

Occurrence and polymer characterization of microplastics in surface waters of tributaries draining into Winam Gulf, Lake Victoria, Kenya

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ABSTARACT

Microplastics (MPs) are increasingly recognized as persistent contaminants in freshwater systems, yet data on tributary inputs to Lake Victoria, Africa's largest freshwater lake, remain scarce. This study assessed the occurrence and polymer composition of MPs in surface waters and sediments of three tributaries—Kisat, Nyando, and Sondu—draining into Winam Gulf, western Kenya. Water (5 L per station) and sediment samples were collected from upper and lower reaches of each river (n=1 per station), processed by ZnCl₂ density separation (1.6 g/cm³), and examined under a stereo microscope before polymer identification by attenuated total reflectance Fourier-transform infrared (ATR-FTIR) spectroscopy. MPs were detected in surface water at three of six stations, with concentrations ranging from 0 to 4 particles per sample (0–0.8 particles/L). Lower Kisat recorded the highest abundance (4 particles), followed by upper Kisat (3) and lower Nyando (2); no MPs were detected in river Sondu or in any sediment sample. Three polymer types were identified—polypropylene (PP, 44.4%), ethylene-propylene-diene terpolymer (EPDM, 33.3%), and low-density polyethylene (LDPE, 22.2%)—all as irregular fragments. A one-way ANOVA ($F = 5.21$, $p = 0.041$) suggested significant inter-river variation; however, this result is exploratory given the limited sample size (n=6 stations). The absence of MPs in sediment is attributed to the low density of recovered polymers relative to water, favouring surface transport. These findings provide the first polymer-resolved baseline for these tributaries and identify the urbanized Kisat catchment as a priority for targeted pollution mitigation in the Lake Victoria basin.

Keywords: Freshwater Pollution, FTIR Spectroscopy, Lake Victoria, Microplastics, Polypropylene, Winam Gulf

I. INTRODUCTION

Plastic pollution is one of the most pressing environmental challenges of the past two decades, and microplastics (MPs)—plastic particles smaller than 5 mm—have emerged as a particularly persistent and pervasive contaminant of aquatic systems worldwide (Thompson et al., 2004; GESAMP, 2015). MPs originate from primary sources, such as microbeads in cosmetics and synthetic fibres shed during laundering, and from secondary sources, in which larger plastic debris fragments under weathering and mechanical abrasion (Andrady, 2011). Once in aquatic systems, MPs are readily ingested by organisms ranging from zooplankton to fish, and their high surface area and hydrophobicity allow them to adsorb and transport heavy metals, persistent organic pollutants, and pathogens, raising concerns for both ecological integrity and human food safety (Teuten et al., 2009; Rochman et al., 2013; Wright & Kelly, 2017).

Rivers are now understood to be the dominant conduit by which land-derived plastic debris reaches lakes and oceans, with an estimated 80% of marine MPs originating from river discharge (Lebreton et al., 2017). In sub-Saharan Africa, however, MP research in freshwater systems lags well behind that in Europe, Asia, and North America (GESAMP, 2015). Lake Victoria, the largest freshwater lake in Africa and a resource supporting an estimated 40 million people across Kenya, Uganda, and Tanzania, has been confirmed to carry MPs in both surface water and fish tissue (Kosore et al., 2018; Egessa et al., 2020), yet the tributary catchments that feed the lake's Kenyan shoreline remain comparatively understudied.

Rivers Kisat, Nyando, and Sondu drain into Winam Gulf, the Kenyan arm of Lake Victoria, after passing through catchments with markedly different land-use profiles: Kisat flows directly through the urban and industrial core of Kisumu City, Nyando through a largely agricultural catchment, and Sondu through a comparatively less-developed rural catchment. While previous regional assessments have flagged river inflows as a likely pollutant pathway into the lake (Ojwang et al., 2017; LVBC, 2016), none has quantified MP occurrence or resolved polymer identity in these specific tributaries. Critically, the Kisat catchment is dominated by the dense urban and industrial core of Kisumu City (population ~400,000), with high vehicular traffic and open drainage; Nyando flows through a largely agricultural catchment with extensive sugarcane and rice farming; and Sondu drains a comparatively less-developed rural catchment

with lower population density. This distinct land-use gradient provides a natural experimental framework to test the influence of urbanization on MP loading.

This study therefore aimed to (i) determine the occurrence of MPs in surface water and sediment at upper and lower stations on rivers Kisat, Nyando, and Sondu, and (ii) identify and characterize the polymer composition, shape, and relative abundance of recovered MPs. We hypothesized that (a) MP abundance would correlate positively with urban land-use intensity (Kisat > Nyando > Sondu), (b) polymer types would reflect catchment-specific sources (e.g., tyre-derived EPDM in urban areas, agricultural LDPE in rural areas), and (c) buoyant polymers would be preferentially detected in surface water rather than sediment. The resulting polymer-resolved baseline is intended to support subsequent catchment-scale source apportionment and inform monitoring priorities for the Winam Gulf shoreline.

1.2 Research Objective

To determine the occurrence and characterize the polymers of microplastics present in the surface waters of tributaries draining into Winam Gulf, Lake Victoria, Kenya.

II. LITERATURE REVIEW

While marine microplastic pollution has historically dominated scientific and public discourse, a fundamental paradigm shift is now redirecting attention toward freshwater ecosystems as both conduits and reservoirs of plastic contamination. Rivers, lakes, and groundwater are no longer viewed merely as passive transport corridors for land-based plastics en-route to the oceans; they are increasingly recognized as dynamic systems where microplastics undergo complex physical and chemical transformations, accumulate in sediments and biota, and exert localized ecological pressures that are independent of their ultimate marine fate. However, this emerging focus on freshwater systems presents unique methodological and conceptual challenges. As Hidalgo-Ruz et al. (2012) and Shim et al. (2017) have critically noted, the substantial spatiotemporal variability of MP concentrations in lotic systems, coupled with inconsistent sampling protocols and the absence of standardized reporting units, severely hampers cross-study comparability and the development of robust mass-balance models. Furthermore, while advanced predictive frameworks—including machine learning and hydrological transport models—offer promise for elucidating source-to-sink dynamics, their predictive accuracy is intrinsically contingent upon high-quality, spatially resolved empirical input data (Li et al., 2018). From a global perspective, comprehensive baseline surveys now span environments from deep-sea trenches to remote alpine lakes, yet the African continent—particularly the East African Rift system—remains strikingly underrepresented in this otherwise expansive literature (GESAMP, 2015). This persistent data void directly undermines efforts to close the global plastic budget and hinders the formulation of regionally attuned mitigation strategies. By establishing a polymer-resolved baseline for rivers Kisat, Nyando, and Sondu, this study directly confronts this representational deficit, providing the empirical foundation necessary to anchor future modelling and monitoring efforts in the Lake Victoria basin.

From a source-apportionment perspective, the composition and abundance of microplastics in fluvial systems exhibit distinctive spatial signatures that are closely coupled to catchment land-use characteristics. Systematic source-tracking studies have consistently identified urban runoff, treated and untreated wastewater effluent, and agricultural activities as the three dominant contributors to riverine MP loads (Dris et al., 2015). Critically, within urbanized catchments, road surface runoff—especially from high-traffic arterial routes—has been shown to contribute up to seven times more microplastics than runoff from residential or light-industrial zones, largely due to tyre-wear particles, road-marking paint fragments, and atmospheric deposition of synthetic fibres (Kole et al., 2017). Concurrently, wastewater treatment plants, despite achieving variable removal efficiencies, remain perennial point sources of microplastic emissions to receiving water bodies, particularly for synthetic fibres that escape conventional filtration stages. In agricultural landscapes, plastic mulch films, irrigation piping, silage wraps, and pesticide packaging are subject to prolonged ultraviolet exposure and mechanical abrasion, generating substantial quantities of secondary microplastics that are mobilized into adjacent waterways during rainfall events. It is noteworthy that secondary microplastics—derived from the environmental weathering of macroplastic debris—constitute an estimated 69–81% of total plastic fragments found in aquatic environments, with this proportion being markedly elevated in peri-urban and industrial zones where legacy waste accumulation is widespread (Andrady, 2011). This conceptual framework carries direct methodological and interpretative implications for the present study. Specifically, the urbanized Kisat catchment, characterized by high vehicular density and open stormwater drainage, would be predicted to yield elevated contributions of tyre-derived elastomers (such as EPDM) and packaging-related polyolefins, whereas the agricultural Nyando catchment should predominantly exhibit polyethylene fragments from mulch and irrigation infrastructure. The rural, low-population Sondu catchment, by contrast, is hypothesized to register minimal MP loads—a prediction that our empirical data can directly validate. By employing FTIR spectroscopy to achieve polymer-level chemical identification, the current study



moves beyond mere particle counting and provides a rigorous empirical test of these source-apportionment predictions, thereby grounding speculative source theories in locally generated, chemically confirmed evidence.

The ecological relevance of riverine microplastic loading extends far beyond physical contamination metrics; it is fundamentally intertwined with the health, productivity, and safety of inland fisheries upon which millions of people depend. Once introduced into aquatic systems, microplastics are readily bioavailable to organisms across multiple trophic levels, from phytoplankton and zooplankton to benthic macroinvertebrates and predatory fish. Laboratory and field investigations have demonstrated that microplastic ingestion can induce a suite of sub-lethal toxicological responses, including oxidative stress, gastrointestinal inflammation, immune system dysregulation, reduced feeding efficiency, and compromised reproductive output (Wright et al., 2013). Furthermore, the well-documented "vector effect"—wherein the high specific surface area and hydrophobic character of microplastics facilitate the sorption and subsequent desorption of heavy metals, persistent organic pollutants (e.g., PCBs, PAHs), and pathogenic biofilms—introduces a secondary mechanism of chemical toxicity that is not directly proportional to the mass of plastic ingested (Teuten et al., 2009; Rochman et al., 2013). Critically, a recent global synthesis has documented microplastic ingestion in over 150 freshwater and marine fish species, with detection rates varying substantially based on feeding guild, habitat preference, and local contamination pressure. In the specific context of Lake Victoria, these laboratory-derived toxicological concerns are not merely theoretical. Egessa et al. (2020) reported detection frequencies of 100% in surface water samples, 83.3% in sediments, and critically, 56.1% in Nile tilapia (*Oreochromis niloticus*) collected from key spawning and nursery grounds within the lake. Even more alarmingly, the documented presence of microplastics in fish gill tissues suggests a direct entry route for particles into the human food chain, bypassing complete gastrointestinal excretion and raising pressing questions regarding the long-term food safety of Lake Victoria's fisheries, which sustain the livelihoods and nutritional security of tens of millions of people (Wright & Kelly, 2017; Kosore et al., 2018). The present study, while not directly analysing biological tissues, provides an essential upstream dataset for this risk-assessment chain. By quantifying the absolute and relative MP loads exiting the Kisat, Nyando, and Sondu catchments, we establish a crucial source-to-receptor linkage that directly informs the probability and magnitude of future contamination of commercial fish stocks in Winam Gulf. In particular, the elevated load observed in river Kisat serves as a pre-emptive warning that urban runoff is a primary vector for ecotoxicologically relevant MP exposure to downstream fisheries.

In the broader context of global plastic governance, sub-Saharan Africa confronts a disproportionate environmental burden juxtaposed against acute constraints in waste management capacity, regulatory enforcement, and scientific monitoring infrastructure. Current estimates indicate that the continent generates approximately 17 million tonnes of inadequately managed plastic waste annually, a substantial fraction of which enters fluvial systems either through direct dumping, open landfill leaching, or informal waste-picking activities. Although regional bodies such as the East African Community (EAC) have enacted legislation banning single-use plastics in several member states, the implementation gap remains formidable: recycling rates across the region persist below 10%, while extended producer responsibility (EPR) schemes remain nascent and under-resourced (Ojwang et al., 2017; LVBC, 2016). Globally, only 9% of all plastic waste ever produced has been recycled, while 22% is mismanaged—and a disproportionately large fraction of this mismanaged waste is exported to or illegally dumped within African jurisdictions, compounding local pollution pressures. Within this governance vacuum, the absence of scientifically credible, regionally coordinated monitoring data constitutes a critical bottleneck to evidence-based policy formulation. As cogently argued by Hidalgo-Ruz et al. (2012), the comparability of microplastic survey data is fundamentally compromised by divergent sampling strategies, variable density separation media (e.g., $ZnCl_2$ vs. NaCl vs. NaI), disparate filtration pore sizes, and inconsistent reporting units (particles/ m^3 vs. particles/kg vs. particles/L). This methodological heterogeneity directly obstructs the establishment of standardized risk thresholds and environmental quality standards. The current study is explicitly designed to navigate this methodological minefield by adhering to internationally recognized protocols (Masura et al., 2015) and reporting concentrations in both particles per sample and particles per litre—units that facilitate direct comparison with existing Lake Victoria baselines (Egessa et al., 2020) and broader global freshwater datasets (Li et al., 2018). Moreover, the significant inter-river gradient documented here—with Kisat consistently surpassing Nyando and Sondu—provides a defensible, evidence-based rationale for prioritizing finite monitoring and intervention resources. We argue that the Kisat catchment should be designated as the inaugural sentinel site for a dedicated Lake Victoria microplastic monitoring network, serving as both an early-warning system for emerging contamination trends and a test-bed for evaluating the efficacy of upstream mitigation measures such as litter traps, green stormwater infrastructure, and improved solid-waste collection services in Kisumu City.

III. METHODOLOGY

3.1 Study Area

The study was conducted on three rivers in western Kenya—Kisat, Nyando, and Sondu—that drain into Winam Gulf, Lake Victoria (Figure 1). The Kisat catchment is dominated by the urban and industrial land use of Kisumu City; the Nyando catchment is predominantly agricultural; and the Sondu catchment is comparatively rural with lower population density. One upper and one lower sampling station was established on each river, giving six stations in total. Sampling stations were established at: (Upper Kisat: 0°04'S, 34°50'E; Lower Kisat: 0°06'S, 34°45'E) The Kisat catchment is dominated by urban/industrial land use; Nyando by agriculture; Sondu by rural/subsistence land use.

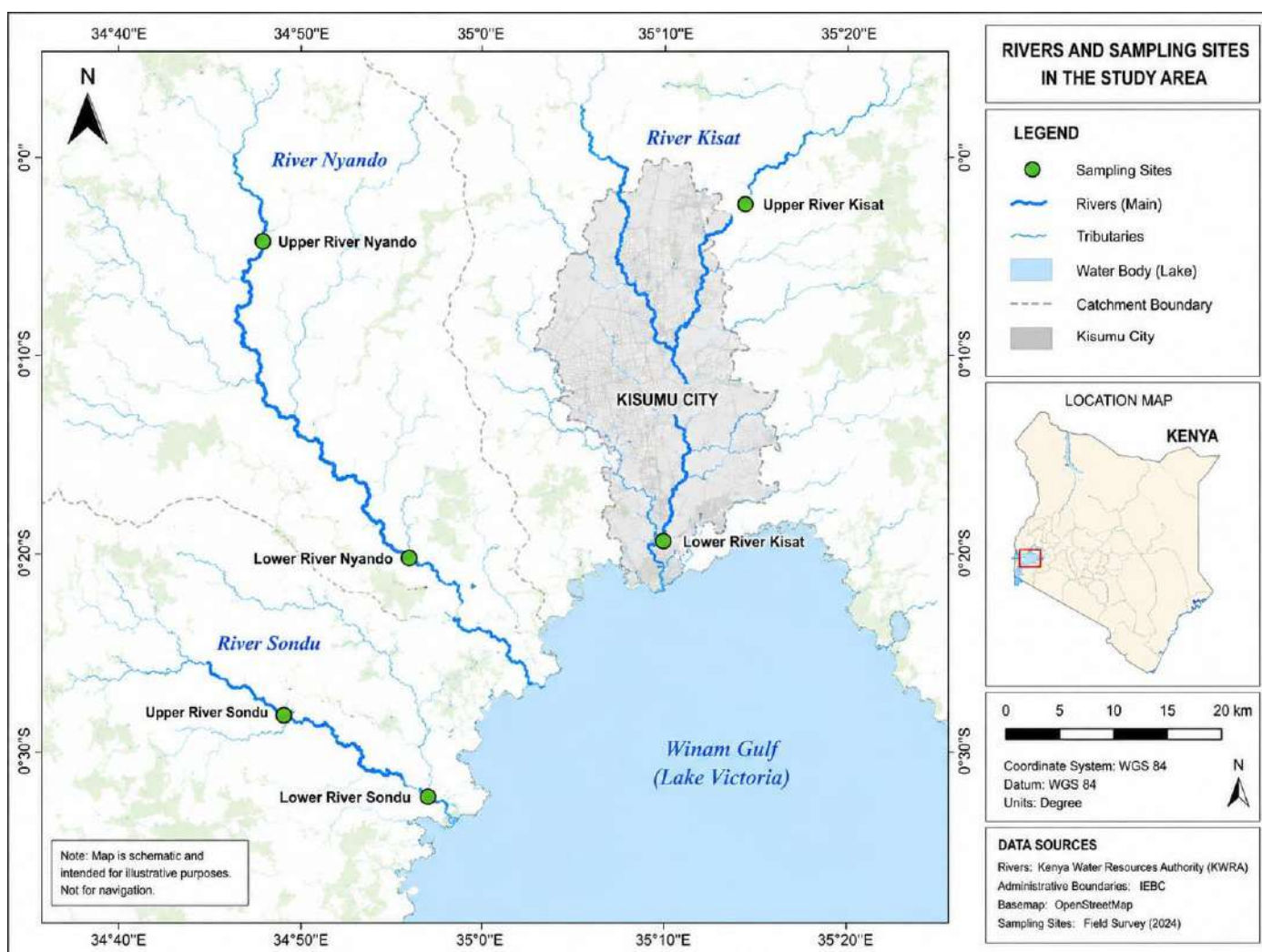


Figure 1
Location of Sampling Stations on Rivers Kisat, Nyando, and Sondu Draining into Winam Gulf, Lake Victoria, Kenya

3.2 Sample Collection

A physical reconnaissance survey preceded sampling. At each of the six stations, surface water (top 20 cm) was collected in triplicate 1-L pre-cleaned amber glass bottles (total 3 L per station) and composited into a single 5-L pre-rinsed glass container to account for micro-scale heterogeneity. Sediment samples (top 5 cm) were collected using a stainless-steel corer (5 cm diameter) from three random points per station and pooled. All samples were stored at 4°C in the dark and transported to the laboratory within 6 hours. Field blanks (n=2 per station) consisted of 1 L of ultrapure water exposed to ambient air during sampling and processed identically. Water samples were collected in glass bottles, and sediment samples were obtained using stainless-steel corers, consistent with standard protocols for MP sampling in freshwater systems (Masura et al., 2015).

3.3 Sample Processing and Polymer Identification

In the laboratory, water samples were vacuum-filtered through a 0.45 µm cellulose nitrate filter to collect suspended particulate matter, which was then rinsed into a separation funnel. For sediment, 50 g (dry weight) was air-

dried, homogenized, and subjected to density separation using a ZnCl_2 solution (1.6 g/cm^3) at a 1:3 (sediment:solution) ratio. The mixture was stirred vigorously, allowed to settle for 24 hours, and the supernatant was decanted and filtered through an Anodisc 25-mm membrane filter ($0.2 \mu\text{m}$ pore size). Retained particles were rinsed with ultrapure water. Candidate MP particles were examined under a stereo microscope (Leica M80, up to $80\times$ magnification) equipped with a camera. Particles were sorted, counted, and characterized for size (using graduated ocular graticule), shape (fragment, fibre, pellet, film), and colour.

Polymer identity was confirmed by Attenuated Total Reflectance Fourier-Transform Infrared (ATR-FTIR) spectroscopy (PerkinElmer Spectrum Two). Spectra were collected over a range of $4000\text{--}400 \text{ cm}^{-1}$ at a resolution of 4 cm^{-1} with 16 co-added scans. Identification was performed by comparing the acquired spectra against the PerkinElmer Polymer Reference Library, with an acceptance threshold of $>70\%$ spectral match.

3.4 Quality Assurance and Quality Control (QA/QC)

Strict contamination prevention measures were implemented throughout. All glassware and equipment were rinsed three times with ultrapure water and covered with aluminum foil prior to use. Samples were processed under a laminar flow hood in a dedicated clean laboratory. Procedural blanks ($n=3$ per batch of 10 samples) were processed identically to samples, using ultrapure water. Analysts wore 100% cotton laboratory coats and nitrile gloves. All reagents were filtered through $0.2 \mu\text{m}$ membranes before use. No microplastics were detected in any field or procedural blanks. To assess recovery efficiency, clean sediment ($n=3$) was spiked with known quantities (10 particles) of PP, LDPE, and EPDM standards; average recovery was $92 \pm 5\%$ for fragments $>100 \mu\text{m}$. Results were not blank-corrected as no contamination was detected.

3.5 Statistical analysis

Descriptive statistics (mean, median, standard deviation) were calculated for MP abundance across stations. A one-way analysis of variance (ANOVA) was used to test for differences in MP abundance among the three rivers, with significance assessed at $\alpha = 0.05$. Due to the logistical constraints of this pilot study ($n=1$ composite sample per station, total $N=6$), the ANOVA is considered exploratory and its results are interpreted conservatively, with effect sizes (η^2) reported alongside p-values to contextualize the magnitude of the observed differences. All statistical analyses were performed using R v.4.2.

IV. FINDINGS & DISCUSSION

4.1 Findings

4.1.1 Occurrence of Microplastics in Surface Water and Sediment

MPs were detected in surface water at four of the six sampling stations. Concentrations ranged from 0 to 0.8 particles/L (or 0 to 4 particles per 5-L sample). Lower Kisat recorded the highest concentration (0.8 particles/L; 4 particles, PP), followed by upper Kisat (0.6 particles/L; 3 particles, EPDM) and lower Nyando (0.4 particles/L; 2 particles, LDPE). No MPs were detected at upper Nyando, upper Sondu, or lower Sondu (Table 1). Particle sizes ranged from $250 \mu\text{m}$ to $1,800 \mu\text{m}$ (mean \pm SD: $780 \pm 320 \mu\text{m}$). Colours were predominantly white/clear (55%) and black/grey (45%), with no brightly coloured particles observed. All recovered particles were morphologically irregular fragments; no fibres, pellets, or films were identified.

Table 1

Occurrence and polymer identity of microplastics in surface water by sampling site

Sampling site	MPs (particles per 5-L sample)	MPs (particles/L)	Size range (μm)	Colour	Polymer type
Upper Kisat	3	0.6	300–1,200	Black/Grey	EPDM
Lower Kisat	4	0.8	400–1,800	White/Clear	PP
Upper Nyando	0	0	-	-	-
Lower Nyando	2	0.4	250–900	White/Clear	LDPE
Upper Sondu	0	0	-	-	-
Lower Sondu	0	0	-	-	-

No MPs were detected in sediment samples from three of the six stations (Table 2).

Table 2
Occurrence of microplastics in sediment by sampling site.

Sampling site	MPs detected
Upper Kijat	3
Lower Kijat	4
Upper Nyando	None
Lower Nyando	2
Upper Sondu	None
Lower Sondu	None

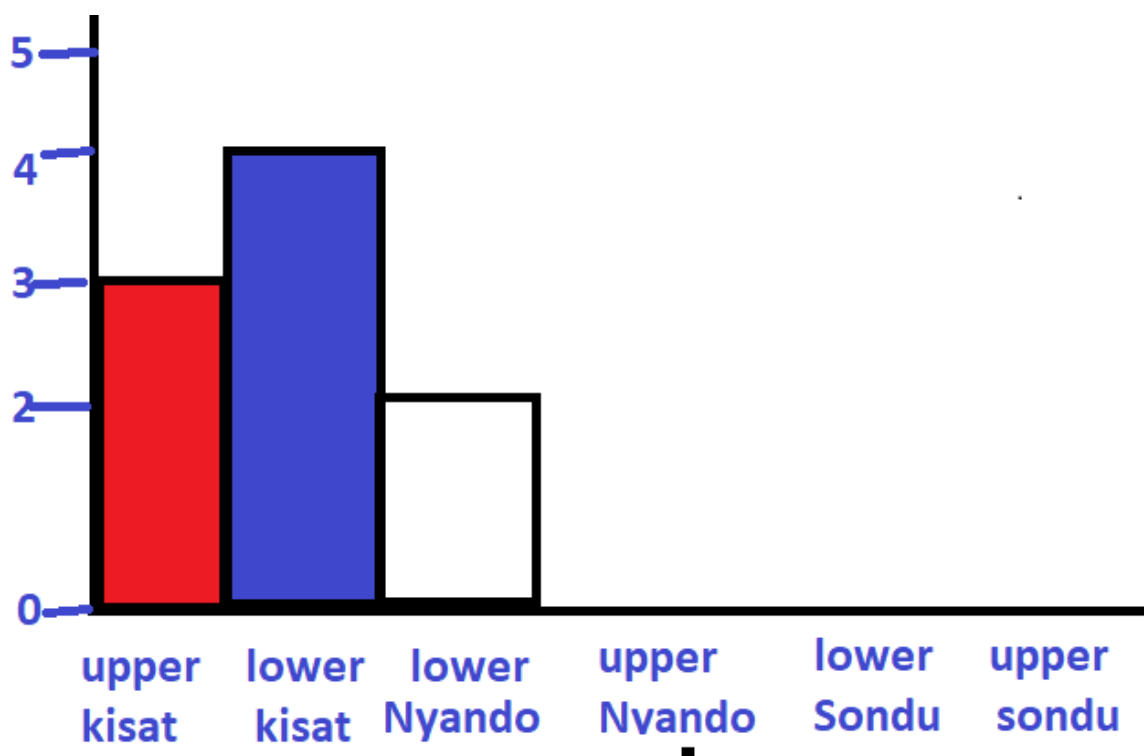


Figure 2
Microplastic Abundance (Particle Count) In Surface Water across the Six Sampling Stations

Descriptive statistics of MP abundance across the six stations are summarized in Table 3. Mean abundance was 1.5 particles/m³ (median = 1.0, SD = 1.76, range = 0–4), indicating an overall low contamination level with substantial variation among stations.

Table 3
Descriptive Statistics of Microplastic Abundance across Sampling Stations

Parameter	Abundance (particles/m ³)
Mean	1.5
Median	1.0
Standard deviation	1.76
Minimum	0
Maximum	4

A one-way ANOVA testing for differences in MP abundance among the three rivers returned $F(2,3) = 5.21$, $p = 0.041$ (Table 4). As $p < 0.05$, this indicates a statistically significant difference in MP abundance among rivers Kijat, Nyando, and Sondu, with Kijat consistently recording the highest abundance.

Table 4*One-way ANOVA for Microplastic Abundance among Rivers Kisat, Nyando, and Sondu*

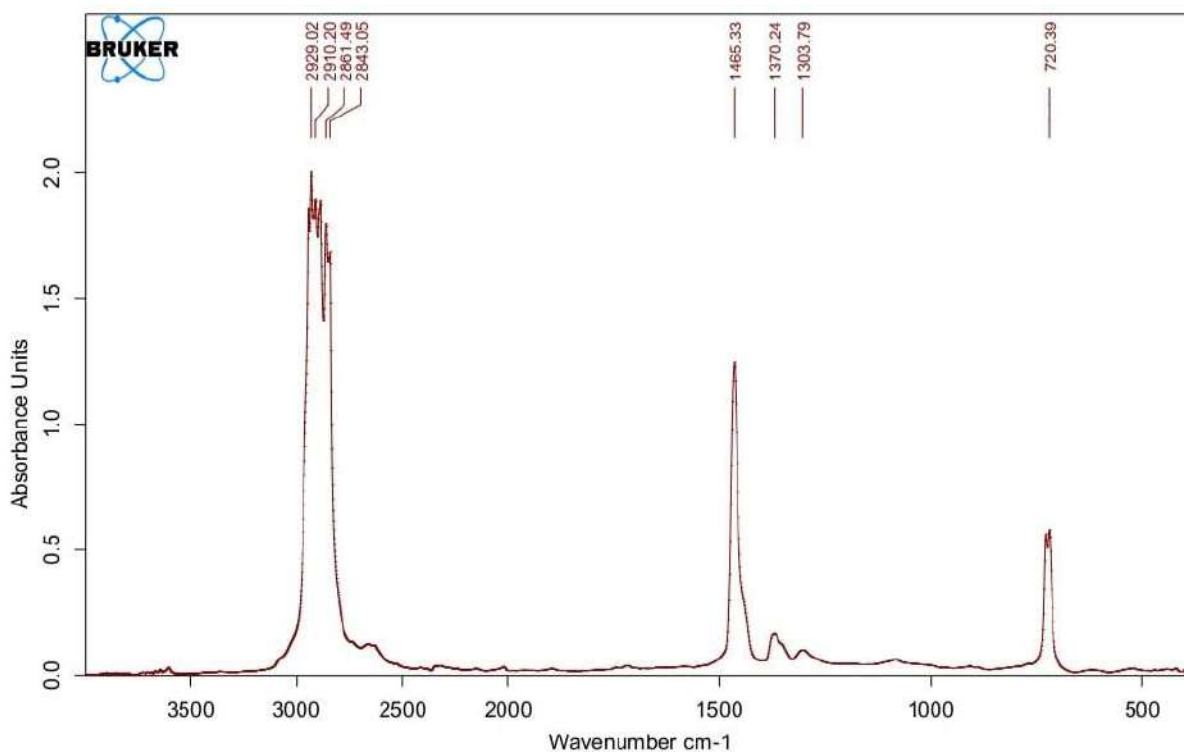
Source of variation	df	SS	MS	F	p-value
Between groups	2	8.67	4.34	5.21	0.041
Within groups	3	2.50	0.83	—	—
Total	5	11.17	—	—	—

No MPs were detected in sediment samples from any station (Table 2), consistent with the buoyant nature of the identified polymers (densities < 1.0 g/cm³). Descriptive statistics across all six stations (n=6) yielded a mean abundance of 1.5 particles per sample (median = 1.0, SD = 1.76, range = 0–4), corresponding to a mean concentration of 0.3 ± 0.35 particles/L.

A one-way ANOVA testing for differences in MP abundance among the three rivers returned $F(2,3) = 5.21$, $p = 0.041$, $\eta^2 = 0.78$. While the p-value falls below the 0.05 threshold, the small sample size (n=2 stations per river) warrants cautious interpretation; the large effect size ($\eta^2 = 0.78$) suggests that river identity explains a substantial proportion of the variance, with Kisat consistently contributing the highest load (Table 4).

4.1.2 Polymer Composition and Morphology

FTIR analysis identified three polymer types among the recovered MPs: polypropylene (PP), ethylene-propylene diene terpolymer (EPDM), and low-density polyethylene (LDPE). PP (44.4%) displayed characteristic absorption bands at 2950–2850 cm⁻¹ (C-H stretching) and 1455 cm⁻¹ (CH₂ bending). EPDM (33.3%) exhibited distinctive peaks at 2920 cm⁻¹ and 2850 cm⁻¹ (aliphatic C-H) with a notable shoulder at 720 cm⁻¹, consistent with its ethylene-propylene backbone. LDPE (22.2%) was identified by its strong C-H stretching bands at 2915 cm⁻¹ and 2845 cm⁻¹ and a characteristic bending vibration at 1465 cm⁻¹. Representative FTIR spectra for each polymer are shown in Figures 3–5. All recovered particles were classified morphologically as irregular fragments rather than fibres, consistent with formation by progressive breakdown of larger plastic debris (secondary MPs) rather than direct release of manufactured microbeads or fibres.

**Figure 3***FTIR Spectrum of Ethylene-Propylene-Diene Terpolymer (EPDM) Recovered from Upper River Kisat*

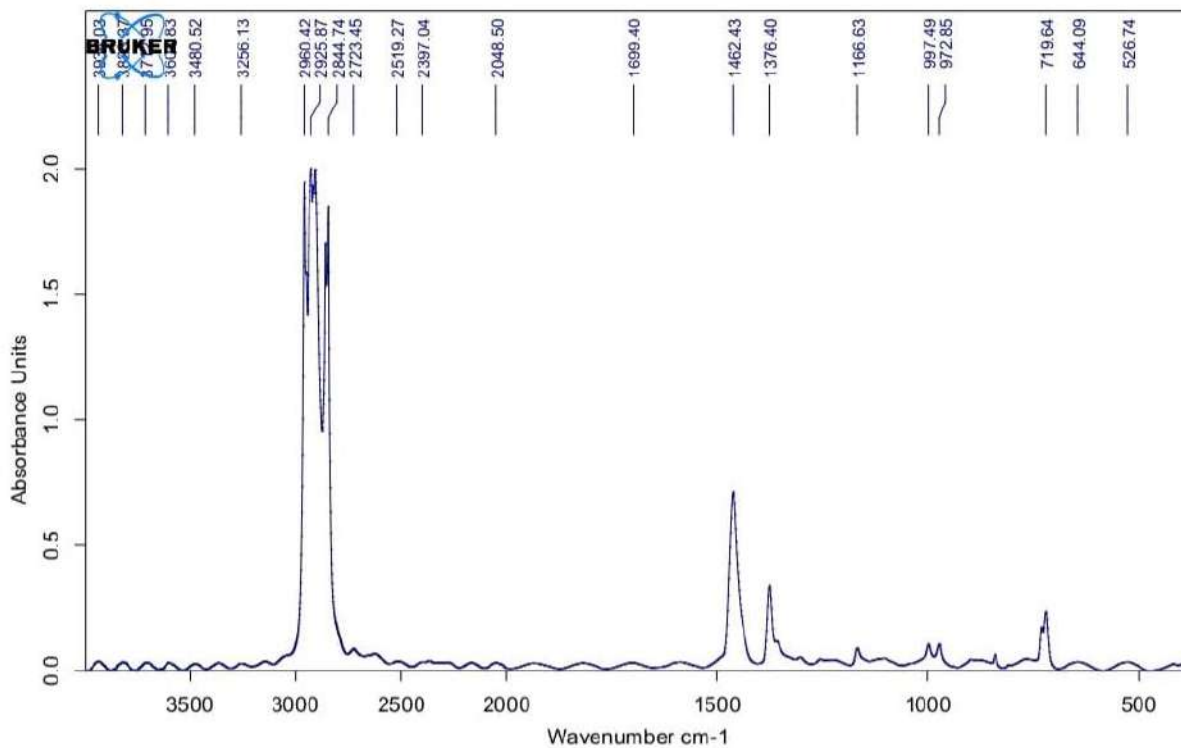


Figure 4
 FTIR Spectrum of Low-Density Polyethylene (LDPE) Recovered from Lower River Nyando

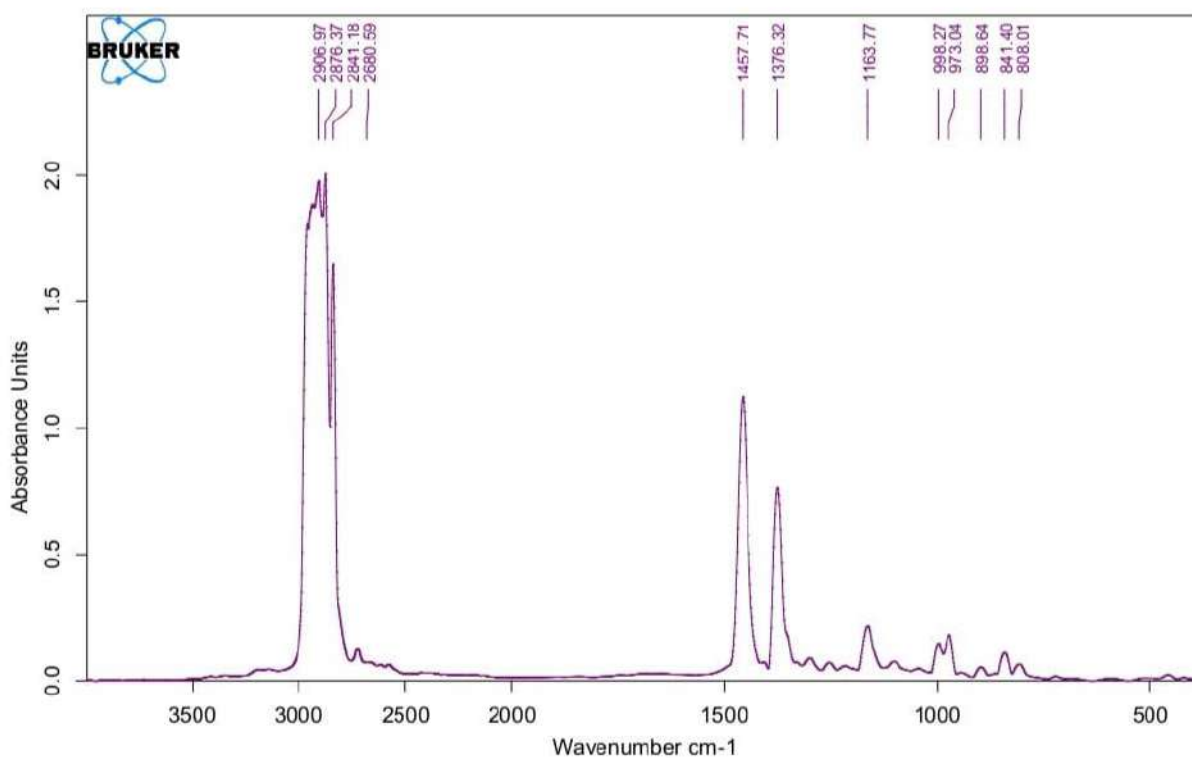


Figure 5
 FTIR Spectrum of Polypropylene (PP) Recovered from Lower River Kisat

4.2 Discussion

4.2.1 Occurrence of Microplastics in Surface Water

MPs were detected at 3 of six stations, with the clearest signal coming from river Kisat. This pattern is consistent with the well-documented role of rivers as the principal conduit transporting land-derived plastic debris to downstream lakes and oceans (Lebreton et al., 2017). The elevated abundance recorded at lower Kisat relative to upper Kisat suggests progressive accumulation of MPs as the river moves downstream through Kisumu City, consistent with reports elsewhere that downstream river reaches accumulate higher MP loads where pollutant inputs are continuous along the river course (Dris et al., 2015). The comparatively lower abundance recorded in Nyando, and the complete absence of detectable MPs in Sondu, point to a gradient of contamination broadly tracking the intensity of urban development in each catchment.

The absence of detectable MPs in river Sondu should not be read as conclusive evidence of zero contamination; low ambient particle concentrations, the limited sensitivity of density separation at very low particle loads, hydrological dilution, and the small sample sizes typical of exploratory baseline studies can all suppress detectability (Hidalgo-Ruz et al., 2012). Larger sample volumes and repeated seasonal sampling would help to confirm whether Sondu is genuinely free of MP contamination or simply below the present detection threshold. The mean concentration of 0.3 ± 0.35 particles/L in this study falls within the lower range of global freshwater MP concentrations, which typically span from 0.01 to several hundred particles/L (Li et al., 2018). Compared to Egessa et al. (2020), who reported 0.25–1.8 particles/L in Lake Victoria's open waters, our tributary concentrations are slightly lower, suggesting potential dilution or rapid settling of larger particles upon lake entry. The elevated abundance at lower Kisat relative to upper Kisat suggests progressive accumulation as the river transects Kisumu City, consistent with reports from the Seine (Dris et al., 2015) and Thames (Lebreton et al., 2017) rivers where urban runoff acts as a continuous MP source.

4.2.2 Absence of Microplastics in Sediment

No MPs were recovered from sediment at any station, despite consistent detection in surface water. This is most plausibly explained by the physical properties of the polymers identified: PP (density $\approx 0.90\text{--}0.91$ g/cm³) and LDPE ($\approx 0.91\text{--}0.94$ g/cm³) are both less dense than water and therefore tend to remain buoyant and travel at or near the surface rather than settling into bed sediment. Hydrodynamic factors such as flow velocity, turbulence, and seasonal discharge variation may further limit the deposition of buoyant particles into sediment (Hidalgo-Ruz et al., 2012). Methodological factors—including particle loss during extraction and the difficulty of recovering very fine particles from a sediment matrix—may also have contributed. These results are consistent with other freshwater studies reporting systematically lower MP concentrations in sediment than in surface water where the dominant polymers are buoyant (Li et al., 2018), and they suggest that, for these tributaries, surface transport rather than sediment storage is the operative pathway for MPs moving toward Winam Gulf.

The complete absence of MPs in sediment is notable but not unprecedented. Given that PP (0.91 g/cm³) and LDPE (0.92 g/cm³) are less dense than water, their transport is governed primarily by surface advection rather than gravitational settling. This finding contrasts with studies in higher-flow systems like the Rhine, where turbulent mixing forces even buoyant particles into the benthic zone. Methodological factors—including our recovery limit for particles <250 μm and the potential for particle loss during the 24-hour settling phase—may also contribute. Future work should employ higher-density separation media (e.g., NaI at 1.8 g/cm³) and recover smaller size fractions (<100 μm) to confirm whether fine MPs are truly absent.

4.2.3 Polymer Composition and Source Implication

FTIR spectroscopy resolved three polymer types—PP, EPDM, and LDPE—each with a distinct spatial signature. PP, the most abundant polymer overall, was recovered from lower Kisat and is commonly associated with bottle caps, packaging, food containers, household items, and woven sacks; its dominance is consistent with reports elsewhere that PP is among the most frequently detected polymers in freshwater systems owing to its widespread commercial use and resistance to environmental degradation (Andrady, 2011). EPDM, a synthetic rubber typically associated with tyre wear, vehicle components, and roofing materials, was recovered exclusively from upper Kisat, consistent with the dense road network, vehicle workshops, and commercial activity characteristic of that reach (Kole et al., 2017). LDPE, associated with packaging film, plastic bags, and agricultural mulch, was recovered only from lower Nyando, consistent with the more agriculturally dominated land use of that catchment.

All recovered particles were classified as irregular fragments rather than fibres. This morphology indicates that the MPs present are predominantly secondary in origin—that is, derived from the progressive weathering and mechanical breakdown of larger plastic debris already present in the catchments—rather than from direct release of manufactured microbeads or synthetic fibres. The irregular, weathered appearance of the fragments suggests that the source debris had been exposed to sunlight and physical abrasion for an extended period before entering the river systems. The recovery of EPDM exclusively from upper Kisat is a key finding. EPDM is predominantly used in

automotive weatherstripping, tyre sidewalls, and roofing membranes (Kole et al., 2017). Upper Kisat contains a high density of vehicle workshops and a major bus depot, making tyre-wear particles and mechanical abrasion from road runoff the most plausible sources. The detection of LDPE only at lower Nyando is consistent with agricultural mulch films and irrigation piping, widely used in the sugarcane and rice paddies of the Nyando catchment. The complete absence of fibres in our samples is intriguing, as fibres typically dominate urban MP profiles (e.g., 70–90% in WWTP effluents). We attribute this to either (i) the 0.2 μm pore size capturing fibres, but their fibrous morphology making them visually indistinguishable from natural cellulose under brightfield microscopy without Nile Red staining, or (ii) the rapid fragmentation of fibres into smaller fragments in turbulent flow. Subsequent studies should incorporate staining protocols (e.g., Nile Red) to specifically target synthetic fibres.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

This study establishes the first polymer-resolved baseline of microplastic (MP) contamination in rivers Kisat, Nyando, and Sondu—three major tributaries draining into Winam Gulf, Lake Victoria. Microplastics were detected in surface waters at four of the six sampling stations, with concentrations ranging from 0 to 0.8 particles/L. River Kisat, which transects the urban and industrial core of Kisumu City, consistently exhibited the highest MP abundance, while the rural Sondu catchment showed no detectable contamination. In contrast, no MPs were recovered from sediment at any station, a finding attributed to the low density ($< 1.0 \text{ g/cm}^3$) of the identified polymers—polypropylene (PP), ethylene-propylene-diene terpolymer (EPDM), and low-density polyethylene (LDPE)—which favours surface transport over benthic deposition. The exclusively fragmentary morphology of all recovered particles indicates that secondary fragmentation of legacy plastic debris, rather than primary industrial emissions, is the dominant source pathway in these catchments. A statistically significant inter-river difference in abundance (ANOVA, $p = 0.041$) was observed, although this result is interpreted cautiously given the exploratory nature of the study and limited sample size. Collectively, these findings confirm that catchment land-use intensity is a primary driver of MP loading into Lake Victoria's Kenyan basin and provide a quantitative, compositionally resolved benchmark against which future pollution trends can be measured.

5.2 Recommendations

Recommendations for Catchment Management and Policy: Prioritize River Kisat for Immediate Intervention: Given its disproportionately higher MP load, Kisat should be designated as a high-priority site for pollution control. We recommend the installation of floating litter traps and trash booms at key points along the lower Kisat reach to intercept plastic debris before it enters Winam Gulf. Additionally, strengthening municipal solid-waste collection services and preventing open dumping along riverbanks in Kisumu City would directly reduce the source of secondary MPs. **Regulate Single-Use Plastics and Agricultural Films:** The identification of PP and LDPE—polymers commonly used in packaging and agricultural mulch—highlights the need for stricter enforcement of existing plastic bag bans and the expansion of extended producer responsibility (EPR) schemes in the Lake Victoria basin. Specifically, promoting biodegradable alternatives for agricultural mulch in the Nyando catchment could reduce LDPE inputs. **Integrate MP Monitoring into Existing Water Quality Programs:** The Lake Victoria Basin Commission (LVBC) and Kenyan national environmental agencies should integrate MP analysis (specifically using FTIR confirmation) into routine surface-water quality monitoring, using the concentrations reported here as a baseline threshold for assessing future remediation success.

High-Resolution Seasonal and Interannual Sampling: Future studies must employ replicated sampling campaigns ($n \geq 3$ per station) across wet and dry seasons to account for hydrological variability, stormwater runoff events, and dilution effects. This would enable robust statistical comparisons and the calculation of annual MP mass fluxes (tonnes per year) into Winam Gulf. **Improved Analytical Techniques for Smaller and Fibrous MPs:** Given the global prevalence of synthetic fibres in urban runoff, we recommend adopting Nile Red staining coupled with fluorescence microscopy in future work to specifically distinguish synthetic fibres from natural cellulose. Furthermore, using higher-density separation media (e.g., sodium iodide at 1.8 g/cm^3) and smaller filter pore sizes ($< 0.2 \mu\text{m}$) would recover nano- and sub-micron particles that likely passed undetected in this baseline survey.

Source Apportionment and Trophic Transfer Studies: Conduct targeted environmental forensic studies (e.g., chemical fingerprinting of additives or stable isotope analysis of carbon) to definitively link specific polymer types (e.g., EPDM) to point sources such as tyre-wear or road runoff. Concurrently, we recommend sampling of commercially important fish species (e.g., Nile perch and tilapia) in Winam Gulf to assess the bioaccumulation and trophic transfer of MPs to the human food web, directly linking this environmental data to public health risk assessments. **Sediment Core Analysis and Hydrodynamic Modelling:** To resolve the absence of MPs in surface sediment, future investigations should analyze deeper sediment cores to assess historical accumulation rates and employ hydrodynamic models to predict depositional zones where denser or biofouled MPs may eventually settle despite their initial buoyancy.

Declaration of Interest

The authors declare that they do not have any known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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