et al, 2024). For example, River Argungu, which had the second-highest MP concentration in the dry season (22.00 ± 3.61 MP particles/g), showed lower fish-associated MPs in the rainy season compared to River Benue. The marked increase in River Benue suggests that rainy season flooding and runoff may enhance microplastic bioavailability and transfer into the food chain (Dalu et al, 2024). Studies conducted on edible fishes in Lagos Nigeria found highly accumulation of MPs during rainy season (Ndibe et al, 2023), agreeing with the results of this study.

The distribution of MPs in water also revealed a seasonal shift. In the dry season, Rivers Ogun (7 ± 2 MP particles/50 mL) and Benue (7 ± 3 MP particles/50 mL) showed the highest concentrations, while River Argungu recorded the lowest (1.53 ± 0.58 MP particles/50 mL) (Doherty et al, 2024). By contrast, in the rainy season, River Argungu exhibited the highest MP abundance (48 ± 8.12 MP particles/50 mL), followed by River Orashi (31 ± 2 MP particles/50 mL). The lowest rainy season values were recorded in Rivers Yauri and Ethiope (9–16 MP particles/50 mL). This reversal in trends suggests that rivers with lower dry season values (e.g., Argungu and Orashi) are more strongly influenced by runoff and flood-driven plastic inputs during rainfall, while rivers like

Ogun and Benue experience relatively smaller seasonal increases. However, in general, the rainy season concentrations were higher than those obtained during the dry season. In contrast to water and fish, sediment samples showed consistently higher MP concentrations during the dry season compared to the rainy season. The dry season was dominated by River Yauri (773 ± 257.67 MP particles/g), followed by River Benue (441 ± 147 MP particles/g) and River Ogun (283 ± 94.33 MP particles/g) (Doherty et al, 2024). During the rainy season, however, River Benue (135 ± 11.36 MP particles/g) and River Ogun (106 ± 6.93 MP particles/g) emerged as the most contaminated sites, while Rivers Ethiope, Orashi, Yauri, and Jamare exhibited relatively low MP levels (22–33 MP particles/g). The substantial seasonal decrease in sediment concentrations, particularly at River Yauri (773 ± 257.67 to 23 ± 1 MP particles/g), indicates that increased water flow and turbulence during the rainy season resuspend MPs, redistributing them into the water column or transporting them downstream.

These findings demonstrate a clear seasonal influence on MPs distribution compared to dry season (Doherty et al, 2024). Fish and water samples tend to accumulate more MPs during the rainy season due to increased surface runoff and mobilization of land-based plastics, whereas sediment stores are reduced, likely as a result of resuspension and downstream transport. The elevated MP burden in River Benue across both seasons underscores its status as a hotspot of plastic contamination, while River Argungu's dramatic rainy season increase highlights the impact of rainfall on local pollution dynamics. Collectively, these results point to the complex and dynamic interactions between hydrological conditions and microplastic pollution, emphasizing the need for seasonal monitoring when assessing the ecological risks of MPs in freshwater ecosystems

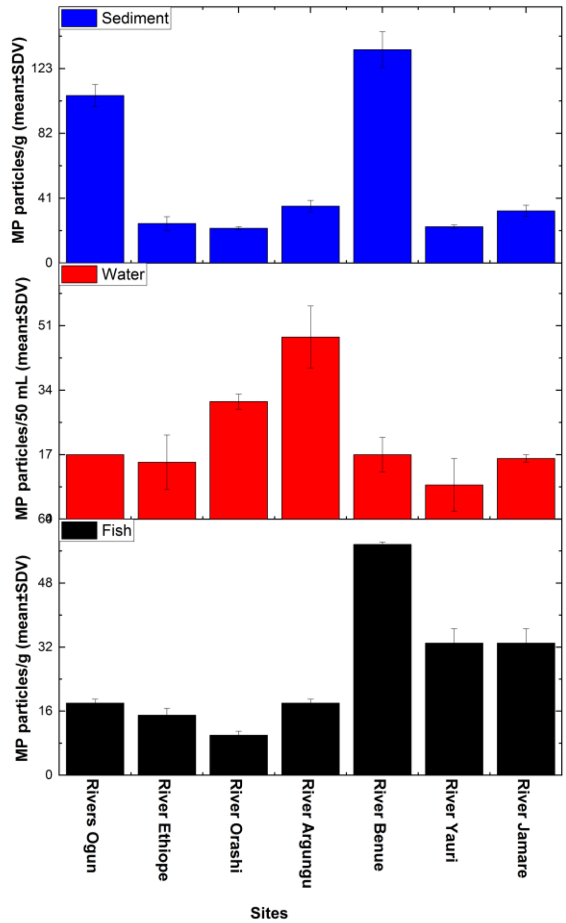
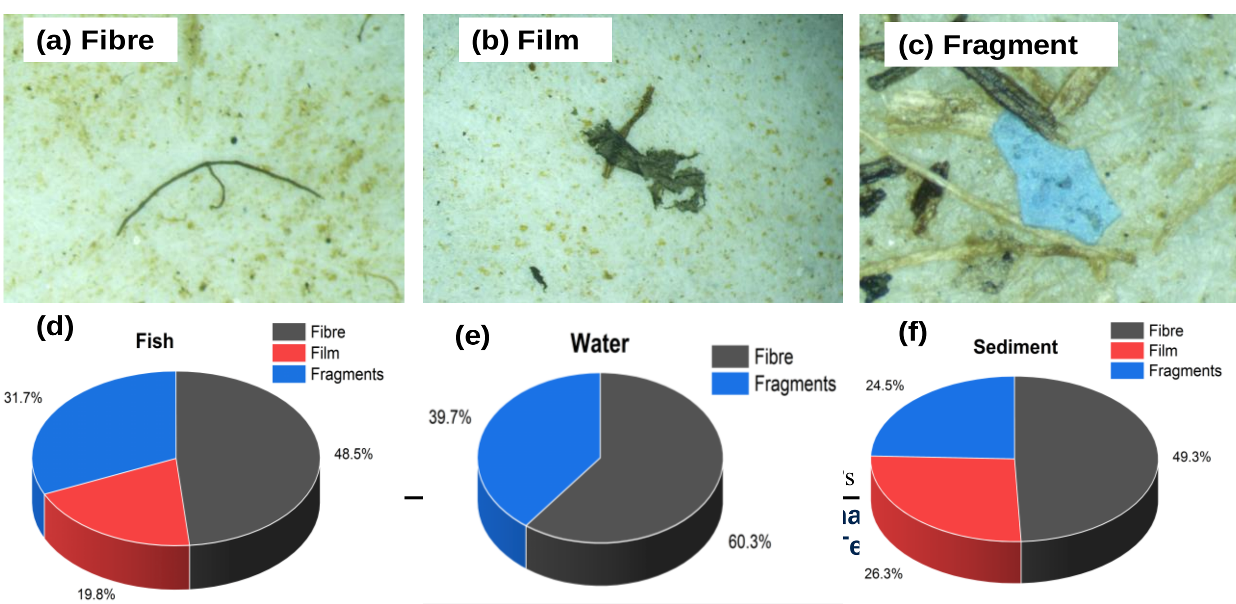


Figure 1. Wet/rainy season microplastics abundance in fish, water and sediments samples from the different rivers. Bars indicates standard deviations (SDV) (n = 3).

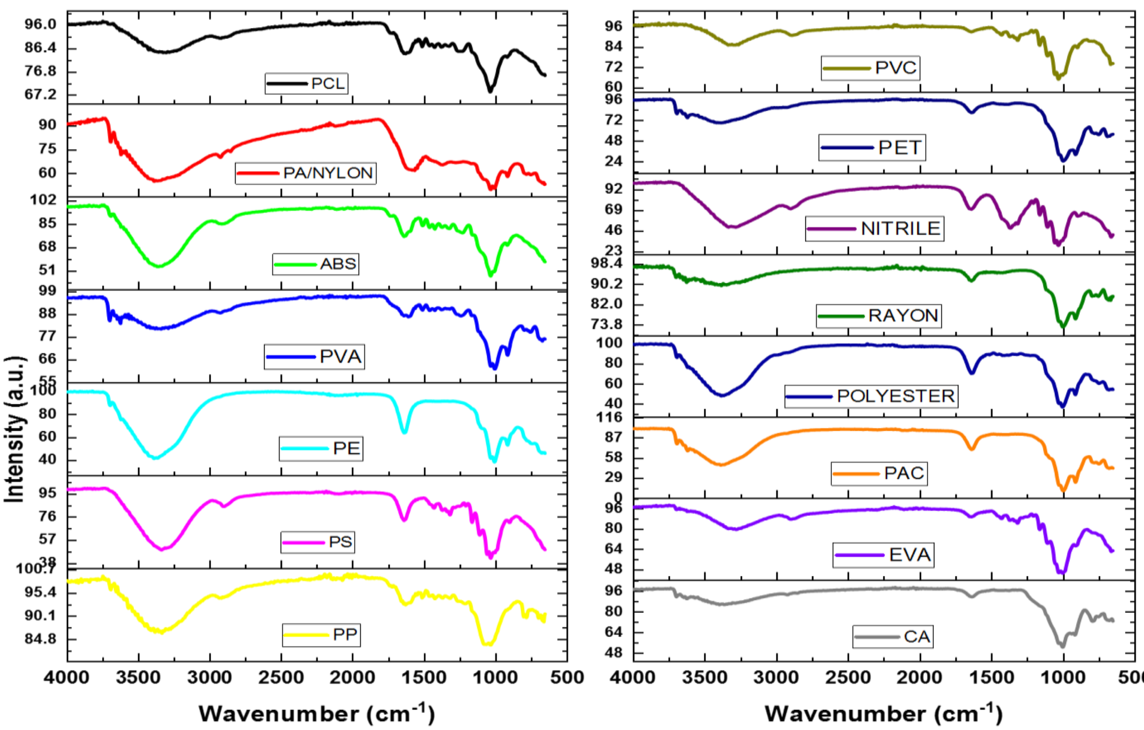


The MP shapes and distributions are presented in Figure 2. The distribution of MP shapes across environmental compartments (fish, water, and sediment) during the rainy season revealed clear differences in their relative abundance (Figure 2). The MPs identified were mainly fibres, films, and fragments, with their proportions varying depending on the matrix. In fish, fibres were the dominant type, accounting for 48.5% of the total MPs, followed by fragments (31.7%) and films (19.8%). The predominance of fibres in fish is consistent with global patterns, where fibres often represent the most ingested shape due to their prevalence in aquatic environments and resemblance to natural prey items (Lim et al., 2022). Fibrous MPs likely originate from textile sources, synthetic ropes, and fishing gear, which are widespread in riverine systems (Kaliszewicz et al., 2023). Their elongated structure facilitates entanglement with food particles or passive ingestion during filter-feeding or respiration, increasing bioavailability to fish (Enyoh et al., 2021). In water samples, fragments were the most abundant shape, comprising 60.3% of the MPs, followed by fibres (39.7%). This dominance of fragments in the water column aligns with observations in systems influenced by seasonal runoff and weathering processes, where photodegradation, turbulence, and mechanical abrasion during heavy rainfall fragment larger plastics into irregular pieces (Shahariar et al, 2025). The rainy season likely intensifies these dynamics by enhancing runoff and river flow, mobilizing fragmented debris from land-based sources and promoting breakdown in the water column (Enyoh et al, 2021). In sediments, fibres (49.3%) were again the dominant type, followed by films (26.3%) and fragments (24.5%). The prevalence of fibres in sediments reflects their tendency to settle and accumulate in benthic environments, often through biofouling, density modification, or entanglement with organic matter and finer sediment particles (Wang et al, 2022). Films and fragments, being lighter or more buoyant, are more susceptible to resuspension by currents, potentially explaining their relatively lower abundance in sediments compared to fibres (Woods et al., 2021).

Figure 2. Wet/rainy season shapes of MPs showing (a) fibre, (b) film and (c) fragment and their distribution in fish (d), water (e) and sediment (f) from the rivers.

3.3. Polymer composition

The FTIR analysis of MP particles isolated from fish, water, and sediment samples confirmed the presence of 15 distinct polymer types. Their representative FTIR spectra are shown in Figure 3. The identified polymers include polypropylene (PP), polystyrene (PS), cellulose acetate (CA), polyamide or nylon (PA), polyvinyl acetate (PVA), polyethylene (PE), polyethylene terephthalate (PET), polyester, rayon, ethylene vinyl acetate (EVA), acrylonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), polylactic acid (PAC), polycaprolactone (PCL), and nitrile. These polymers reflect diverse sources of plastic pollution, ranging from packaging materials (PP, PE, PS, PVC,

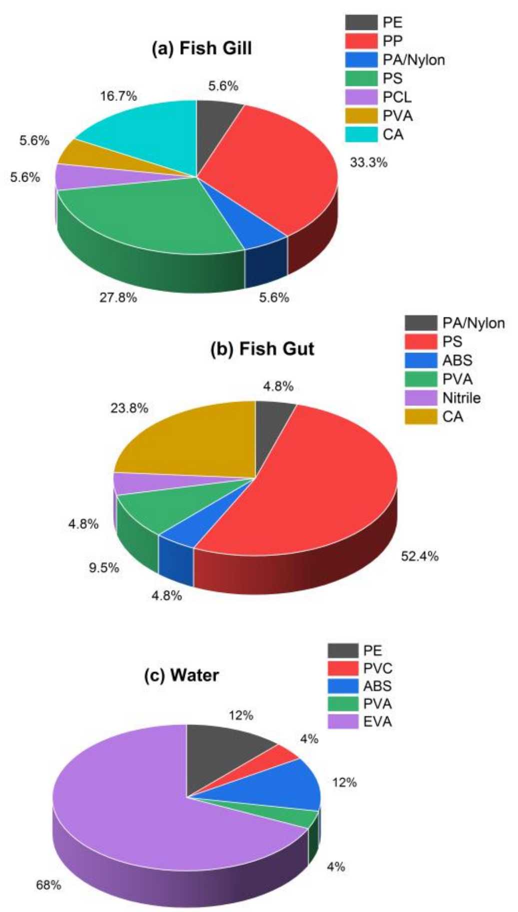


PET) and textiles (polyester, rayon, nylon) to specialty and biodegradable plastics (PVA, PAC, PCL, EVA). The wide spectrum of polymers suggests multiple anthropogenic inputs, such as domestic waste, industrial activities, and degradation of consumer products. Importantly, the coexistence of conventional plastics alongside biodegradable polymers (e.g., PAC, PCL) indicates not only persistent but also emerging sources of microplastic contamination in aquatic ecosystems (Costa et al, 2025).

Figure 3. Representative FTIR spectra of 15 identified microplastic polymers found in fish, water, and sediment samples: Polycaprolactone (PCL), Polyamide/Nylon (PA), Acrylonitrile Butadiene Styrene (ABS), Polyvinyl Acetate (PVA), Polyethylene (PE), Polystyrene (PS), Polypropylene (PP), Polyvinyl Chloride (PVC), Polyethylene Terephthalate (PET), Nitrile, Rayon, Polyester, Polylactic Acid (PAC), Ethylene Vinyl Acetate (EVA), and Cellulose Acetate (CA).

Figure 4 illustrates the polymer composition of microplastics (MPs) in fish gills, fish guts, water, and sediments during the rainy season across multiple river sites. In fish gills, polypropylene (PP) was the predominant polymer (33.3%), followed by polystyrene (PS) at 27.8%, and cellulose acetate (CA) at 16.7%, with minor contributions from polyamide (PA), polyvinyl acetate (PVA), and nitrile (each 5.6%). The high abundance of PP and PS in gills aligns with their widespread use in packaging and consumer products, rendering them readily available in the water column for filtration (Amponsah et al., 2024). This passive uptake via gills is a primary exposure pathway for buoyant or suspended polymers like PP and PS (Gao et al, 2025). In fish guts, PS dominated (52.4%), followed by CA (23.8%) and PVA (9.8%), with other polymers each at 4.8%. The marked increase in PS from gills (27.8%) to guts (52.4%) indicates active ingestion and gastrointestinal retention, suggestive of bioaccumulation (Gao et al, 2025). The notable CA presence likely stems from degraded cigarette filters or textiles, common environmental sources that fragment into ingestible particles (Novotny and Hamzai, 2024). In water samples, ethylene vinyl acetate (EVA) overwhelmingly prevailed (68%), followed by polyethylene (PE) and acrylonitrile butadiene styrene (ABS) at 12% each, and PVC and PVA at 4% each. High prevalence of EVA have been reported in Mula rivers in India (Verma et al, 2025). EVA's dominance, though less commonly reported as primary in many rivers where PE/PP prevail, may reflect specific inputs from foams, footwear, and packaging that degrade rapidly during rainy season runoff (Li et al., 2024).The diversity of lesser polymers (PE, ABS, PVC, PVA) underscores multiple sources, including industrial and domestic wastes. In sediments, PP led (26.7%), followed by polylactic acid (PLA/PAC) (21.2%), polyester (PET) (14.4%), and PE (12.3%), with others <7%. PP's prominence reflects its persistence and deposition despite lower density, often facilitated by biofouling or aggregation (Amponsah et al., 2024). The substantial PLA fraction highlights emerging inputs from biodegradable plastics, which degrade incompletely in natural conditions and accumulate in sediments (Ali et al, 2023). PET and PE align with ubiquitous bottle and packaging waste (Enyoh et al., 2019).

Overall, PS poses a key concern in fish due to its escalating proportion from gills to guts, signaling bioaccumulation and potential trophic transfer risks (Barboza et al., 2020). PP's consistency across gills (33.3%) and sediments (26.7%) underscores its pervasive distribution. EVA's water dominance (68%) points to targeted consumer product sources amplified by seasonal runoff. Sediments reveal a mix of conventional (PP, PET, PE) and biodegradable (PLA) polymers, illustrating diverse inputs and hydrological influences on deposition.



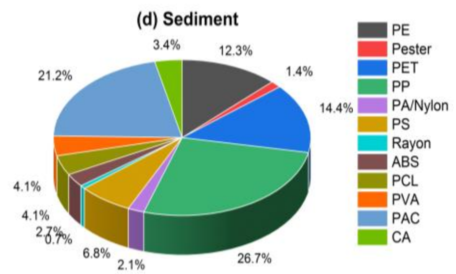


Figure 4. Wet/rainy season distribution of MPs by composition category registered in fish samples (a-b), water (c) and sediments (d) from all sites

3.4 Source analysis- Principal component analysis

The principal component analysis (PCA) biplot (Figure 5) exposes the potential sources and relationships of MPs across fish, water, and sediment samples from the studied rivers. The first two principal components (PC1 and PC2) explained 60.77% and 27.67% of the total variance, respectively, together accounting for 88.44% of the variability in the dataset.

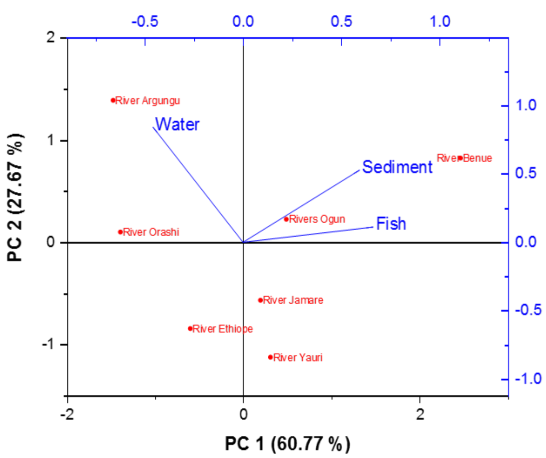


Figure 5. PCA biplot for MPs in the fish, water and sediment from the different rivers.

Along PC1, fish and sediment samples clustered together, while water samples formed a distinct group (Figure 4). This separation indicates that MPs in fish and sediments are closely related, suggesting a common source or strong interaction between these two compartments. The overlap between fish and sediment is expected, as MPs deposited in sediments can become bioavailable to benthic organisms and subsequently enter the food chain. In contrast, MPs in water samples are more strongly influenced by direct surface inputs and hydrodynamic processes, which explains their separation along PC1. The PC2 axis further differentiates between sites. Rivers Argungu and Orashi are strongly associated with the water component, reflecting higher MP abundances in the water column at these sites. In contrast, River Benue aligns closely with the sediment vector, consistent with its high MP load in sediments. Rivers Ogun is positioned near the fish vector, indicating a stronger association of MPs in fish at this site compared to water or sediments. On the lower quadrant, Rivers Ethiope, Yauri, and Jamare are positioned away from the main vectors, suggesting relatively lower MP contributions or differing pollution sources compared to the other rivers. Their distribution may indicate localized pollution inputs or reduced interaction between MPs in water, sediment, and fish at these sites.

Overall, the PCA highlights clear compartmental differences in MP sources and distributions. Water samples appear to be driven primarily by direct runoff and surface pollution, whereas sediments and fish share stronger linkages, likely due to sedimentation and subsequent uptake by aquatic organisms. The strong association of River Benue with sediments and River Argungu with water points to site-specific pollution dynamics, reflecting differences in land use, waste management practices, and hydrology. These findings suggest that while MPs in water represent transient inputs during the rainy season, sediments act as long-term sinks and potential secondary sources, with fish serving as bioindicators of microplastic transfer through the food web.

3.5. Estimated daily intake risks assessment

The results of the estimated daily intake (EDI) assessment reveal low levels of human exposure to MPs through the ingestion of fish and water from the studied rivers during the rainy season (Figure 5). These exposures are quantity-based (expressed as MP particles per individual per day) and differentiated by age group (adults and children), reflecting differences in assumed consumption rates which is higher for adults due to greater body weight and intake volumes. Fish consumption emerges as the predominant exposure pathway, with EDI values substantially exceeding those from water across all sites. For adults, fish-derived EDI ranges from 0.002971 MP particles/day (River Orashi) to 0.017135 MP particles/day (River Benue), while for children, it spans 0.013867 MP particles/day (River Orashi) to 0.079964 MP particles/day (River Benue). This pattern aligns with the higher MP abundance observed in fish tissues, particularly in River Benue, which consistently exhibits elevated contamination across matrices. In contrast, water-derived EDI is markedly lower, with adult values peaking at 0.001509 MP particles/L-day (River Argungu) and generally below 0.001 in most sites, and children's values similarly low but scaled accordingly (highest at 0.00576 MP particles/L-day in River Argungu). The dominance of fish as an exposure vector underscores its role in bioaccumulation, where MPs transfer from water and sediment into aquatic organisms, amplifying human intake in communities reliant on these rivers for protein sources.

Site-specific variations highlight River Benue as a hotspot for potential exposure, driven by its high MP loads in fish, likely attributable to intense anthropogenic pressures such as urban runoff and waste discharge during the rainy season. Rivers Ogun and Argungu also contribute meaningfully via fish for both age groups, whereas water contributions remain minor overall, suggesting that direct ingestion from these sources poses limited additional risk compared to dietary pathways.

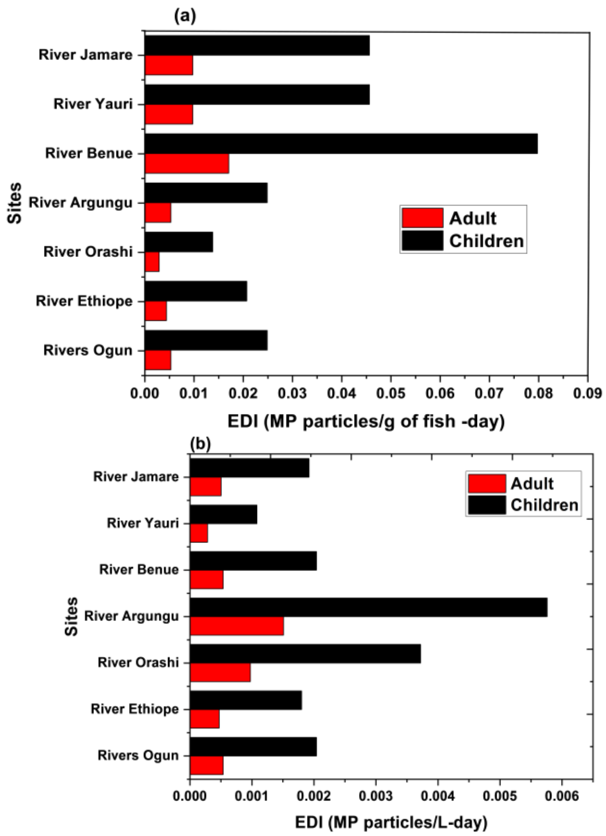


Figure 9. Quantity based estimated daily intake from ingestion of fish (a) and water (b) from the different rivers

Comparatively, these EDI values are orders of magnitude lower than global estimates reported in the literature. For instance, broader human exposure assessments indicate annual ingestion of 39,000–52,000 MP particles from seafood and other foods alone, with total dietary and inhalation routes reaching 74,000–121,000 particles/year per person (Cox et al, 2019). Specific to fish and water, contributions can vary widely, but even conservative global figures for seafood-derived intake often exceed hundreds to thousands of particles annually, far surpassing the fractional daily exposures calculated here (which translate to roughly 1–28 particles/year from fish, depending on site and age group). The low figures in this study likely stem from conservative assumptions in consumption rates tailored to local contexts, as well as potentially lower MP concentrations in these riverine fish compared to marine or heavily industrialized systems. Children exhibit proportionally higher EDI per unit body weight in some cases (e.g., River Benue fish), reflecting their lower body mass and vulnerability to chronic low-dose exposures (Ibeto et al, 2021). Although absolute intakes remain small, this age group warrants particular attention, as developing systems may be more susceptible to MP-associated effects.

From a health risk perspective, the numerical EDI values suggest negligible immediate hazard based on current quantity-alone assessments, as they fall well below thresholds associated with acute toxicity in available models. However, MPs act as vectors for adsorbed chemicals (e.g., persistent organic pollutants, heavy metals) and additives, potentially amplifying risks through additive or synergistic effects not captured in particle-count-based EDI. Emerging evidence links chronic MP exposure to oxidative stress, inflammation, neurotoxicity, endocrine disruption, and metabolic alterations, though direct causation in humans remains inconclusive due to knowledge gaps in long-term low-dose impacts (Ririe et al, 2025).

In the context of Nigerian inland rivers, where communities often depend heavily on local fish and untreated river water, these findings emphasize the need for integrated risk management. While the assessed exposures appear low, they contribute to cumulative burdens in populations already facing multiple environmental stressors. Prioritizing River Benue for monitoring, improving waste management to curb rainy-season runoff, and promoting awareness of alternative protein sources could mitigate potential long-term risks. Further research incorporating chemical contaminants, multiple exposure routes, and probabilistic modeling is essential to refine these assessments and inform policy.

Conclusions

This study provides comprehensive insights into the distribution, characteristics, and potential human health risks of microplastics (MPs) in seven Nigerian inland rivers during the rainy season. The results reveal significant seasonal influences on MP abundance and distribution across environmental compartments. Fish and water samples exhibited markedly higher MP concentrations during the rainy season compared to dry season values reported previously, primarily driven by enhanced surface runoff, flooding, and mobilization of land-based plastics. In contrast, sediment MP levels generally decreased in the rainy season due to resuspension and downstream transport, highlighting sediments as dynamic sinks that release particles under high-flow conditions. River Benue emerged as a persistent hotspot across matrices and seasons, while sites like River Argungu showed dramatic rainy season increases in water, underscoring site-specific hydrological and anthropogenic factors.

Morphological analysis indicated fibres as the dominant shape in both fish (48.5%) and sediments (49.3%), reflecting their prevalence from textile and fishing-related sources and tendency to settle or be ingested. Fragments prevailed in water (60.3%), consistent with fragmentation processes intensified by rainy season turbulence and runoff. Polymer characterization identified 15 types, with polystyrene (PS) showing bioaccumulation in fish (increasing from 27.8% in gills to 52.4% in guts), polypropylene (PP) pervasive across gills and sediments, and ethylene vinyl acetate (EVA) overwhelmingly dominant in water (68%), likely linked to consumer product degradation. Principal component analysis further elucidated compartmental relationships, with fish and sediments clustering together indicating transfer pathways and water influenced by transient inputs.

Human exposure assessment via estimated daily intake (EDI) revealed low quantity-based risks, with fish consumption as the primary pathway and River Benue posing the highest potential exposure, particularly for children on a body-weight basis. Although EDI values were orders of magnitude lower than global estimates, the presence of MPs as vectors for chemical contaminants and emerging evidence of chronic health effects emphasize the need for caution in populations reliant on these rivers. Overall, the rainy season exacerbates MP pollution in Nigerian inland rivers through enhanced transport and bioavailability, amplifying ecological and human health concerns in a region already burdened by poor waste management. These findings contribute to the limited body of knowledge on seasonal MP dynamics in African freshwater systems and highlight the urgency of addressing plastic pollution at its sources.

There is a need to implement long-term, seasonal monitoring programs across Nigerian rivers, prioritizing hotspots like River Benue, to track MP trends and incorporate chemical contaminant analysis (e.g., POPs, heavy metals) for more comprehensive risk assessments. Furthermore, strengthening enforcement of single-use plastic bans, improve solid waste collection and recycling infrastructure in riparian communities, and promote extended producer responsibility to reduce land-based plastic inputs, particularly during the rainy season.

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