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Microplastics in Surface Water of River Nun in Bayelsa Central, Nigeria: Occurrence, Distribution Pattern, and Ecological Risk

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ABSTRACT: Microplastic pollution poses a growing threat to aquatic ecosystems and biodiversity due to its persistence and potential harm to human health. This study examines the occurrence, distribution, and ecological impact of microplastics in surface water from River Nun, Bayelsa Central, Nigeria. Sampling was conducted at six locations over six months (January–March and July–September 2024). Samples were processed using NOAA techniques, including filtration, density separation, and microscopy, while FTIR and GC-MS were used for polymer and additive analysis. Microplastic abundance was lowest in February (40 particles/L) and peaked in August (148 particles/L). Smaller microplastics (<0.3 mm) accounted for 64.1%, with fragments at 61% and beads at 39%. Concentrations ranged from 0.22 ± 0.05 g/L to 0.54 ± 0.16 g/L, with higher values during the rainy season. Some locations exceeded risk thresholds, with risk quotients up to 10.77, posing ecological threats. FTIR identified polymers like polyethylene, polypropylene, and PVC, while GC-MS detected high phthalate levels, particularly dibutyl phthalate and diethylhexyl phthalate (36.72 ppm). These findings emphasize the need for environmental management and community awareness to mitigate microplastic contamination in the Nun River.

Keywords: Microplastics, River Nun, Surface water pollution, Ecological risk, Chemical additives

Introduction

Due to their flexibility, strength, and relatively low cost, plastics are now crucial to people's everyday lives (Haque *et al.,* 2023). Plastics are used in packaging, building, transportation, medicine, and even technology. Nonetheless, irresponsible manufacturing and disposal of plastics create major environmental challenges (Alfonso *et al.,* 2020; Estherrani *et al.,* 2024). The accumulation of these materials in land and water bodies poses a global threat because of their highly durable nature, with the tendency to break down for centuries into microplastics (MPs) (Alfonso *et al.,* 2021; Ta & Babel, 2022; Junaid *et al.,* 2023). According Thi *et al.,* (2021) define microplastics as plastic particles smaller than 5 mm in size. They can either be primary microplastics, created from the breakdown of other materials, or secondary microplastics, resulting from the breakdown of larger plastic waste (Ta & Babel, 2019; Kigera *et al.,* 2020). Their ubiquitous distribution in the environment, particularly in water bodies, is of great concern because it poses a significant threat to ecosystems and human health that requires urgent scientific and policy action (Debroy *et al.,* 2021; Zhang *et al.,* 2019).

Freshwater rivers, lakes, deep-sea sediments, and even polar ice caps are all recorded to contain Microplastics (Agbekpornu et al. 2023). The estimate of tons of plastic that are deposited in the ocean every year is in the millions, with rivers acting as the main distributing channels for the contamination (Naqvi *et al.,* 2024; Ronda et al 2021). Microplastics present various environmental challenges (Eales *et al.,* 2022). They transport severe contaminants throughout the ecosystem, which include metals, organic poly-pollutants (OPPs), and disease-causing microorganisms (Ta & Babel, 2020; Li *et al.,* 2023). In addition, microplastics are ingested by aquatic animals that can cause severe danger due to chemical bioaccumulation and biomagnification throughout the

food web (Benson *et al.,* 2022; Kim *et al.,* 2022; Krause *et al.,* 2021). It undermines biodiversity, ecology, and human health, especially those dependent on water for food and economic development (Eales *et al.,* 2022).

Africa, like many other parts of the world, is suffering from the effects of plastic pollution, especially microplastics (Talukdar *et al.,* 2023). Rapid urbanization, population expansion, and poor waste treatment infrastructure have all contributed to the continent's plastic garbage accumulation (Agarwal *et al.,* 2020; Ta *et al.,* 2020a; Ezeudu *et al.,* 2022). Many African nations, including Nigeria, engage in open dumping and burning of plastic trash, which results in the release of microplastics into terrestrial and aquatic habitats (Duru *et al.,* 2019; Junaid *et al.,* 2023). Plastic garbage is becoming increasingly prevalent in rivers, which serve as lifelines for many communities (Guven, 2021; Valdivia *et al.,* 2024). Despite this, research on microplastics in African aquatic ecosystems is lacking in comparison to other regions, resulting in a severe information vacuum that impedes the development of effective mitigation solutions (Alfonso *et al.,* 2024).

The Niger Delta is an ecologically and economically significant region in Nigeria. It is home to enormous river networks, diverse biodiversity, and significant natural resources (Adeogun *et al.,* 2020; Akinhanmi *et al.,* 2023). However, the Niger Delta is under intense environmental pressures, including as oil exploration, deforestation, and pollution from home and industrial operations (Attah *et al.,* 2023). The River Nun, a significant tributary of the Niger River, runs through Bayelsa Central, an area where populations rely significantly on the river for fishing, transportation, and water provision (Briggs *et al.,* 2019; Alfonso *et al.,* 2020). Poor waste management techniques, urbanization, and industrial operations have all contributed to the river's plastic contamination. Microplastics in the River Nun endanger aquatic ecosystems and human health and livelihoods, given the area's dependency on the river for food and water (Yalwaji *et al.,* 2022).

As microplastics emerge as a worldwide environmental concern, it is critical to evaluate their effects from several scales, including global, regional, and local perspectives (Zhang *et al.,* 2019; Han *et al.,* 2019; Babel *et al.,* 2022). The River Nun, a key but understudied water body in the Niger Delta in terms of plastic pollution, provides a unique case study for understanding the relationship between human activities, plastic pollution, and aquatic ecosystem health (Ta & Babel, 2019; Sarin & Klomjek, 2022). This study is a step toward resolving the environmental concerns of microplastics in Nigeria, with larger implications for policy, research, and sustainable development throughout Africa and beyond.

This study will look at microplastics' content, distribution, and properties in the River Nun's surface water in Bayelsa Central, Nigeria. Using a scientific method, the study aims to offer baseline data on microplastic contamination in the region, emphasizing likely sources and routes. By placing this study in a global and regional perspective, it aims to fill key information gaps about microplastics in tropical riverine systems, notably in Africa (Oceng *et al.,* 2023). Furthermore, this study highlights the necessity of combining scientific research, policy development, and community participation to combat the rising problem of microplastics.

Materials and methods

Study area: Bayelsa Central is located in the Central Niger Delta region of Nigeria, which lies at Latitude/Longitude 4°48′17″N 6°04′44″E, and 5°5′55″N 6°15′50″E. This region is renowned for its complex network of rivers, creeks, estuaries, and mangrove forests, which support a diverse and unique ecosystem. Bayelsa Central serves as a critical ecological zone, hosting rich biodiversity that includes endangered species such as sea turtles, manatees, and various bird species. The indigenous communities in Bayelsa Central depend heavily on its aquatic and marine resources for their livelihoods, with fishing, agriculture, and tourism forming integral parts of their economy and cultural heritage. The River Nun, a prominent freshwater body in the region, plays a vital role in sustaining these communities, making it a focal point for ecological and environmental studies.

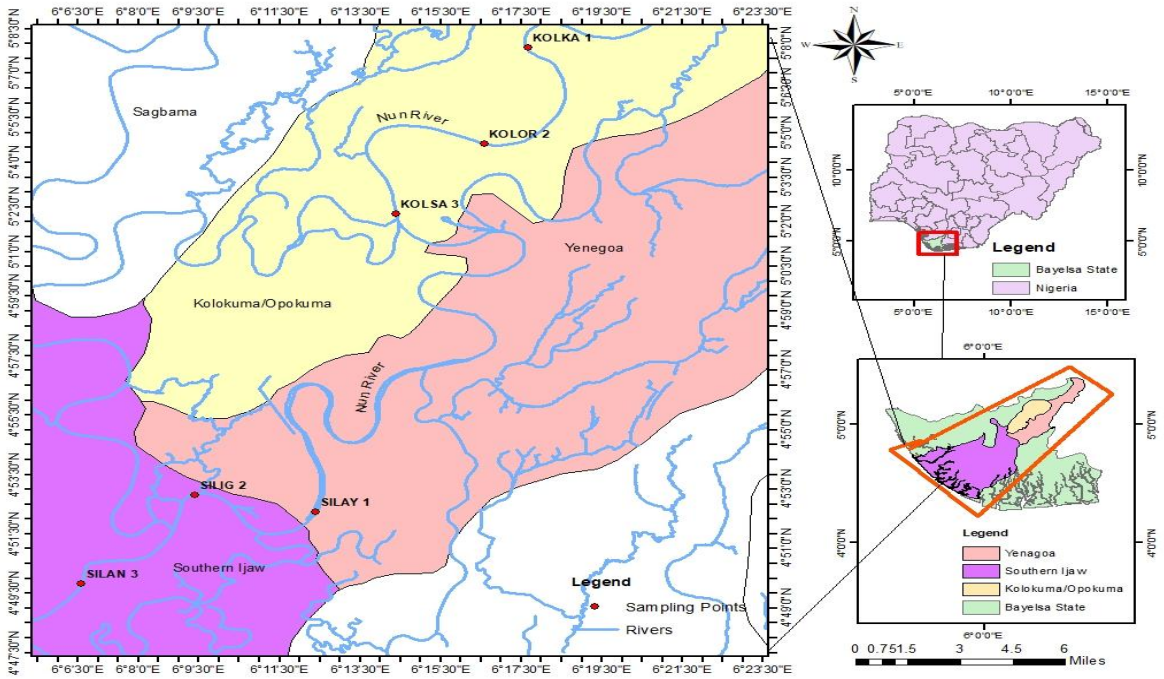

Figure 1: Surface water sampling locations for microplastics in River Nun, Bayelsa Central, Nigeria

Sample collection: Sample collection was conducted following the methodologies outlined by Attah *et al.,* (2023) and Briggs *et al.,* (2019), with adjustments made to accommodate the study's objectives and environmental conditions. Samples were collected were collected along River Nun in six (6) locations, these are: Kaiama (KOLKA 1), Orubiri (KOLOR 2), Sabagreia (KOLSA 3), Ayama (SILAY 1), Igeibiri (SILIG 2) and Angiama (SILAN 3). These locations were strategically chosen based on their ecological significance and relevance to local socio-economic activities, ensuring comprehensive spatial coverage of the study area. The sampling was conducted over six (6) months (January to March and July to September 2024) to account for spatio-temporal variations in microplastic distribution. Plankton nets (50 µm mesh) were used for surface water collection. Samples were filtered through a 5 mm sieve to selectively collect particles smaller than 5 mm. Samples were transferred into 36 sterile glass sample bottles to prevent contamination from all the sample locations for 6 months. A total of thirty-six (36) samples were collected across all sites during the study period.

Sampling preparation and extraction of microplastics: Surface water samples were processed using NOAA protocols with slight modifications (Masura *et al.*, 2015; Lusher & Hernandez-Milian, 2018; Attah *et al.*, 2023). Samples were pretreated by filtration through a GF/F (0.45 µm) glass fiber filter, and residues were digested with 30% hydrogen peroxide (H_2 O_2) at 60 °C for 12 h. Post-digestion, residues were filtered again, dissolved in a saturated NaCl solution, and left to settle for 24 h. The final residue was vacuum-filtered, dried at 60 °C, and rinsed into a Petri dish with ethanol for analysis. Microplastics were analyzed under light electron microscopy, with parameters recorded for shape (e.g., fragment, fiber, pellet), color (e.g., black, white, brown), and length (e.g., 5 mm, 4 mm, 3 mm). This preparation ensured the reliable identification and characterization of microplastics.

Analysis of microplastics: FTIR Spectroscopy analysis (350 to 4000 wave numbers cm-1) was performed for each sample in triplicate for plastic identification and Gas Chromatography-Mass Spectrometry (Agilent Technologies, Santa Clara, USA) was used to identify various chemical additives such as phthalates associated with microplastics in the water samples (Masura *et al.*, 2015).

Quality assurance and quality control: To ensure cleanliness during the experiment, researchers avoided wearing materials like cotton and linen that could shed particles. Measures were taken to minimize airflow in the experimental area and prevent the introduction of contaminants. All liquids used were filtered through a GF/C filter (1.2 µm, Whatman®) before testing. Instruments were cleaned with ultrapure water and absolute ethanol, then covered with foil after use. A control experiment was conducted to assess the impact of liquids, air movement, and environmental conditions on the results. Airborne particles were evaluated by drawing air through a 0.45 µm glass microfiber filter for 90 minutes under vacuum filtration. On average, 0.33 ± 0.47 particles were observed under a stereoscopic microscope. No plastic particles were detected after filtering 10 liters of ultrapure water through the filter. Thus, contamination during the analysis was negligible.

Statistical analysis: The data collected were analyzed using One-way ANOVA statistical methods with the aid of the Statistical Package for Social Sciences (SPSS), version 25.

Microplastic risk assessment method: The potential ecological risk assessment of this study was conducted using the method adopted by Wang *et al.,* (2021) and Mehinto *et al.,* (2022) with some modifications. To assess the potential ecological risk associated with microplastics, Risk Quotient (RQ) methods were employed using the equation:

$$RQ = \frac{PEC}{PNEC}$$

where:

- PEC: Predicted Environmental Concentration, determined through laboratory analysis of microplastics in water.
- PNEC: Predicted No-Effect Concentration, obtained from literature or calculated using toxicity data and safety factors.

The risk is categorized as follows:

- RQ<1: Low or negligible risk.
- RQ≥1: Potential risk to the environment or organisms.

Two PNEC values were used for this study (Mehinto *et al.,* 2022):

- PNEC Low = 0.05 mg/L/day
- PNEC High = 6 mg/L/day

Results

The result of the abundance of microplastics in surface water during both dry (January-March) and rainy (July-September) seasons across the sampling locations is shown in Figure 2 below.

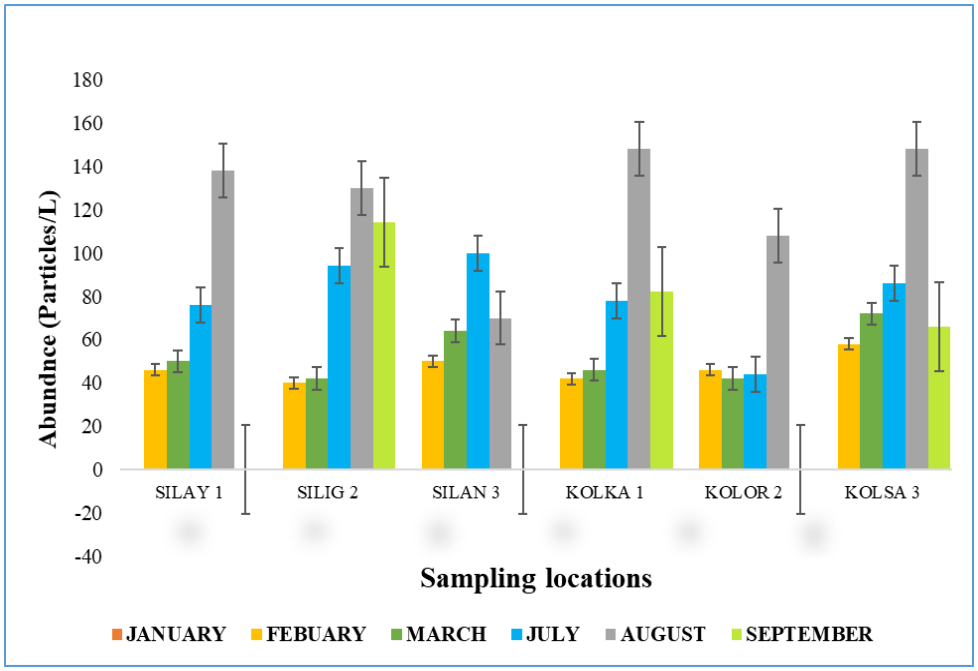

Figure 2. Abundance of microplastics in surface water during both dry and wet season (January – September 2024) across sampling locations in Bayelsa Central, Nigeria

The shape distribution of microplastics in surface water during both dry (January-March) and rainy (July-September) seasons across the sampling locations is illustrated in Figure 3 below.

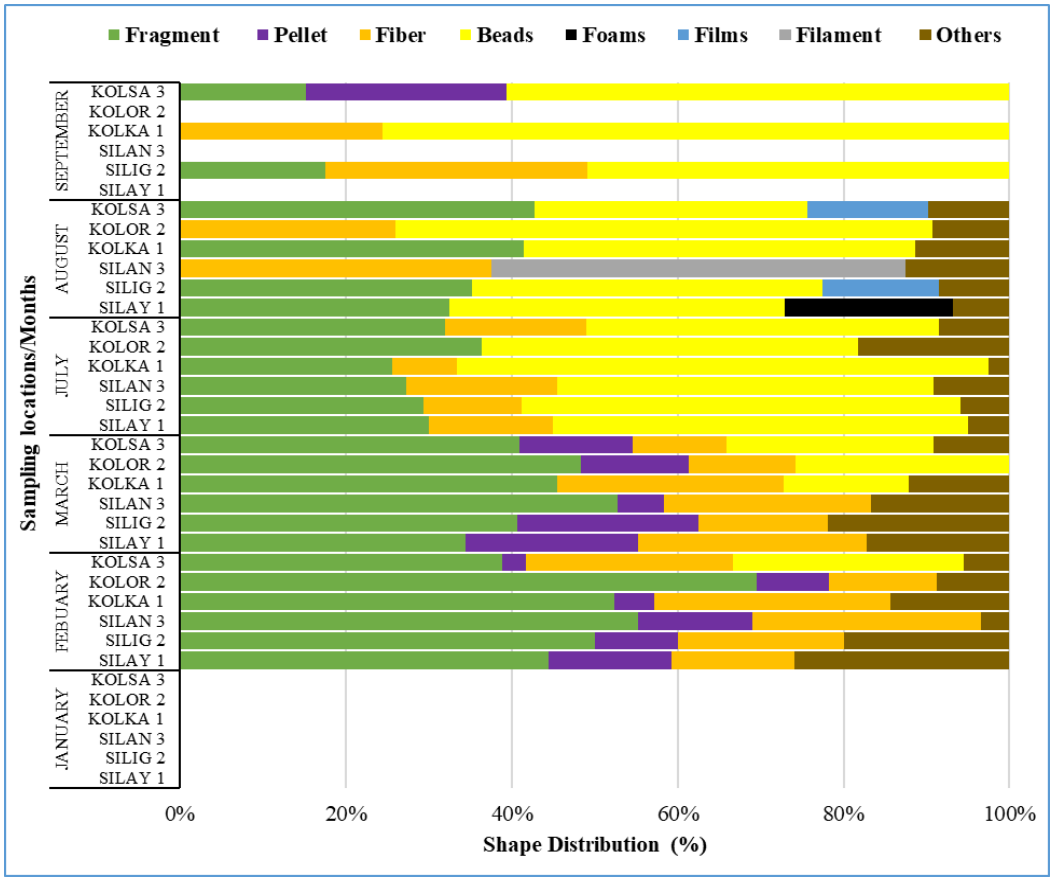

Figure 3. Shapes distribution of microplastics in surface water during both dry and wet season (January – September 2024) across sampling locations in Bayelsa Central, Nigeria

Figure 4 depicts the color distribution of microplastics in surface water throughout both the dry (January-March) and rainy (July-September) seasons at various sample locations as shown below.

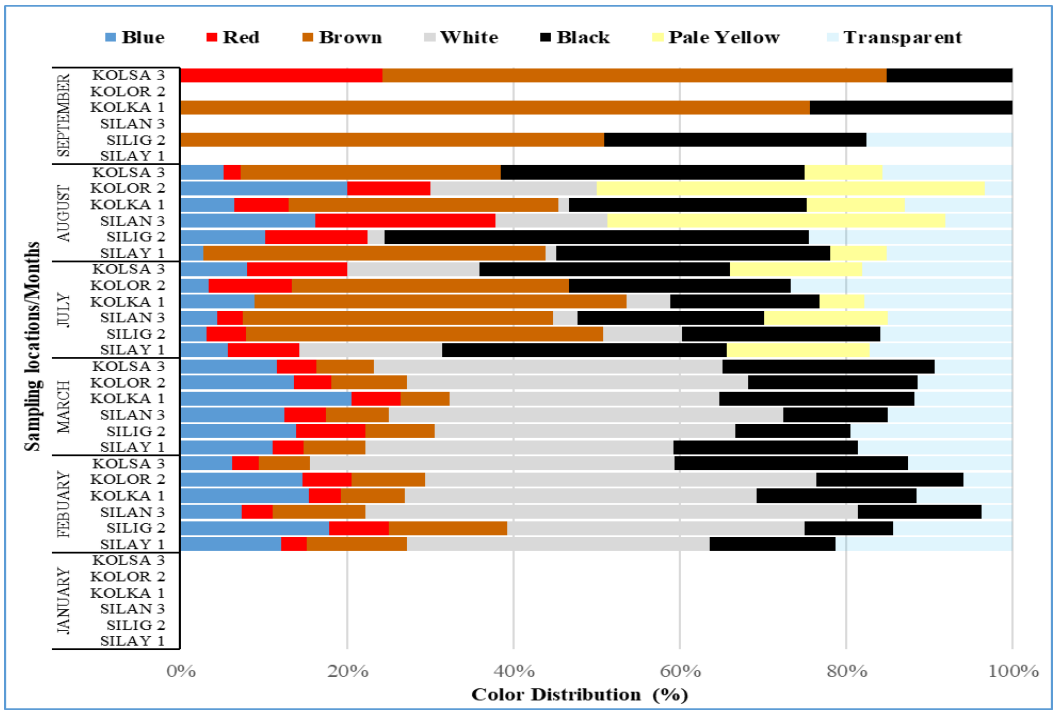

Figure 4: Colour distribution of microplastics in surface water during both dry and wet seasons (January – September 2024) across sampling locations in Bayelsa Central, Nigeria

Figure 5 depicts the size distribution of microplastics in surface water, comparing changes seen during the dry (January-March) and rainy (July-September) seasons at several sample locations as displayed below.

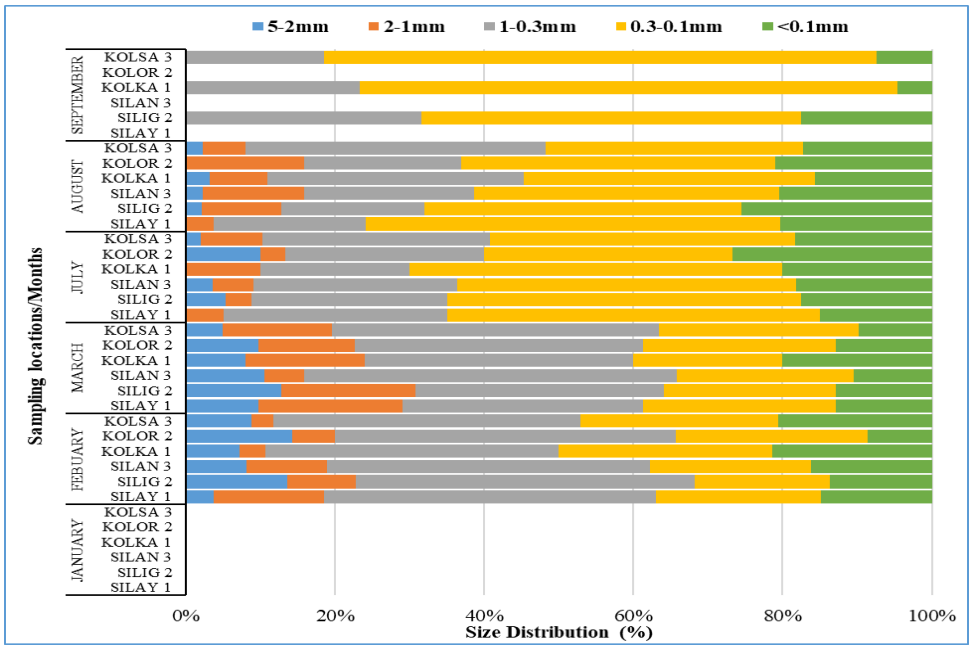

Figure 5: Size distribution of microplastics in surface water during both dry and wet seasons (January – September 2024) across sampling locations in Bayelsa Central, Nigeria

Table 1 shows the various types and concentrations of phthalates and other chemical additives found in surface water samples collected during both dry (January-March) and rainy (July-September) seasons as presented in the following.

Table 1: Phthalate and additives detected in Surface Water during both dry and rainy seasons (January – September 2024).

Phthalate/Additives	RT (min)	Peak Area (ppm)	Locations/Months
Dibutyl phthalate	6.056, 6.027, 4.810, 7.389	13.25, 8.94, 3.41, 5.64, 22.33, 27.19, 23.77	SILAY 1 (JUL), SILIG 2 (JUL), SILAN 3 (JUL), KOLKA 1 (JUL, MAR), KOLOR 2 (JUL)
Bis(2-ethylhexyl) phthalate	7.389	13.17, 22.33, 19.97, 30.66, 26.41, 32.82, 36.80, 33.08, 31.41, 31.51	SILAY 1 (AUG), SILIG 2 (AUG), KOLKA 1 (AUG), KOLOR 2 (AUG), KOLSA 3 (AUG, SEPT)
Benzyl butyl phthalate	11.185, 12.217	38.42, 30.66, 26.41, 36.72, 33.08, 31.41, 31.51, 11.50, 23.77	SILAY 1 (AUG), SILIG 2 (AUG), KOLKA 1 (JUL, AUG), KOLOR 2 (JUL, AUG), KOLSA 3 (JUL, AUG)
Di(2-ethylhexyl) phthalate	6.045, 11.190, 12.229	27.19, 22.33, 19.97, 32.82, 36.80, 33.08, 31.51, 31.41	KOLOR 2 (JUL), KOLSA 3 (JUL, AUG), KOLKA 1 (AUG), SILAY 1 (AUG)
Diisooctyl phthalate	7.389	3.41, 5.64, 3.33	SILIG 2 (FEB), KOLKA 1 (MAR), KOLSA 3 (MAR, SEPT), KOLOR 2 (JUL)
Phthalic acid, di(2-propyl pentyl) ester	7.389	22.33, 22.33, 22.33	KOLSA 3 (MAR), SILIG 2 (FEB), KOLKA 1 (MAR)
Phthalic acid, monoamide, N-isopropyl-, pentyl ester	4.805	12.58	KOLOR 2 (FEB)
Phthalic acid, 5-methylhex-2-yl isobutyl ester	4.810	10.82	KOLKA 1 (FEB)
Phthalic acid, 5-ethyl-1,3-dioxan-5-yl propyl ester	4.810	13.17	KOLSA 3 (FEB)

Phthalate/Additives	RT (min)	Peak Area (ppm)	Locations/Months
Phthalic acid, di(3,4,5-trifluorobenzyl) ester	4.805	11.00	SILAN 3 (FEB)
Phthalic acid, cyclohexylmethyl butyl ester	4.804	10.85	SILAY 1 (FEB)
Phthalic acid, butyl isohexyl ester	4.804	10.85	SILAY 1 (FEB)
Phthalic acid, 2-cyclohexylethyl ethyl ester	4.804	10.85	SILAY 1 (FEB)
Phthalic acid, 2-hexyl ester	7.389	7.65	SILAY 1 (MAR)
Mono(2-ethylhexyl) phthalate	7.389	7.65	SILAY 1 (MAR)
Didodecyl phthalate	7.389	7.65	SILAY 1 (MAR)
Phthalic acid, monooctyl ester	4.810	3.36	KOLKA 1 (SEPT)
Phthalic acid, pentyl pentadecyl ester	4.810	3.36	KOLKA 1 (SEPT)
Phthalic acid, hexadecyl pentyl ester	7.389	3.33	KOLKA 1 (SEPT)
Phthalic acid, butyl tetradecyl ester	4.805	1.53	SILIG 2 (SEPT)
1,2-Benzenedicarboxylic acid, bis(2-methylpropyl) ester	4.805	1.53	SILIG 2 (SEPT)
Dimethyl Phthalate	4.724	0.34	SILAN 3 (SEPT)
Diisodecyl Phthalate	4.735	1.43	KOLKA 1 (SEPT)
Dibut-3-enyl phthalate	4.718	2.19	KOLSA 3 (SEPT)
Phthalic acid, 5-ethyl-1,3-dioxan-5-yl isobutyl ester	4.810	2.19	KOLSA 3 (SEPT)

Figure 6 depicts the distribution of polymer types in surface water throughout both dry (January-March) and rainy (July-September) seasons across sample locations as displayed below.

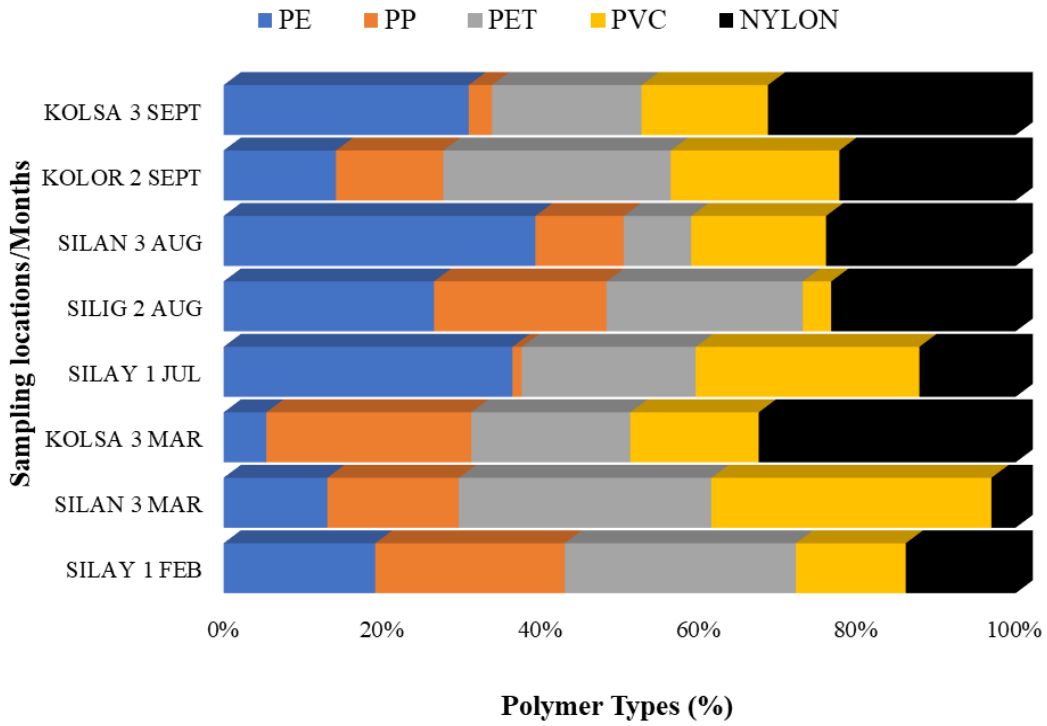

Figure 6: **P**olymer types in surface water during both dry and wet season (January – September 2024) across selected sampling locations of River Nun in Bayelsa Central, Nigeria

Table 2 shows the FTIR analysis, which identifies distinct functional groups linked with certain polymers across the sampling locations during both the dry (January-March) and wet (July-September) seasons.

Table 2: Identification of Polymer Types with the Functional Groups using FTIR

Wavenumbers (cm^{-1}) Ranges	Functional Groups	Polymer Types	Locations/Months
3500–3200	Amide (–CONH–)	Polyamide (Nylon)	SILAY 1 FEB, SILAN 3 MAR, KOLSA 3 MAR, SILAY 1 JUL, SILIG 2 AUG, SILAN 3 AUG, KOLOR 2 SEPT, KOLSA 3 SEPT
2970–2840	Carbon-carbon single bond	Polyethylene (PE)	SILAY 1 FEB, SILAN 3 MAR, KOLSA 3 MAR, SILAY 1 JUL, SILIG 2 AUG SILAN 3 AUG, KOLOR 2 SEPT, KOLSA 3 SEPT
2975–2840	Methyl group	Polypropylene (PP)	SILAY 1 FEB, SILAN 3 MAR, KOLSA 3 MAR, SILAY 1 JUL, SILIG 2 AUG SILAN 3 AUG, KOLOR 2 SEPT, KOLSA 3 SEPT
1750–1700	Carbonyl group	Polyethylene Terephthalate (PET)	SILAY 1 JUL, KOLOR 2 SEPT
1300–1100	Ester (–COO–)	Polyethylene Terephthalate (PET)	SILAY 1 FEB, SILAN 3 MAR, KOLSA 3 MAR, SILAY 1 JUL, SILIG 2 AUG, SILAN 3 AUG, KOLOR 2 SEPT, KOLSA 3 SEPT
550-850	Chlorine (–Cl)	Polyvinyl Chloride (PVC)	SILAY 1 FEB, SILAN 3 MAR, KOLSA 3 MAR, SILAY 1 JUL, SILIG 2 AUG, SILAN 3 AUG, KOLOR 2 SEPT, KOLSA 3 SEPT

Table 3 shows the mean microplastic concentrations after analysis of variance (ANOVA) in surface water across sample locations is displayed below.

Table 3: Analysis of variance (ANOVA) of mean microplastic concentrations (± Standard Error) in surface water across sampling locations

Variable	Mean±Std Error (g/L)	F(p-value)
SILAY 1	0.24±0.10	0.900 (0.525)
SILIG 2	0.22±0.05	
SILAN 3	0.31±0.10	
KOLKA 1	0.37±0.09	
KOLOR 2	0.30±0.12	
KOLSA 3	0.54±0.16	

Table 4 presents a detailed ecological risk assessment of microplastics in surface water from the different sampling locations as been displayed as follows.

Table 4: Ecological risk assessment of microplastic in surface water across the sampling locations

Location	Average Concentration (mg/L)	$PNEC_{Low}$	RQ_{Low}	Risk Level (Low/High)	$PNEC_{High}$	RQ_{High}	Risk Level (Low/High)
SILAY 1	0.23	0.05	4.76	High	6	0.039	Low
SILIG 2	0.21	0.05	4.36	High	6	0.036	Low
SILAN 3	0.31	0.05	6.23	High	6	0.051	Low
KOLKA 1	0.36	0.05	7.33	High	6	0.061	Low
KOLOR 2	0.29	0.05	5.9	High	6	0.049	Low
KOLSA 3	0.53	0.05	10.76	High	6	0.089	Low

Discussion

Abundance of microplastics: According to Figure 2, microplastic concentrations in River Nun varied significantly over six months in 2024, peaking in the wet season (July–August) with up to 130, 138, and 148 particles/L at SILIG 2, SILAY 1, and KOLSA 3 respectively. The high microplastic concentrations in these locations are likely influenced by local factors such as proximity to urban areas or industrial activities as reported similarly by Pazos *et al.*, (2021). No microplastics were detected in January, indicating minimal

microplastic input into the river during this time. This aligns with studies by Tang & Luo, (2023), who reported reduced microplastic concentrations in water bodies during dry seasons due to lower runoff and anthropogenic inputs. However, levels of microplastic abundance rose from February, with moderate concentrations (40–72 particles/L) in February and March, driven by rainfall and runoff (Sekudewicz *et al.,* 2021; Ta & Babel, 2020). Higher concentrations at KOLSA 3, SILIG 2, and KOLKA 1 reflect urban pollution sources and hydrological factors, consistent with reports by Klein *et al.,* (2015) and Zhao *et al.,* (2023). These findings highlight the need for focused monitoring during rainfall peaks to understand microplastic sources and guide mitigation strategies (Vermaire *et al.,* 2017; Tibbetts *et al.,* 2018; Kallenbach *et al.,* 2022).

Shapes of Microplastics: The distribution of microplastic shapes in surface water samples from River Nun over six months in 2024 is presented in Figure 3. A total of 1,148 microplastic particles were identified, with fragments (34.7%) and beads (33.8%) emerging as the dominant shapes. Fibers contributed 14.3%, while pellets accounted for 4.1%. Other shapes, including foams, films, and filaments, were detected in smaller quantities, collectively contributing 4.97%. Fragments consistently constituted the largest proportion of microplastics across the six months, with their highest counts observed in February and March. Beads showed a similar prominence, particularly in July and August, where their contributions increased significantly. Fibers were consistently present, though in lower proportions compared to fragments and beads, with notable occurrences in February and March. Pellets, foams, films, and filaments were sporadically detected, contributing minimally to the overall microplastic load as similarly reported in a study conducted by Adeogun *et al.,* (2020) and Amelia *et al.,* (2021). These findings highlight the predominance of fragments and beads, suggesting that the microplastic pollution in River Nun is heavily influenced by the breakdown of larger plastics, synthetic fibers, and possible industrial or consumer product sources as revealed by a similar research by Gupta, *et al.,* (2023). The consistent presence of these shapes across the six months points out the need for targeted interventions to mitigate microplastic pollution and its potential ecological impacts as noted by Mkuye *et al.,* (2022) and Abd Rahman *et al.,* (2021).

Color distribution: Figure 4 illustrates the color distribution of microplastics identified in surface water samples from River Nun over six months in 2024. A total of 1,220 microplastic particles were recorded, with black (26.48%) and brown (22.70%) being the most dominant colors. White microplastics accounted for 16.97%, while transparent particles contributed 14.51%. Blue and red particles were less prevalent, comprising 8.44% and 5.66%, respectively. Pale yellow microplastics made up the smallest proportion at 5.25%. The dominance of black and brown particles suggests a significant contribution from weathered plastics, tire wear, and industrial sources, which are commonly associated with these colors as noted by Baldwin *et al.,* (2020) and Alomar *et al.,* (2016), who linked these hues to synthetic fibers and coating materials entering aquatic systems. Transparent and white particles are likely linked to packaging materials and plastic films that degrade over time. This aligns with the findings of Bakir *et al.,* (2023). The presence of blue and red microplastics, although lower in proportion, may indicate contributions from synthetic fibers, dyed plastics, and fishing gear as reported similarly in studies by Christensen *et al.,* (2020) and Corcoran *et al.,* (2020). The variation in color distribution reflects the diverse sources and pathways of microplastics entering the River Nun ecosystem. These findings emphasize the need for further studies to identify the primary contributors to microplastic pollution in the region and to develop strategies to mitigate their environmental impact which aligns with studies by Graca *et al.,* (2017) and Haque *et al.,* (2023).

Sizes of Microplastics: Figure 5 illustrates the size distribution of microplastics identified in surface water samples from River Nun over six months in 2024. A total of 1,137 microplastic particles were recorded, with the majority falling within the smaller size ranges of 0.3-0.1 mm (36.94%) and 1-0.3 mm (33.77%). Particles measuring <0.1 mm constituted 16.97% of the total, while larger microplastics, including 2-1 mm (7.83%) and 5-2 mm (4.49%), were less prevalent. The dominance of smaller microplastics (<1 mm) underscores the extent of fragmentation and degradation of larger plastic debris in the River Nun ecosystem, consistent with studies by Leslie *et al.,* (2017) and Li *et al.,* (2023) on urban riverine systems. This finding is significant, as smaller particles have a higher surface area-to-volume ratio, potentially increasing their capacity to adsorb contaminants and posing greater risks to aquatic organisms and trophic transfer as reported similarly by Kiss *et al.,* (2021). The relatively lower abundance of larger particles (5-2 mm and 2-1 mm) may indicate either a higher rate of degradation or preferential removal from the water column due to settling or ingestion by biota, this was observed in similar studies by Nel *et al.,* (2018), McEachern *et al.,* (2019) and Niu *et al.,* (2021). These results highlight the importance of focusing on smaller microplastics in future monitoring efforts to better understand their environmental behavior and potential impacts on the River Nun ecosystem.

Phthalate and additives as associated microplastics: Phthalates and additives were detected in surface water samples from River Nun throughout the 2024 sampling period as demonstrated in Table 1, with Dibutyl phthalate being the most prevalent compound. It was identified across all sampling locations during both dry and wet periods, with notable concentrations observed from July to September. Bis(2-ethylhexyl) phthalate also appeared frequently, particularly in the wet period, at locations such as SILAY 1, SILIG 2, and KOLSA 3. Benzylbutyl phthalate was found at multiple sites during the wet period, although in lower concentrations

compared to Dibutyl phthalate and Bis(2-ethylhexyl) phthalate. Other phthalates like Diisooctyl phthalate and Di(2-propylpentyl) ester were detected at lower levels, mainly in the dry season. These findings indicate widespread contamination in the river, primarily from plasticizers commonly used in plastics as reported in similar studies of Briggs *et al.,* 2019 and Cashman *et al.,* 2022. The consistent presence of these additives suggests ongoing pollution, raising concerns about their potential impact on aquatic life and human health through bioaccumulation which aligns with recent studies by Zhang *et al.,* (2021) and Eales *et al.,* (2022). Generally speaking, Dibutyl phthalate and Bis(2-ethylhexyl) phthalate were the most dominant contaminants, with their detection in multiple locations pointing to significant contamination as reported by Gao *et al.,* (2019) and Sedha *et al.,* (2021). These results underline the need for continued monitoring to assess the long-term ecological and health risks associated with phthalate pollution in River Nun.

Polymer Types Distribution: Figure 6 presents the distribution of polymer types in surface water from River Nun, showing significant variations across locations and months during 2024. Polyethylene (PE) was the dominant polymer, particularly at SILAY 1 in July (36.47%) and KOLSA 3 in September (30.95%), highlighting its widespread use in packaging and persistence in aquatic environments. Polypropylene (PP), another major polymer, peaked at SILIG 2 in August (21.83%) and KOLSA 3 in March (25.8%), reflecting its common use in packaging materials. Similarly, Polyethylene Terephthalate (PET), associated with bottles and containers, was abundant at SILAN 3 in March (31.89%) and KOLOR 2 in September (28.71%). Polyvinyl Chloride (PVC), often linked to industrial and commercial activities, showed its highest proportion at SILAN 3 in March (35.4%) (Hendrickson *et al.,* 2018). Although less prevalent overall, Nylon peaked at KOLSA 3 in March (32.4%) and September (31.3%), likely originating from fishing activities and industrial discharges (Cincinelli *et al.,* 2017; Junaid *et al.,* 2023). These variations indicate that microplastic pollution in the river arises from diverse sources, including consumer products and industrial activities, consistent with findings by Xu *et al.,* (2023). The study emphasizes the complexity of microplastic pollution in River Nun and the need for targeted monitoring and mitigation strategies. Improved waste management, public awareness campaigns, and innovative material designs are critical to reducing plastic pollution's ecological footprint (Uzomah *et al.,* 2021; Valdivia *et al.,* 2024).

Identification of Polymer Functional Groups: The FTIR analysis in Table 2 identifies distinct functional groups linked to specific polymers across sampling locations, emphasizing their varied sources and persistence in the River Nun. Nylon, detected by its amide groups (3500–3200 cm^{-1}) at sites like SILAY 1 FEB and KOLOR 2 SEPT, likely originates from textiles and fishing gear. Polyethylene (PE), characterized by its carbon-carbon single bond (2970–2840 cm^{-1}), was found consistently across all sites, reflecting its widespread use in packaging and environmental persistence as reported similarly in recent studies (Cincinelli *et al.,* 2017; Liu *et al.,* 2020). Similarly, polypropylene (PP), identified by its methyl group in the same range, was prevalent at all locations, highlighting its role in consumer and industrial products. Polyethylene terephthalate (PET) was detected at SILAY 1 JUL and KOLOR 2 SEPT via its carbonyl group (1750–1700 cm^{-1}) and across all sites through its ester group (1300–1100 cm^{-1}), indicating sources such as bottles and synthetic fibers. Polyvinyl chloride (PVC), marked by chlorine groups (550–850 cm^{-1}), was consistently present, suggesting contributions from construction and piping materials (Lv *et al.,* 2020; Ogbomida *et al.,* 2023). These findings confirm the dominance of PE, PP, PET, PVC, and nylon in the River Nun, reflecting diverse sources like packaging, industrial discharges, and consumer products (Hahn *et al.,* 2019; Calcaterra *et al.,* 2024). The presence of these polymers across all sites and months underscores the importance of continued monitoring and research into microplastic sources and ecological impacts (Yalwaji *et al.,* 2022; Yang *et al.,* 2023).

Statistical Analysis: The analysis of variance (ANOVA) of mean microplastic concentrations in surface water across sampling locations as shown in Table 3, revealed variations in concentrations but no statistically significant differences ($F = 0.900$, $p = 0.525$). The mean concentrations (± standard error) ranged from 0.22±0.05 g/L at SILIG 2 to 0.54±0.16 g/L at KOLSA 3. SILAY 1 recorded a mean concentration of 0.24±0.10 g/L, while SILAN 3 and KOLOR 2 had slightly higher means of 0.31±0.10 g/L and 0.30±0.12 g/L, respectively. KOLKA 1 exhibited a mean concentration of 0.37±0.09 g/L. The highest concentration observed at KOLSA 3 may indicate localized sources of microplastic pollution, possibly due to specific anthropogenic activities or hydrodynamic conditions favoring accumulation as similarly suggested by Sekudewicz *et al.,* (2021) and Vidayanti & Retnaningdyah, (2024). Despite the observed differences in mean concentrations, the lack of statistical significance suggests that microplastic distribution across these locations is relatively uniform, potentially influenced by similar pollution sources and environmental factors within the river system as reported in a recent study by Wang *et al.,* (2021) and Peng *et al.,* (2022). Further investigations with larger sample sizes and extended temporal coverage may be necessary to discern finer spatial patterns.

Ecological Risk Assessment of Microplastics: The ecological risk assessment of microplastic concentrations in Bayelsa Central, shown in Table 4, utilized risk quotient (RQ) calculations based on Predicted No-Effect Concentration (PNEC) values. RQ values calculated for PNEC Low (0.05 mg/L) were above 1 at all locations, indicating high ecological risks, with the highest values at KOLSA 3 (10.76), KOLKA 1 (7.33), and SILAN 3 (6.23). These results suggest significant risks to aquatic organisms in these areas. In contrast, RQ values for

PNEC High (6 mg/L) were below 1 across all locations, reflecting a low ecological risk under this threshold. KOLSA 3 consistently showed the highest microplastic concentration (0.53 mg/L) and associated RQ values, marking it as a pollution hotspot. SILAY 1 and SILIG 2 had the lowest average concentrations (0.23 mg/L and 0.21 mg/L, respectively), with correspondingly lower RQ values. These findings align with Beaumont *et al.*, (2019) and Attah *et al.*, (2023), who reported substantial ecological risks in regions with high anthropogenic activity. The variation in RQ values between the PNEC thresholds highlights the challenge of standardizing microplastic ecological risk assessments (Ellen *et al.*, 2019; Estherrani *et al.*, 2024). The study emphasizes the need for targeted mitigation strategies at high-risk locations, such as KOLSA 3 and KOLKA 1 (Haque *et al.*, 2023; Estherrani *et al.*, 2024) and recommends further research to inform effective policy and management interventions

Conclusion

This research highlights the pervasive presence of microplastic pollution in the surface water of River Nun, revealing significant ecological risks. The analysis of polymer types, phthalates, and concentrations indicates that industrial waste, consumer goods, and improper disposal are key contributors. PVC, PET, and polyethylene were identified as dominant pollutants due to their extensive use and environmental persistence. The ecological risk assessment revealed hazardous contamination levels at several sites, threatening aquatic biodiversity, ecosystem health, and potentially human health through exposure and trophic transfer. These findings emphasize the need for effective management strategies, continued monitoring, refined risk assessment models, and long-term studies on microplastic impacts. Addressing the root causes of pollution through sustainable solutions is critical to safeguarding ecosystems and human health.

Declaration of competing interest

The authors declare that there is no competing interest.

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