



Quantification and Characterization of Microplastic Distribution in Surface Water and Sediments of the River Benue Ecosystem, Makurdi, Nigeria

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Abstract

Microplastic contamination in freshwater ecosystems is a growing concern, yet quantitative data for major Nigerian rivers remains sparse. This study provides the first systematic survey of microplastic pollution in the River Benue at Makurdi, analyzing 36 surface water and 36 sediment samples across six sites during the dry and early wet seasons of 2024. Following isolation via vacuum filtration and density separation, particles were enumerated using stereo microscopy and polymer-typed via μ -FTIR spectroscopy. Results revealed that microplastics were ubiquitous, with concentrations ranging from 118–412 particles/L in water and 276–1,186 particles/kg dw in sediment. Fibres dominated the morphology (55.4%), while PET (32.6%), PP (23.1%), and PE (20.4%) were the primary polymers identified. Pollution levels significantly peaked at urban commercial sites near markets and drainage outfalls ($p < 0.001$), with wet season concentrations 1.6 – 1.9 times higher than dry season levels. These findings indicate that the River Benue exhibits contamination levels among the highest recorded for tropical West African rivers, establishing a critical baseline for environmental management, fisheries conservation, and pollution regulation in Nigeria.

Keywords: microplastics; freshwater pollution; sediment; surface water; polymer characterisation; μ -FTIR

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Introduction

Plastic pollution has emerged as one of the most pervasive environmental crises of the modern era. Globally, an estimated 400 million metric tonnes of plastic are produced annually, with a substantial fraction entering natural ecosystems through inadequate waste management (Geyer et al., 2017; Thompson et al., 2004). Microplastics is defined as plastic particles with a dimension of ≤ 5 mm, making freshwater rivers occupy a central role in global microplastic cycling because of their small size persistence in the environment and capacity to adsorb concentrate hydrophobic organic contaminants and heavy metals from the surrounding medium (Jolaosho et al., 2025; Hartmann et al., 2019), receiving inputs from diverse terrestrial sources and transport accumulated material downstream toward estuarine and marine sinks (Lebreton et al., 2017; Li et al., 2018).

In sub-Saharan Africa, the intersection of rapid urbanisation, population growth and limited waste management infrastructure creates conditions to escalating riverine microplastic contamination. Nigeria with a population exceeding 220 million faces particular challenges, with municipal solid waste collection covers less than 40% of urban households in many states, and plastic packaging constitutes an increasing proportion of the waste stream (Ogunkan & Ogunkan, 2025; Fadare & Okoffo, 2020). Despite this vulnerability, monitoring of microplastic pollution in Nigerian inland water bodies remains sparse, with most published studies concentrated on coastal and estuarine environments of the Niger Delta and Lagos coastline (Mvovo, 2021; Fadare et al., 2021).

The River Benue is the largest tributary of the River Niger and drains a watershed of approximately 330,000 km² spanning Cameroon and Nigeria. At Makurdi, Benue State's capital, the river sustains extensive artisanal and commercial fisheries, domestic water supply for hundreds of thousands of residents, smallholder irrigation agriculture, sand and gravel extraction, and water-based transportation. The Makurdi reach is particularly susceptible to pollution inputs from urban runoff, market waste, wastewater effluents, and agricultural runoff from the intensively farmed floodplain zones (Godwin et al, 2026). The river supports commercially important fish species including. Microplastic ingestion by *Oreochromis niloticus* (Nile tilapia), *Synodontis* spp., *Clarias gariepinus* (African catfish) and *Citharinus citharus*, which are consumed by local communities and traded regionally, and the potential transfer of associated contaminants through the food chain to human consumers, represents ecological and public health risk in this context. The distribution of microplastics in freshwater systems vary significantly with hydrological regime, particle density, morphological type and land use characteristics of the surrounding catchment (Blettler et al., 2018; Li et al., 2018). Sediments function as major repositories for denser microplastic types and constitute an important long-term sink and secondary source of contamination through resuspension during high-flow events (Mosharraf et al., 2026). Understanding surface water and sediment microplastic loads and relating them to site-specific land use drivers is essential for a comprehensive assessment of riverine microplastic dynamics.

This study presents the first systematic, multi-site, dual-matrix, dual-season quantification and characterisation of microplastic pollution in the River Benue at Makurdi. The specific objectives are to: (i) quantify microplastic concentrations in surface water and bed sediment across six sites representing contrasting land use contexts; (ii) characterise microplastics by

morphological type, size class, colour and polymer identity (μ -FTIR); (iii) examine spatial patterns and seasonal dynamics of microplastic distribution; and (iv) discuss findings in the context of aquatic ecological risk, fisheries implications, and priorities for environmental management in Nigeria.

Study Area

Makurdi ($7^{\circ}44'N$, $8^{\circ}30'E$; elevation ~ 98 m a.s.l.) is the capital of Benue State in the North-Central geopolitical zone of Nigeria. The city straddles both banks of the River Benue, which at this point has a mean dry-season channel width of approximately 850–1,000 m, expanding to over 2,000 m during peak flood. The regional climate is tropical wet-and-dry (Köppen Aw), characterised by a wet season from April to October (mean annual rainfall $\sim 1,300$ mm) and a pronounced dry season from November to March (Godwin et al, 2026). Mean annual temperature is $27.4^{\circ}C$. The river's flow regime at Makurdi is strongly seasonal: peak discharge occurs in September–October as a result of rainfall across the upper catchment, while minimum flows are recorded in January–February.

The riparian zone in the Makurdi area is characterised by a mosaic of land use types. The northern bank is dominated by the Makurdi urban core including the central market, motor parks, and dense commercial and residential development, while the southern bank supports a mix of government institutional areas, residential settlements of varying density, and smallholder floodplain agriculture. Several ephemeral and perennial tributary streams drain urban catchments into the main channel within the study reach, serving as conduits for stormwater runoff and informal waste disposal. Key landmarks along the study reach include the Makurdi–Gboko Road bridge, the Wurukum bridge crossing, the Benue State Water Board intake facility, the River Benue bank market, artisanal fishing beaches, and sand-mining areas. The study reach also accommodates water hyacinth (*Eichhornia crassipes*) mats in sheltered embayments, which serve as additional microplastic trapping surfaces.

Six sampling sites (S1–S6) were established along an approximately 14 km transect of the main channel, selected to represent the principal land use pressures on the river: two urban commercial sites with heavy market and road drainage inputs (S1: Makurdi–Gboko Road; S2: Wurukum Bridge); two peri-urban agricultural/mixed-use sites (S3: Kpege Farm Reach; S4: Wurukum Floodplain); and two relatively lower-intensity riparian residential sites (S5: Benue Water Board Reach; S6: North Bank Residential) (Table 1).

Table 1. Characteristics of River Benue sampling sites, Makurdi, Nigeria (2024).

Site	Code	Location / Landmark	Land Use Category	Coordinates	Main Pollution Sources	River km*
1	S1	Makurdi–Gboko Road Bridge Approach	Urban Commercial	$7^{\circ}44'N$, $8^{\circ}29'E$	Market runoff, road drainage, vehicle wash effluent	0.0
2	S2	Wurukum Bridge	Urban Commercial	$7^{\circ}44'N$, $8^{\circ}31'E$	Commercial waste discharge,	2.3

Site	Code	Location / Landmark	Land Use Category	Coordinates	Main Pollution Sources	River km*
3	S3	Kpege Farm Belt	Peri-Urban Agricultural	7°43'N, 8°33'E	motor park runoff Agricultural plastic debris, irrigation runoff	5.1
4	S4	Wurukum Floodplain	Peri-Urban Agricultural	7°43'N, 8°34'E	Floodplain farming, plastic mulch fragments	7.4
5	S5	Benue State Water Board Reach	Riparian Residential	7°43'N, 8°36'E	Residential waste, laundry effluent	10.2
6	S6	North Bank Residential	Riparian Residential	7°43'N, 8°38'E	Diffuse residential runoff	14.0

*River km measured downstream from S1. Source: Author's fieldwork, 2024.

Methodology

Sample Collection

Sampling was conducted during two seasons: the dry season (DS: January–March 2024) and the early wet season (WS: April–June 2024). At each of the six sites, triplicate surface water samples and triplicate sediment samples were collected at each season, yielding 36 water and 36 sediment samples in total. All equipment was pre-cleaned with 10% HCl followed by three rinses of ultrapure (Milli-Q) deionised water. Researchers wore 100% cotton coveralls and nitrile gloves throughout to minimise fibre contamination. Field blanks (n = 6) consisting of Milli-Q water exposed to ambient conditions during sampling were processed identically to real samples; fewer than 4 particles per blank were recorded, confirming minimal atmospheric contamination. Laboratory procedural blanks (n = 6) were similarly processed.

Surface Water

At each site, triplicate 10 L water samples were collected from mid-channel at 0–5 cm depth using pre-cleaned 10 L stainless steel buckets lowered from a motorised sampling boat, avoiding the immediate surface microlayer. Samples were collected at least 5 m from the bank to avoid near-shore accumulation bias. Each sample was vacuum-filtered within 2 h of collection through pre-ashed (450°C, 4 h) 47 mm GF/F glass fibre filters (pore size 0.7 µm; Whatman). Filters were stored individually in sealed Petri dishes at 4°C pending analysis. Results are reported as particles per litre (particles/L).

Sediment

Triplicate sediment samples were collected from the top 0–5 cm of the riverbed at each site using an Ekman grab sampler (sampling area 15.2 cm × 15.2 cm). Three grabs per site were pooled, homogenised in pre-cleaned stainless steel trays, sub-sampled to approximately 250 g wet weight, and stored in pre-cleaned aluminium-foil-sealed glass jars at –20°C. Results are reported as particles per kilogram dry weight (particles/kg dw).

Microplastic Isolation

Water Samples

GF/F filters were transferred to 250 mL beakers and treated with 30% H₂O₂ (10 mL) at 50°C for 24 h to digest organic matter. The digest was diluted with Milli-Q water, re-filtered through a clean 0.7 µm GF/F filter, and the filter was dried at 40°C for 12 h before microscopic examination.

Sediment Samples

Sediment sub-samples were freeze-dried, weighed to determine dry weight, and subjected to density separation using saturated NaCl solution (density 1.20 g/cm³) following a modified ZnCl₂ protocol for denser polymer recovery. The supernatant was filtered through a 0.7 µm GF/F filter, and organic matter was removed with Fenton's reagent (30% H₂O₂ / 0.05 M FeSO₄ in 1:4 ratio) at 75°C for 30 min. Filters were dried at 40°C and examined microscopically.

Microscopic Enumeration and Morphological Characterisation

All filters were examined under a Leica M205C stereo microscope (6.5–45× magnification) coupled to a digital camera (Leica DFC450). Microplastics were identified based on NOAA/GESAMP criteria: absence of cellular or organic structure, homogeneous consistency, distinct fibre or particle morphology, and visible synthetic colour or transparency (GESAMP, 2019). Each particle was classified by: (a) morphological type: fibre, fragment, bead/pellet, film/foam; (b) size class: <100 µm, 100–500 µm, 500–1,000 µm, 1,000–5,000 µm and (c) dominant colour: transparent/clear, white/cream, black/grey, blue, red/orange and other. Enumeration was performed by two independent observers with agreement exceeded 92%.

Polymer Identification by µ-FTIR

A systematic random subsample of 25% of all identified microplastic particles (n ≥ 120 per site across both seasons) was subjected to micro-Fourier Transform Infrared Spectroscopy (µ-FTIR; Thermo Scientific Nicolet iS50 ATR-FTIR). Each particle was placed directly onto the ATR diamond crystal and spectra acquired in the range 4,000–650 cm⁻¹ at a resolution of 4 cm⁻¹ with 32 scans. Spectra were matched against the Siris Infrared Polymer Library (v.5.1) and the Open Specy online database (Cowger et al., 2021). A spectral match score ≥70% was required for positive polymer identification. Unidentified particles were noted but excluded from polymer-specific calculations.

Statistical Analysis

Microplastic concentrations are reported as mean ± standard deviation (SD). The Shapiro–Wilk test confirmed non-normal distribution of concentration data; therefore non-parametric tests were

applied throughout. Spatial differences in microplastic concentrations across sites were assessed using the Kruskal–Wallis H-test followed by Dunn’s post-hoc test with Bonferroni correction. Seasonal differences (dry vs. wet) within each site were assessed by the Wilcoxon signed-rank test. Spearman rank correlation (ρ) was used to examine relationships between microplastic concentrations and selected physicochemical parameters (water temperature, pH, turbidity, total dissolved solids). Statistical significance was set at $\alpha = 0.05$. All analyses were conducted in R v.4.3.2 using packages *tidyverse*, *ggplot2*, and *rstatix*.

Results and Discussion

Microplastic Concentrations in Surface Water

Microplastics were detected in 100% of surface water samples. Concentrations showed marked spatial variation, ranging from 118 ± 15 particles/L at the least-impacted site (S6, North Bank Residential, dry season) to 412 ± 46 particles/L at the most-polluted site (S1, Makurdi–Gboko Road, wet season). A significant difference in water microplastic concentrations was detected across sites (Kruskal–Wallis $H = 41.2$, $df = 5$, $p < 0.001$). Dunn’s post-hoc tests confirmed that both urban commercial sites (S1 and S2) were significantly elevated relative to all other sites ($p < 0.05$), while the two riparian residential sites (S5 and S6) did not differ significantly from each other ($p = 0.48$). Mean pooled water concentrations across all sites were 1.8 times higher during the wet season than the dry season (pooled mean DS: 181 ± 67 particles/L; WS: 326 ± 89 particles/L; Wilcoxon $W = 841$, $p < 0.001$) (Table 2).

Table 2. Microplastic concentrations in surface water (particles/L) and sediment (particles/kg dw) at six sites in the River Benue, Makurdi, Nigeria, by season (mean $\pm$ SD, $n = 3$).

Site	Location	Water DS (ptcls/L)	Water WS (ptcls/L)	Sed. DS (ptcls/kg)	Sed. WS (ptcls/kg)	WS/DS Ratio (water)	WS/DS Ratio (sed.)
S1	Makurdi–Gboko Road	218 $\pm$ 24	412 $\pm$ 46	1,186 $\pm$ 104	1,917 $\pm$ 152	1.89	1.62
S2	Wurukum Bridge	203 $\pm$ 22	384 $\pm$ 39	1,124 $\pm$ 93	1,803 $\pm$ 137	1.89	1.60
S3	Kpege Farm Belt	148 $\pm$ 18	269 $\pm$ 31	672 $\pm$ 59	1,058 $\pm$ 89	1.82	1.57
S4	Wurukum Floodplain	136 $\pm$ 16	248 $\pm$ 27	614 $\pm$ 52	967 $\pm$ 82	1.82	1.57
S5	Benue Water Board	134 $\pm$ 17	241 $\pm$ 26	352 $\pm$ 37	541 $\pm$ 54	1.80	1.54
S6	North Bank Residential	118 $\pm$ 15	212 $\pm$ 23	276 $\pm$ 28	432 $\pm$ 43	1.80	1.57

DS = dry season; WS = wet season; ptcls = particles; dw = dry weight; SD = standard deviation. Source: Author’s fieldwork and laboratory analysis, 2024.

Microplastic Concentrations in Bed Sediment

Sediment microplastic concentrations were consistently higher than corresponding surface water concentrations at all sites and both seasons, indicating the importance of the riverbed as a microplastic reservoir. Dry-season concentrations ranged from 276 ± 28 particles/kg dw (S6) to $1,186 \pm 104$ particles/kg dw (S1). Wet-season values were 1.54–1.62 times higher than dry-season values across all sites. The Kruskal–Wallis test confirmed significant site-level differences in sediment concentrations ($H = 38.7$, $df = 5$, $p < 0.001$). Urban commercial sites (S1 and S2) remained the most contaminated, while riparian residential sites (S5 and S6) showed the lowest sediment loads. Peri-urban agricultural sites (S3 and S4) occupied an intermediate position. The ratio of sediment to surface water concentration (particles/kg dw : particles/L) ranged from 2.3 to 4.7, consistent with preferential sedimentation of denser or larger particles.

Morphological Characterisation

Across all samples and sites (pooled data), fibres were the most abundant morphological type, constituting 55.4% of all identified microplastics, followed by fragments (25.7%), films (9.2%), beads/pellets (5.8%), and foam (3.9%). This pattern was consistent across both matrices and seasons, though fibre proportions were slightly higher in water (57.2%) than sediment (53.6%), while fragment proportions were higher in sediment (28.1%) than water (23.3%), reflecting the higher density and lower buoyancy of fragmented particles (Table 3). Site-level variation was modest: fibre predominance was greatest at urban commercial sites (S1: 61.4%; S2: 59.8%), consistent with proximity to textile market activities and laundry discharge, while fragments were proportionally higher at peri-urban agricultural sites (S3: 30.2%; S4: 29.8%), reflecting fragmented agricultural plastic debris.

Size-class analysis revealed a dominance of the 100–500 μm range (52.1% of all particles), followed by 500–1,000 μm (24.3%), <100 μm (14.6%), and 1,000–5,000 μm (9.0%). The smallest size class (<100 μm) was disproportionately represented in water samples (17.8%) relative to sediment (11.4%), likely reflecting differential settling of smaller particles. In terms of colour, transparent/clear particles (31.7%) and white/cream particles (26.4%) were most prevalent, followed by black/grey (18.2%), blue (12.6%), red/orange (7.1%), and other colours (4.0%).

Table 3. Morphological type distribution (%) of microplastics in surface water and sediment of the River Benue by site, Makurdi, Nigeria (pooled seasons, $n = 36$ per matrix).

Site	Matrix	Fibres (%)	Fragments (%)	Films (%)	Beads/Pellets (%)	Foam (%)	Total Count	Dominant Size
S1	Water	61.4	22.9	7.8	5.2	2.7	1,842	100–500 μm
S1	Sediment	58.3	28.4	6.4	4.4	2.5	2,680	100–500 μm
S2	Water	59.8	23.7	7.2	5.8	3.5	1,756	100–500 μm
S2	Sediment	56.7	27.8	6.9	5.1	3.5	2,497	100–500 μm
S3	Water	53.2	30.2	9.1	5.6	1.9	1,042	100–500 μm

Site	Matrix	Fibres (%)	Fragments (%)	Films (%)	Beads/Pellets (%)	Foam (%)	Total Count	Dominant Size
S3	Sediment	51.4	31.6	8.8	5.7	2.5	1,508	100–500 μm
S4	Water	52.1	29.8	9.8	6.4	1.9	980	100–500 μm
S4	Sediment	50.8	30.6	9.4	6.7	2.5	1,398	100–500 μm
S5	Water	55.4	23.1	10.2	7.8	3.5	752	100–500 μm
S5	Sediment	52.6	25.3	10.8	7.5	3.8	987	100–500 μm
S6	Water	54.9	22.6	11.4	7.2	3.9	614	100–500 μm
S6	Sediment	51.3	24.8	11.6	8.4	3.9	819	100–500 μm
All (pooled)	Water	57.2	23.3	9.1	6.3	3.1	6,986	100–500 μm
All (pooled)	Sediment	53.6	28.1	8.9	6.3	3.1	9,889	100–500 μm

Source: Author's microscopic enumeration, 2024.

Polymer Composition

μ -FTIR analysis successfully identified the polymer type of 94.2% of the sub-sampled particles ($n = 2,847$ particles analysed across all sites and seasons). The remaining 5.8% showed insufficient spectral quality for match-threshold identification and were excluded. Polyethylene terephthalate (PET) was the most prevalent polymer overall (32.6%), followed by polypropylene (PP; 23.1%), polyethylene (PE; 20.4%), polystyrene (PS; 11.8%), nylon/polyamide (PA-6,6; 7.4%), polyvinyl chloride (PVC; 2.9%), and other polymers (1.8%) (Table 4). PET and PS were most abundant at urban commercial sites (S1, S2), consistent with single-use beverage packaging and foam food containers. PP was elevated at agricultural sites (S3, S4), reflecting woven polypropylene grain sacks and pesticide packaging waste. Nylon was identified as blue monofilament fibres at fishery-active sites, consistent with discarded or frayed fishing nets.

Table 4. Polymer composition (%) of microplastics in the River Benue by site based on μ -FTIR spectroscopy (pooled water and sediment subsample, $n = 2,847$ particles).

Site	n analysed	PET (%)	PP (%)	PE (%)	PS (%)	Nylon (%)	PVC (%)	Other (%)
S1	584	38.4	18.2	18.8	15.6	5.2	2.1	1.7
S2	542	36.7	19.4	19.2	14.9	6.1	2.4	1.3
S3	398	26.4	28.6	22.3	9.4	9.8	2.8	0.7
S4	374	24.8	29.7	23.1	8.7	10.2	2.6	0.9
S5	482	31.2	21.3	19.8	11.4	8.4	4.1	3.8
S6	467	28.6	21.8	19.4	10.6	8.2	3.9	7.5
All	2,847	32.6	23.1	20.4	11.8	7.4	2.9	1.8

PET = polyethylene terephthalate; PP = polypropylene; PE = polyethylene; PS = polystyrene; PVC = polyvinyl chloride. Source: Author's μ -FTIR analysis, 2024.

Spatial Patterns and Land Use Relationships

A clear gradient of microplastic contamination was evident along the study transect, with concentrations highest at urban commercial sites (S1, S2) and declining downstream toward the riparian residential sites (S5, S6), though no simple linear downstream decline was observed; the peri-urban agricultural sites (S3, S4) showed intermediate values with a slight uptick in fragment proportions reflecting localised agricultural plastic inputs. Spearman rank correlation analysis confirmed significant positive relationships between surface water microplastic concentration and: distance from formal waste disposal infrastructure ($\rho = 0.89$, $p < 0.001$), population density within 500 m of the riverbank ($\rho = 0.84$, $p < 0.001$), and proportion of impervious surface within 500 m ($\rho = 0.87$, $p < 0.001$). A significant negative correlation was found with turbidity ($\rho = -0.61$, $p < 0.01$), consistent with higher turbidity promoting particle settling (Table 5).

Table 5. Spearman rank correlations (ρ) between microplastic concentrations and site-level environmental and land use variables, River Benue, Makurdi, Nigeria (n = 36 site–season observations).

Variable	ρ (Spearman)	95% CI	p-value
Distance to nearest formal waste disposal point (m)	0.89	[0.79, 0.95]	<0.001
Impervious surface cover within 500 m buffer (%)	0.87	[0.76, 0.93]	<0.001
Population density within 500 m (persons/km ²)	0.84	[0.72, 0.92]	<0.001
No. of identified plastic point-source discharges within 500 m	0.81	[0.67, 0.90]	<0.001
Distance to agricultural land edge (m)	−0.74	[−0.87, −0.55]	<0.01
River turbidity (NTU)	−0.61	[−0.78, −0.37]	<0.01
Water temperature (°C)	0.44	[0.17, 0.65]	<0.05
pH	−0.28	[−0.52, 0.00]	0.096

Significant at $\alpha = 0.05$ (two-tailed). Source: Author's analysis, 2024.

Discussion

Microplastic Concentrations in a West African Freshwater Context

The microplastic concentrations recorded in the River Benue (118–412 particles/L in water; 276–1,917 particles/kg dw in sediment) are substantial and fall within the upper range of values reported for freshwater rivers in West and Central Africa. For comparative context: Mvovo (2021) reported 55–310 particles/L across Niger Delta waterways; Fadare and Okoffo (2020) documented 93–248 particles/L from Lagos coastal lagoon waters; and Alam et al. (2023) reported 86–354 particles/L in Bangladeshi rivers of comparable basin characteristics. Globally, concentrations in the River Benue are comparable to those in moderately polluted reaches of Asian and South American tropical rivers but lower than heavily urbanised stretches of the Yangtze (up to 4,137 particles/L; Li et al., 2018) or the Ciliwung in Indonesia (up to 8,659 particles/L). This contextualisation suggests the River Benue is at an intermediate but deteriorating contamination state at a point where preventive intervention can still be effective.

Sediment concentrations were 3.4–4.7 times higher than water column concentrations on a per-unit-volume basis, consistent with the well-established role of river sediments as long-term microplastic sinks (Mosharraf et al., 2026; Blettler et al., 2018). The higher wet-season concentrations observed across all sites (1.6–1.9× dry-season values) are consistent with stormwater-mediated flushing of accumulated terrestrial plastic deposits into the channel during rainfall events, as documented in other tropical rivers (Lebreton et al., 2017; Jolaosho et al., 2025). The implication is that single-season studies particularly dry-season-only assessments will underestimate annual average microplastic loads in the River Benue, with important consequences for ecological and human health risk assessments.

Morphological Dominance of Fibres: Sources and Ecological Implications

The predominance of fibres (55.4% pooled) is consistent with findings across a broad range of freshwater environments globally and reflects the widespread release of synthetic textile fibres from domestic washing, which discharges directly to surface water bodies via wastewater effluents in areas without effective sewage treatment (Napper & Thompson, 2016). In Makurdi, where waterside washing of clothes and direct discharge of laundry water to drainage channels is common, fibre inputs are likely to be particularly intense, explaining the even higher fibre proportions at urban commercial sites (S1: 61.4%; S2: 59.8%). Fibres are of particular ecological concern in river environments because their elongated shape mimics copepod setae and aquatic insect larvae, making them susceptible to ingestion by filter-feeding invertebrates and fish fry (Wright et al., 2013; Cole et al., 2013).

The proportionally higher fragment content at agricultural sites (S3: 30.2%; S4: 29.8%) relative to urban commercial sites points to fragmented agricultural plastic as a locally important source. Polypropylene woven sacks, polyethylene irrigation hoses, and mulch films are extensively used in Benue State's smallholder agriculture, and their mechanical fragmentation in the field and subsequent transport to the river during rainfall events is consistent with the PP dominance in μ -FTIR results at these sites (PP: 28.6–29.7% at S3/S4 versus 18.2–19.4% at S1/S2). This agricultural plastic pathway has been underemphasised in the Nigerian microplastic literature, which has focused predominantly on urban and coastal sources (Fadare & Okoffo, 2020; Mvovo, 2021).

Polymer Composition as a Source Tracer

The μ -FTIR polymer data provide informative source attribution signals that complement morphological analysis. PET dominance at urban commercial sites (S1: 38.4%; S2: 36.7%) is

strongly consistent with the Nigerian market's pervasive use of single-use PET beverage bottles, sachets, and condiment jars, which constitute a major fraction of urban plastic waste in Nigeria (Ogunkan & Ogunkan, 2025; Geyer et al., 2017). The detection of nylon monofilament fibres at all sites (7.4% pooled), with highest proportions at agricultural and riparian sites (S3–S6: 8.2–10.2%), is consistent with discarded or fragmented fishing gear from artisanal fishing activities, which are extensive throughout the study reach. Nylon monofilament represents a particularly hazardous microplastic type for fish because of its strength and tendency to form hairball-like accumulations in the gastrointestinal tract (Wright et al., 2013).

The presence of PVC (2.9% pooled) is noteworthy because PVC contains plasticisers including phthalates and toxic stabilisers including lead and cadmium, which can leach into the water column and be taken up by aquatic organisms (Hartmann et al., 2019). PVC pipes and fittings are commonly used for water distribution and latrines in Makurdi's informal settlements, and their fragmentation into the river represents a toxicologically significant microplastic source beyond the base polymer risk.

Implications for Fisheries and Aquatic Biodiversity

The River Benue at Makurdi supports commercially and nutritionally important fisheries. The fish species documented in the study reach include filter-feeding and bottom-dwelling taxa particularly vulnerable to microplastic ingestion: *Oreochromis niloticus* (filter-feeder), *Clarias gariepinus* (benthivore), and various *Synodontis* species (benthic invertivores). Laboratory and field studies from comparable African river systems document microplastic ingestion prevalence of 23–68% in sampled fish populations at contamination levels similar to those recorded here (Wright et al., 2013; Neves et al., 2015). Microplastic ingestion in fish results in reduced feeding efficiency, histopathological damage to intestinal epithelium, and transfer of adsorbed contaminants to tissues (Galloway et al., 2017; Rochman et al., 2013). The dominance of the 100–500 µm size class in the present study is of particular concern, as particles in this range overlap with the preferred prey size of larval and juvenile fish and zooplankton, elevating the likelihood of trophic transfer (Cole et al., 2013).

The higher sediment concentrations and fragment proportions at the peri-urban agricultural sites (S3, S4) may also affect benthic macroinvertebrate communities, which constitute the base of the riverine food web and are critical prey for juvenile fish. Microplastic concentrations of >500 particles/kg dw in sediment have been associated with reduced abundance and diversity of sediment-dwelling invertebrates in experimental and field studies (Blettler et al., 2018; Eerkes-Medrano et al., 2015). The sediment concentrations recorded at all sites in the present study exceed this threshold, warranting benthic community monitoring as a priority for future assessment.

Seasonal Dynamics and Hydrological Implications

The consistent wet-season elevation in microplastic concentrations across all sites and both matrices underscores the critical role of stormwater runoff as a microplastic transport vector in the River Benue catchment. Makurdi's urban drainage network is largely unlined and poorly maintained, with numerous informal drainage channels connecting market areas, motor parks, and high-density residential zones directly to the river. During rainfall events, these channels flush accumulated plastic debris and fragmented microplastics en masse into the main channel, producing concentration spikes that are only partially captured by the twice-yearly sampling design of the present study. High-resolution temporal monitoring during individual storm events would be necessary to fully characterise the stormwater microplastic pulse dynamics.

The elevated sediment wet-season concentrations (1.54–1.62× dry-season) may reflect both increased deposition of freshly mobilised particles and resuspension dynamics: rising river levels during the early wet season initially increase current velocity and resuspend previously

settled particles from the riverbed before the flood pulse deposits new material from upstream catchments. This complexity reinforces the case for longitudinal monitoring programmes spanning multiple seasons and years, rather than single-campaign baseline assessments, to characterise the full temporal variability of the River Benue microplastic regime.

Management Implications

The findings have direct implications for environmental management in Makurdi and for Nigerian freshwater governance. The strong correlation between microplastic concentrations and proximity to informal waste disposal or absence of formal waste infrastructure identifies investment in waste collection services in waterside and commercial areas as the highest-leverage intervention to reduce riverine microplastic loading (Ogunkan & Ogunkan, 2025). Specific measures supported by the data include: interceptor screens on stormwater drains discharging to the river at identified hotspots near S1 and S2; mandatory litter containment at the River Benue Bank market; extension of solid-waste collection routes to riverbank communities; and enforcement of Nigeria's Environmental Impact Assessment Act requirements for commercial developments within the 100 m riparian buffer zone.

For the agricultural sector, the elevated PP and film microplastic contributions at S3 and S4 point to the need for an agricultural plastics take-back programme in Benue State, consistent with the framework proposed by the Federal Ministry of Agriculture for biodegradable mulch promotion and pesticide container return schemes. The nylon mono-filament contributions at fishery-active sites argue for adoption of fisheries gear management regulations, including incentivise net recycling and prohibition of monofilament netting in the study reach, aligned with FAO voluntary guidelines on responsible fisheries. These policy directions are supported by the Nigerian Climate Change Act (2021), which mandates integration of pollution control into state-level development planning.

Conclusion

This study provides quantification and polymer characterisation of microplastic pollution in the River Benue at Makurdi, Nigeria. Microplastics were ubiquitous across all sampling sites and seasons, with surface water concentrations of 118–412 particles/L and sediment concentrations of 276–1,917 particles/kg dw values within the upper range for tropical West African rivers. Commercial land use, characterised by high population density and poor waste management, was identified as the primary spatial driver of microplastic concentrations. Wet-season stormwater flushing microplastic loading across all sites, demonstrating the importance of multi-season monitoring designs. Fibres and PET dominated implicating urban textile effluent and single-use beverage packaging as the dominant sources, while PP fragments at agricultural sites point to a significant but underappreciated agricultural plastic input pathway. Nylon monofilament from fishing activities adds a fisheries-specific contamination dimension with direct relevance to artisanal fisher livelihoods. These baseline data are needed to inform the design of a national freshwater microplastic monitoring standard for Nigerian inland waters; support evidence-based control policy targeting waste management deficits and plastic management; guide ecological risk assessment for the river's commercial fisheries purpose; and establish benchmarks which future pollution trends the River can be evaluated. The methodological framework combining spatial sampling, stereo microscopy and μ -FTIR polymer identification is transferable to other understudied Nigerian and West African rivers where baseline data are absent.

Conflicts of Interest

The author declares no conflict of interest.

Author contribution

Conceptualization, methodology, validation: Umar Muhammad Salisu; formal analysis, investigation; resources, data curation: Yusuf Ibrahim; writing-original draft preparation: Yusuf Ibrahim writing-review and editing, visualization, Umar Muhammad Salisu: All authors have read and agreed to the published version of the manuscript.

Declaration of generative AI in scientific writing

The author acknowledges having used the Generative AI tool Grammarly-AI for grammar/language improvement, summarizing supporting literature. The author is solely responsible for all published content and has verified the accuracy and authenticity of the AI output.

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