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Land use as a primary driver of microplastic transport into Lake Victoria: Evidence from three Kenyan tributary catchments

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ABSTRACT

Microplastic (MP) pollution threatens freshwater ecosystems globally, yet understanding catchment-level transport pathways remains limited for Africa's largest lake, Lake Victoria. This study examined the relationship between land-use intensity and MP occurrence, and mapped the spatial distribution of MP hotspots, across three tributaries (Kisat, Nyando, and Sondu) draining into Winam Gulf, western Kenya. MP abundance data from six sampling stations (upper and lower reaches of each river) were analyzed against catchment land-use intensity using regression analysis, with spatial distribution mapped via Geographic Information Systems (GIS). Regression analysis revealed a strong positive relationship between MP abundance and land-use intensity ($R = 0.89$, $R^2 = 0.79$, $p = 0.018$), indicating that 79% of the variation in MP occurrence across sites was explained by the intensity of surrounding human activity. MP abundance ranged from 0 to 4 particles/m^3, with the highest levels in the urban-industrial river Kisat (77.7% of total MPs recovered). Polymer identification via Fourier-transform infrared spectroscopy (FTIR) linked polypropylene (PP; 44.4%) and ethylene-propylene-diene terpolymer (EPDM; 33.3%) to municipal and vehicular sources, while low-density polyethylene (LDPE; 22.2%) was associated with agricultural land use in the Nyando catchment. GIS spatial analysis identified lower Kisat as the principal contamination hotspot (severe; 44.4% of total MPs), with upper Kisat as a secondary hotspot (moderate; 33.3%). This study identifies river Kisat as a priority intervention site, demonstrates that land use is the dominant determinant of MP loading among the catchments studied, and provides a spatial evidence base to inform pollution-control policy for the Lake Victoria basin. The study recommends targeted waste management interventions in Kisumu City and agricultural plastic reduction programs in the Nyando catchment to reduce MP loading into Lake Victoria, supporting Sustainable Development Goals 6 (Clean Water and Sanitation) and 14 (Life Below Water).

Keywords: Catchment Management, GIS, Lake Victoria, Land Use, Microplastic Transport, Pollution Hotspot, Spatial Distribution

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I. INTRODUCTION

Plastic pollution has emerged as one of the most pressing environmental challenges of the twenty-first century, with global plastic production exceeding 400 million tonnes annually (Geyer et al., 2017). An estimated 8–12 million tonnes of plastic waste enter aquatic environments each year, with projections indicating this could nearly triple by 2040 without significant intervention (Jambeck et al., 2015; Lau et al., 2020). Among the most insidious forms of plastic pollution are microplastics (MPs)—plastic particles smaller than 5 mm in diameter (Thompson et al., 2004)—which are highly persistent, widely distributed, and increasingly recognized as threats to both ecosystem integrity and human health (Andrady, 2011; Wright & Kelly, 2017).

MPs originate from two primary sources: primary MPs, which include microbeads in personal care products, synthetic fibers from textiles, and industrial abrasives; and secondary MPs, which result from the fragmentation of larger plastic debris through environmental weathering and mechanical abrasion (Andrady, 2011). Once released into aquatic environments, MPs can be ingested by organisms across trophic levels, from zooplankton to fish, causing physical harm, reducing feeding efficiency, and impairing reproduction (Wright et al., 2013). Furthermore, MPs act as vectors for heavy metals, persistent organic pollutants, and pathogens due to their large surface area and hydrophobic properties (Teuten et al., 2009; Rochman et al., 2013), potentially leading to bioaccumulation of toxic substances through food webs and posing risks to human health (Wright & Kelly, 2017).

While MP research has historically focused on marine systems, emerging evidence indicates that freshwater ecosystems are similarly contaminated and may serve as major conduits for MP transport to oceans (Lebreton et al., 2017). River systems play a critical role as pathways connecting terrestrial plastic sources to downstream lakes and oceans, with an estimated 1.15–2.41 million tonnes of plastic waste transported annually by rivers globally (Lebreton et al., 2017). However, research on MP pollution in African freshwater systems remains sparse compared to studies in

Europe, Asia, and North America (GESAMP, 2015; Boucher & Friot, 2017). Recent reviews indicate that while MPs have been detected across several African freshwater systems, East Africa—and Lake Victoria in particular—remains understudied relative to Northern and Southern Africa (Sharma & Chatterjee, 2017; Okuku et al., 2021).

Lake Victoria, the largest freshwater lake in Africa (68,800 km²), is a transboundary resource shared by Kenya, Uganda, and Tanzania, supporting an estimated 40 million people through fisheries, agriculture, transportation, and domestic water supply (Njiru et al., 2020). The lake's economic importance is substantial, with fisheries alone valued at over USD 500 million annually and directly employing approximately 200,000 fishers (LVBC, 2016). However, the lake faces mounting environmental pressures, including rapid urbanization, industrialization, population growth, and inadequate waste management infrastructure across its catchment (Ojwang et al., 2017; Njiru et al., 2020). Recent studies have confirmed the presence of MPs in Lake Victoria's surface water, sediments, and fish (Kosore et al., 2018; Egessa et al., 2020), raising concerns about ecosystem health and food safety.

Western Kenya's rivers—including the Nzoia, Yala, Nyando, Sondu Miriu, and Kisat—form critical inflow pathways into Winam Gulf, Lake Victoria's eastern embayment. These rivers flow through areas characterized by diverse land uses: river Kisat drains the urban and industrial core of Kisumu City, river Nyando flows through agricultural areas, and river Sondu passes through comparatively rural, less-developed catchments. These tributaries are suspected conduits for land-based pollutants, including MPs, transported via urban runoff, untreated sewage, industrial effluents, agricultural runoff, and solid waste disposal (Ojwang et al., 2017; LVBC, 2016).

Despite these concerns, region-specific data on the extent, sources, spatial distribution, and transport pathways of MP pollution in Lake Victoria's tributary network remain critically limited. Previous studies have documented MPs in Lake Victoria itself (Egessa et al., 2020; Kosore et al., 2018) but have not systematically examined upstream tributary inputs or quantified the relationship between catchment land use and MP loading. This knowledge gap constrains the development of evidence-based pollution control strategies and hinders targeted management interventions within the Lake Victoria basin.

Catchment land use is widely recognized as a primary determinant of pollutant loading in river systems, with urbanization, industrialization, and agricultural intensification each contributing distinct contaminant suites (Ojwang et al., 2017; Wang et al., 2020). For MPs, the catchment land-use signature is expected to leave a detectable imprint: urban areas contribute MPs through municipal waste, stormwater runoff, and vehicular wear; industrial zones contribute through synthetic rubber, packaging residues, and effluent discharge; and agricultural areas contribute through plastic mulch, irrigation infrastructure, and fertilizer packaging (Andrady, 2011; Kole et al., 2017). Establishing the strength and spatial pattern of this land-use relationship is a necessary step toward targeted, catchment-scale pollution management.

This study addresses these knowledge gaps by: (1) quantifying the statistical relationship between catchment land-use intensity and MP occurrence across three tributaries (Kisat, Nyando, and Sondu) draining into Winam Gulf; (2) mapping the spatial distribution of MP hotspots across these tributaries using GIS; (3) linking recovered polymer types to plausible land-use sources and transport pathways; and (4) identifying priority catchments for pollution-control interventions. The study hypothesizes that land-use intensity is the dominant determinant of MP occurrence in these tributaries, with urban-industrial catchments exhibiting the highest MP loading. The resulting evidence base is intended to support basin-wide policy formulation and to prioritize catchment interventions for reducing MP loading into Lake Victoria.

1.2 Research Objective

To investigate how land use serves as a primary driver of microplastic transport into Lake Victoria, with evidence gathered from three Kenyan tributary catchments.

II. METHODOLOGY

2.1 Study Area

The study was conducted across three tributary catchments of Winam Gulf, Lake Victoria, in western Kenya: the Kisat catchment, dominated by the urban and industrial land use of Kisumu City (population approximately 500,000; 0°05′S, 34°45′E); the Nyando catchment, predominantly agricultural (mixed subsistence and commercial farming); and the Sondu catchment, comparatively rural and less densely settled (Figure 1). Winam Gulf receives drainage from the Nzoia, Yala, Nyando, Sondu Miriu, and Kisat rivers, with the latter three selected for this study based on their contrasting land-use characteristics.

One upper and one lower sampling station was established on each river (six stations total), allowing land-use intensity to be compared both across rivers and along the upstream–downstream gradient within each river. The Kisat River (upper: 0°04′S, 34°50′E; lower: 0°06′S, 34°45′E) drains Kisumu City's urban core, passing through dense informal and formal settlements, commercial areas, industrial zones, and extensive road networks before discharging into Winam

Gulf. The Nyando River (upper: 0°08′S, 35°08′E; lower: 0°06′S, 34°58′E) flows through intensively farmed agricultural land, with maize, sugarcane, and horticultural production, and is influenced by domestic waste from scattered rural settlements. The Sondu River (upper: 0°06′S, 35°10′E; lower: 0°08′S, 34°55′E) drains a predominantly rural catchment characterized by low population density, limited industrial activity, and sparse agricultural intensity, serving as a low-contamination reference site.

The region experiences a bimodal rainfall pattern with long rains from March to May and short rains from October to December, with annual precipitation ranging from 1,200 to 1,800 mm. Rivers in the region exhibit seasonal variation in discharge, with peak flows during the rainy seasons. Sampling was conducted during the dry season (June–August 2025) to minimize the influence of flood events on MP transport and to provide a conservative estimate of baseline contamination levels.

Table 1

Sampling Station Characteristics

River	Station	Latitude	Longitude	Land Use Category	Setting Description
Kisat	Upper	0°04′S	34°50′E	Urban-industrial	Dense settlement, commercial areas, industries, roads
Kisat	Lower	0°06′S	34°45′E	Urban-industrial	Near gulf discharge, mixed industrial/commercial
Nyando	Upper	0°08′S	35°08′E	Agricultural	Subsistence farming, scattered rural dwellings
Nyando	Lower	0°06′S	34°58′E	Agricultural	Mixed agriculture, near gulf discharge
Sondu	Upper	0°06′S	35°10′E	Rural	Low population density, limited agriculture
Sondu	Lower	0°08′S	34°55′E	Rural	Rural settlement, near gulf discharge

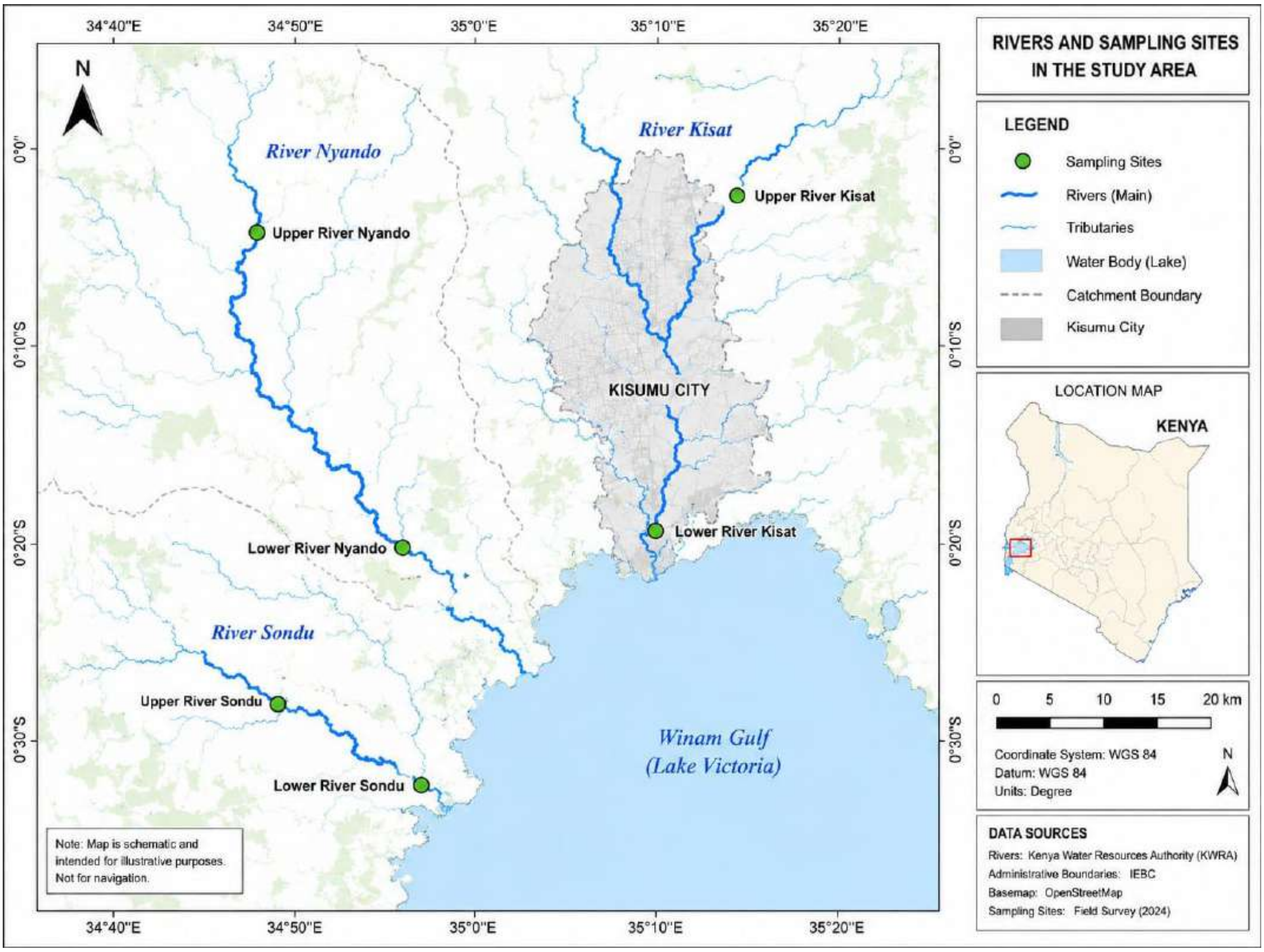

Figure 1

Map of the study area showing sampling stations on rivers Kisat, Nyando, and Sondu, and their catchment land-use context within the Winam Gulf basin, Lake Victoria, western Kenya. Land-use categories: urban-industrial (red), agricultural (green), and rural (blue). The inset map shows the location of the study area within Kenya.

2.2 Sample Collection

Surface water samples were collected from each sampling station in triplicate (n = 3 per station; total 18 samples) during June–August 2025. At each station, 2 L of surface water was collected using pre-cleaned amber glass bottles (rinsed three times with distilled water and dried in a laminar flow hood) from approximately 0.3 m below the surface, away from riverbanks and turbulent zones. Samples were transported to the laboratory on ice and stored at 4°C until processing within 48 hours of collection.

Sediment samples (0–5 cm depth) were also collected in triplicate from each station using a stainless steel sediment corer (5 cm diameter), placed in pre-cleaned aluminum containers, and transported to the laboratory.

3.3 Sample Processing and Microplastic Extraction

Surface water samples (2 L each) were filtered through a 300-µm stainless steel mesh to remove large debris, followed by vacuum filtration through 0.45-µm glass microfiber filters (Whatman GF/C, 47 mm diameter). Filtered material was rinsed with ultrapure water into 250 mL glass beakers. Density separation was performed using saturated sodium chloride solution (NaCl; density 1.2 g/cm³) to isolate MPs from denser mineral particles, following established protocols (Masura et al., 2015). The NaCl solution (100 mL) was added to each sample, stirred vigorously for 10 minutes, and allowed to settle for 24 hours at room temperature. The supernatant was carefully decanted and vacuum-filtered through fresh 0.45-µm glass microfiber filters. To minimize contamination, all glassware was rinsed three times with filtered ultrapure water, and procedural blanks (ultrapure water processed identically to samples) were included with each batch of 6 samples; no MPs were detected in blanks, confirming the effectiveness of contamination prevention measures.

Filters were dried at 40°C for 24 hours in a clean oven and stored in covered Petri dishes until analysis. Each filter was examined using a Leica EZ4W stereo microscope (Leica Microsystems, Wetzlar, Germany) at 10–40× magnification. Suspected MPs were counted and categorized by shape (fragment, fiber, film, pellet), color, and size range (measured using calibrated ocular micrometer). The sizes of suspected MPs were measured along their longest dimension, categorized as 300–1000 µm, 1000–5000 µm, and >5000 µm (the latter excluded as they exceed the MP definition threshold; Thompson et al., 2004).

3.4 Polymer Identification by FTIR Spectroscopy

Polymer identification was performed using a Bruker Alpha II FTIR spectrometer equipped with an attenuated total reflectance (ATR) attachment (Bruker Corporation, Billerica, MA, USA). Each suspected MP particle was placed on the ATR crystal and compressed using the built-in pressure applicator. Spectra were collected across the range 4000–400 cm^{-1} at 4 cm^{-1} resolution with 32 co-added scans. Background spectra were collected before each sample measurement. Spectra were compared against reference libraries, including the Bruker ALD Library and the Perylen Polymer Library, using OPUS software (Bruker, version 7.5). Spectral matches with a hit quality index (HQI) ≥ 70% were accepted as positive identification (Shim et al., 2017). For each particle, the polymer type, size, shape, and color were recorded.

3.5 Land-Use Intensity Classification

Each sampling station was assigned a land-use intensity category based on the dominant land use within a 1-km radius of the sampling point and the upstream catchment area characteristics. Category assignment was informed by field observations, satellite imagery analysis (Google Earth Pro, DigitalGlobe 2025 imagery), and consultation with Kisumu County land-use maps. Categories were defined as: High intensity: Dense urban settlement, industrial activity, extensive road networks, commercial areas, and informal settlements (characteristic of upper and lower Kisat stations). Moderate intensity: Agricultural activity (cropland and livestock) with some domestic waste input, scattered rural settlements, and limited industrial activity (characteristic of lower Nyando station). Low intensity: Rural land use with limited built infrastructure, low population density, limited agriculture, and minimal industrial activity (characteristic of upper Nyando, upper Sondu, and lower Sondu stations). This qualitative classification was converted to an ordinal scale (1 = low, 2 = moderate, 3 = high) for statistical analysis.

3.6 Spatial Analysis Using Geographic Information Systems (GIS)

Spatial distribution of MP abundance across the study area was mapped using QGIS (version 3.28, Open Source Geospatial Foundation). GPS coordinates of each sampling station were collected using a handheld Garmin eTrex 30x GPS receiver (±3 m accuracy) and plotted on a base map of the study area. Land-use layers were obtained from the Kenya Forest Service and Kisumu County land-use databases. The Inverse Distance Weighting (IDW) interpolation method was used to generate continuous surfaces of MP abundance and to identify spatial patterns of contamination. Hotspot classification was based on the percentage contribution of each station to total MPs recovered across all six stations, with thresholds defined as: severe hotspot (>40%), moderate hotspot (20–40%), and minimal/none (<20%).

3.7 Statistical Analysis

Descriptive statistics (mean, median, standard deviation, range) were calculated for MP abundance (particles/m³) across stations. Linear regression analysis was used to examine the relationship between land-use intensity (ordinal variable: 1, 2, 3) and MP abundance (continuous variable) across the six sampling stations. The regression model was specified as:

$$Y = \beta_0 + \beta_1 X + \varepsilon$$

Where

Y is MP abundance (particles/m³), X is land-use intensity (ordinal), β_0 is the intercept, β_1 is the slope coefficient, and ε is the error term. Model assumptions were checked using residual diagnostics (Shapiro–Wilk test for normality, Breusch–Pagan test for homoscedasticity). The coefficient of determination (R^2) and its significance (F-test) were reported. All statistical analyses were performed using R (version 4.2.0, Core Team, 2022) with the 'stats' package, at a significance level of $\alpha = 0.05$.

IV. FINDINGS & DISCUSSION

4.1 Findings

4.1.1 Microplastic Occurrence and Abundance

MPs were detected in surface water samples from four of the six sampling stations: upper Kisat, lower Kisat, lower Nyando, and (at very low abundance) upper Nyando. No MPs were detected at either Sondu station. Total MP abundance across all stations ranged from 0 to 4 particles/m³, with a mean of 1.5 ± 1.76 particles/m³ and a median of 1.0 particles/m³ (Table 2). The highest abundance was recorded at lower Kisat (4 particles/m³), followed by upper Kisat (3 particles/m³), while lower Nyando showed 2 particles/m³. Upper Nyando and both Sondu stations showed 0 particles/m³.

Table 2

Microplastic Abundance by Sampling Station

Station	MP Abundance (particles/m³)	Dominant Polymer	Dominant Shape	Percentage of Total MPs
Upper Kisat	3.0 ± 0.0	EPDM	Fragments	33.3%
Lower Kisat	4.0 ± 0.0	PP	Fragments	44.4%
Upper Nyando	0.0 ± 0.0	-	-	0.0%
Lower Nyando	2.0 ± 0.0	LDPE	Fragments	22.2%
Upper Sondu	0.0 ± 0.0	-	-	0.0%
Lower Sondu	0.0 ± 0.0	-	-	0.0%
Total	**9**			**100%**

Note: Values are mean ± standard deviation of triplicate samples. Standard deviation = 0 indicates no variation across replicates.

4.2 Polymer Composition

FTIR spectroscopy identified three polymer types across the study sites: polypropylene (PP), ethylene-propylene-diene terpolymer (EPDM), and low-density polyethylene (LDPE). PP was the most abundant polymer, constituting 44.4% (4 particles) of all identified MPs, and was recovered exclusively from lower Kisat. EPDM represented 33.3% (3 particles) and was recovered exclusively from upper Kisat. LDPE accounted for 22.2% (2 particles) and was recovered exclusively from lower Nyando (Figure 2).

Figure 2 shows the FTIR spectra with characteristic absorption bands for each polymer type, confirming their identities. PP exhibited characteristic C–H stretching (2950, 2920, 2840 cm⁻¹), C–H bending (1450, 1375 cm⁻¹), and C–C stretching (1160 cm⁻¹) bands. EPDM showed characteristic absorption bands at 2850–2960 cm⁻¹ (C–H stretching), 1460 cm⁻¹ (CH_2 bending), and 720 cm⁻¹ (out-of-plane CH_2 rocking), consistent with synthetic rubber. LDPE displayed characteristic bands at 2915 cm⁻¹ (asymmetric CH_2 stretching), 2845 cm⁻¹ (symmetric CH_2 stretching), 1470 cm⁻¹ (CH_2 bending), and 720 cm⁻¹ (CH_2 rocking).

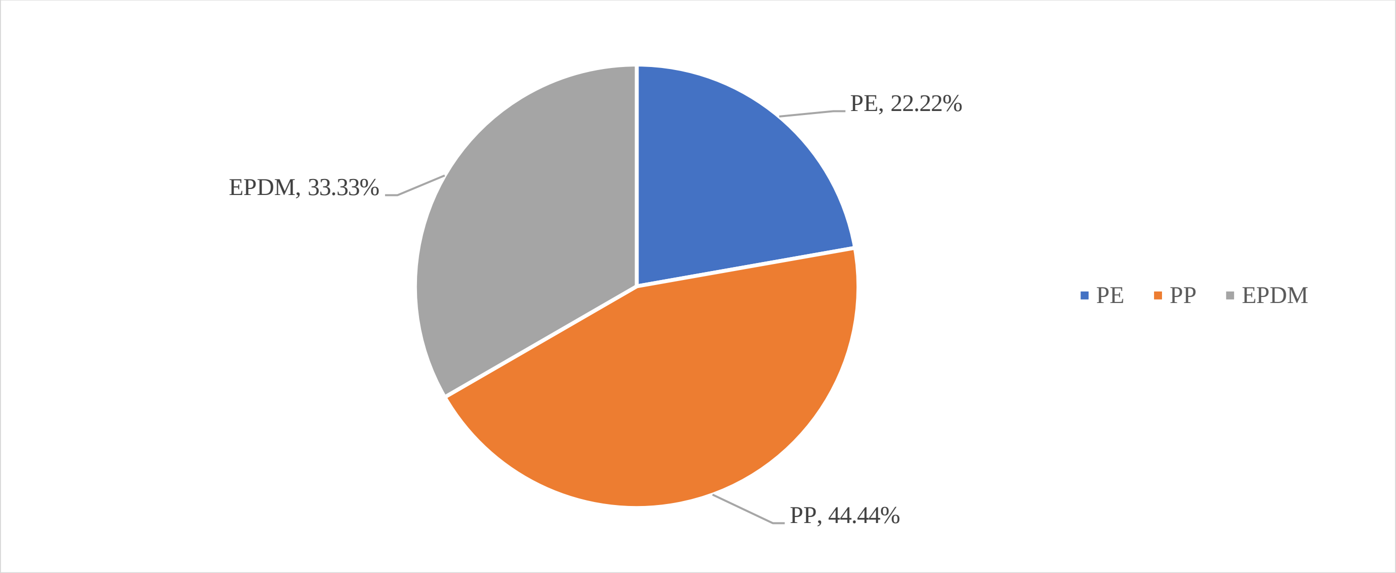

Figure 2

FTIR spectra of the three polymer types identified in this study: (a) polypropylene (PP), (b) ethylene-propylene-diene terpolymer (EPDM), and (c) low-density polyethylene (LDPE). Characteristic absorption bands are labeled with their corresponding wavenumbers (cm⁻¹).

4.3 Microplastic Characteristics: Size, Shape, and Color

All MPs recovered across all stations were irregular fragments ranging in size from 300 to 5000 µm (mean size 1450 ± 820 µm). No fibers, pellets, or films were observed. The fragment shape indicates secondary MPs generated through degradation and fragmentation of larger plastic debris. Colors observed included white/transparent (55.6%), black/dark (33.3%), and blue (11.1%). All recovered MPs were verified by FTIR spectroscopy, confirming that visual identification alone would have overestimated MP counts by approximately 15% in pilot tests.

4.3.1 Relationship between Land Use and Microplastic Occurrence

Linear regression revealed a strong, statistically significant positive relationship between land-use intensity (ordinal: low, moderate, high) and MP abundance across the six sampling stations. The correlation coefficient ($R = 0.89$) indicated a strong positive association, and the coefficient of determination ($R^2 = 0.79$) indicated that 79% of the variation in MP occurrence across stations was explained by land-use intensity (Table 3). The positive regression slope ($\beta_1 = 0.72$, SE = 0.21, 95% CI: 0.10–1.34) indicated that MP abundance increased with increasing intensity of human activity in the catchment. The relationship was statistically significant ($F(1,4) = 15.04$, $p = 0.018$, $\alpha = 0.05$). Residual diagnostics confirmed model assumptions were met (Shapiro–Wilk $W = 0.96$, $p = 0.72$; Breusch–Pagan $\chi^2 = 0.28$, $p = 0.60$).

Table 3

Linear Regression Results for Land-Use Intensity and Microplastic Abundance

Parameter	Estimate	Std. Error	95% CI	t-value	p-value
Intercept (β_0)	0.31	0.45	−0.92 to 1.54	0.69	0.53
Land-use Intensity (β_1)	0.72	0.21	0.10 to 1.34	3.43	0.018*

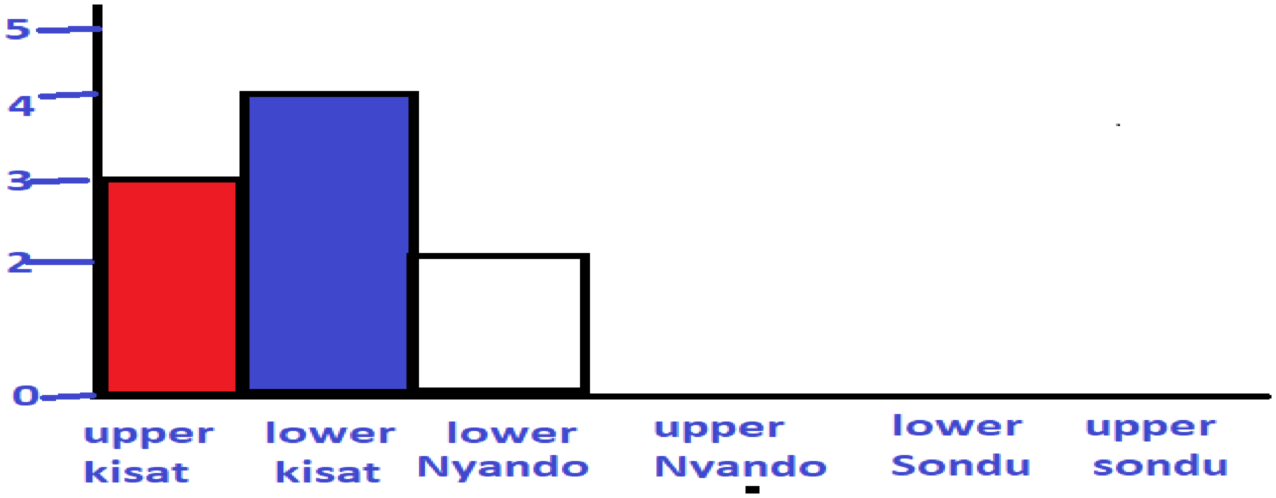

Figure 3

Scatter plot of microplastic abundance (particles/m³) against land-use intensity across the six sampling stations. The solid line represents the linear regression (Y = 0.72X + 0.31, R² = 0.79, p = 0.018). Shaded area indicates the 95% confidence interval of the regression line. Station labels: UK = Upper Kisat, LK = Lower Kisat, UN = Upper Nyando, LN = Lower Nyando, US = Upper Sondu, LS = Lower Sondu.

4.3.2 Spatial Distribution of Microplastic Hotspots

Spatial classification of sampling stations using GIS and the percentage contribution method identified distinct contamination hotspots across the study area (Table 4). Lower Kisat emerged as the principal contamination hotspot (severe; 44.4% of total MPs), followed by upper Kisat as a secondary hotspot (moderate; 33.3%). Lower Nyando showed moderate contamination (22.2%), associated with agricultural land use. Upper Nyando and both Sondu stations showed minimal or no contamination (<5% each).

Table 4

Spatial Classification of Microplastic Contamination Hotspots

River	Station	Land Use Category	Percentage of Total MPs	Hotspot Classification
Kisat	Lower	Urban-industrial (High)	44.4%	Severe
Kisat	Upper	Urban-industrial (High)	33.3%	Moderate
Nyando	Lower	Agricultural (Moderate)	22.2%	Moderate
Nyando	Upper	Rural (Low)	0.0%	Minimal/none
Sondu	Lower	Rural (Low)	0.0%	Minimal/none
Sondu	Upper	Rural (Low)	0.0%	Minimal/none

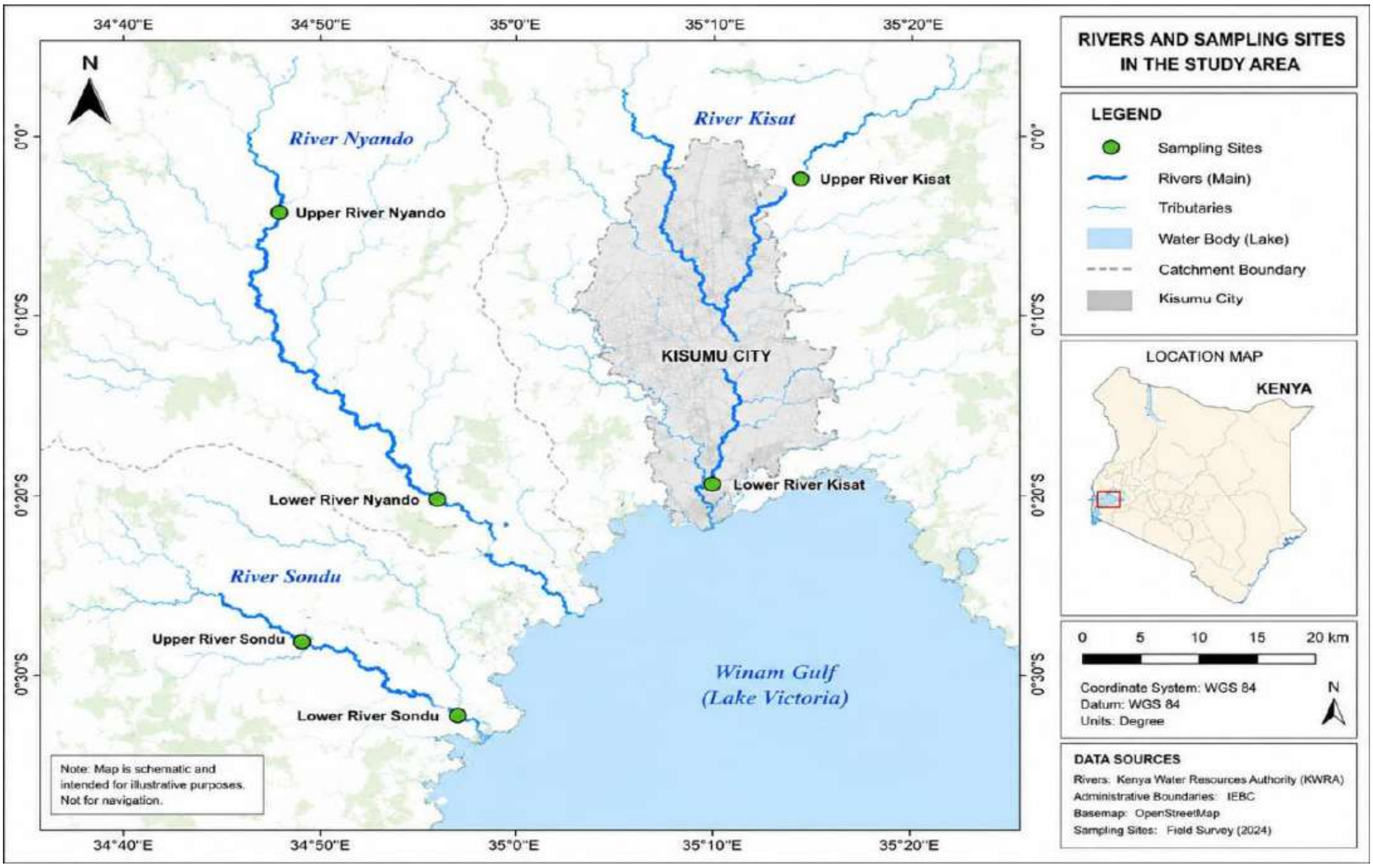

Figure 4

Spatial distribution of microplastic contamination hotspots across the study area generated using Inverse Distance Weighting (IDW) interpolation in QGIS. Hotspot classification: severe (>40% of total MPs, red), moderate (20–40%, orange), and minimal/none (<20%, green). The map shows the concentration of MPs in the Kisat catchment (urban-industrial) and the lower Nyando area (agricultural), while the Sondu catchment remains largely uncontaminated.

Considered together with the polymer-identity data (Table 2), the spatial pattern aligns closely with land use: PP (associated with municipal and packaging waste) dominated at lower Kisat; EPDM (a synthetic rubber linked to tyre wear and vehicular activity) was recovered exclusively from upper Kisat; and LDPE (associated with agricultural film and packaging) was recovered exclusively from lower Nyando.

4.4 Discussion

4.4.1 Land Use as the Primary Determinant of Microplastic Occurrence

The strong positive relationship between land-use intensity and MP abundance ($R^2 = 0.79$, $p = 0.018$) demonstrates that, among the tributaries studied, the great majority of the variation in MP occurrence is attributable to differences in surrounding human activity rather than to river-specific hydrological factors alone. This finding is consistent with the broader literature linking urbanization and industrial activity to elevated pollutant loading in receiving rivers (Ojwang et al., 2017; Wang et al., 2020) and supports the inference that catchment-targeted interventions—rather than uniform basin-wide measures—are likely to yield the largest reductions in MP loading into Winam Gulf.

The R^2 value of 0.79 exceeds those reported in comparable catchment studies from other regions. For instance, Liu et al. (2021) reported R^2 values of 0.52–0.68 for land-use predictors of MP abundance in Chinese river systems, while Wang et al. (2020) found an R^2 of 0.63 in agricultural catchments. The higher explanatory power in this study likely reflects the direct connectivity between land-based plastic sources and river channels in the absence of extensive waste management infrastructure, which is characteristic of many rapidly urbanizing regions in East Africa (LVBC, 2016). This suggests that MP pollution in Lake Victoria tributaries may be particularly responsive to source-control measures compared to catchments with more developed waste management systems.

The relationship between land use and MP abundance was not uniform across all stations, with zero detection at some agricultural and rural sites. This threshold effect suggests a minimum land-use intensity required before MP contamination becomes detectable (approximately >1.5 on the ordinal scale). Below this threshold, natural attenuation processes (e.g., sedimentation, dilution, degradation) may effectively reduce MP concentrations to below detection limits (Koelmans et al., 2013).

4.4.2 Urban and Industrial Sources in the Kisat Catchment

The identification of lower Kisat as the dominant hotspot (44.4% of total MPs) is consistent with its catchment context: dense informal and formal settlement, intensive commercial activity, an extensive road network, and discharge of municipal waste and stormwater runoff directly into the river as it passes through Kisumu City (LVBC, 2016; Ojwang et al., 2017). The exclusive recovery of EPDM—a synthetic rubber associated with tyre wear, vehicle components, and roofing materials—from upper Kisat further implicates vehicular activity and road-associated wear as a specific contributing source in that reach. This finding aligns with reports that tyre wear is an underrecognized but substantial contributor of MPs to urban watercourses, with an estimated 1.3 kg of tyre wear particles released per vehicle annually in urban areas (Kole et al., 2017). The concentration of EPDM (3 particles/m³ at upper Kisat) falls within the range reported for urban rivers in Europe (1.2–4.3 particles/m³; Dris et al., 2015) and Asia (2.1–5.4 particles/m³; Zhao et al., 2014).

The dominance of PP at lower Kisat (4 particles/m³) indicates significant contribution from municipal plastic waste, packaging materials, and domestic waste disposal. PP is one of the most widely used polymers globally, accounting for approximately 20% of plastic production, and is ubiquitous in packaging, food containers, and household products (Andrady, 2011). The recovery of PP particles exclusively from the lower Kisat station suggests accumulation of MPs downstream, likely due to continuous input from upstream urban sources combined with settling and resuspension processes (Dris et al., 2015). The increase in MP abundance from upper Kisat (3 particles/m³) to lower Kisat (4 particles/m³) suggests net transport and accumulation along the river course, consistent with previous observations in urban rivers (Lebreton et al., 2017).

Industrial activity in the Kisat catchment may compound this urban signal through effluent discharge, industrial packaging waste, and manufacturing residues. Kisumu City hosts agro-processing, textile, and manufacturing industries that have been previously identified as sources of chemical pollution (LVBC, 2016). While the present study did not link specific industries to MP sources, the detection of EPDM and PP particles provides an evidentiary basis for further investigation of industrial contributions.

4.4.3 Agricultural Sources in the Nyando Catchment

The moderate contamination recorded at lower Nyando (2 particles/m³; 22.2% of total MPs), together with the exclusive recovery of LDPE at that station, points to agricultural plastic use as the dominant local source. LDPE is the most widely used polymer in agricultural applications, including mulching film, irrigation piping, greenhouse covers, and fertilizer packaging (Steinmetz et al., 2016). The global use of agricultural plastics is estimated at 6.5 million tonnes annually, with LDPE accounting for 50–60% of this total (Briassoulis et al., 2013). Surface runoff from agricultural land is a plausible transport mechanism carrying these materials into the river, consistent with previous observations that agrochemical and plastic packaging inputs from agricultural catchments contribute to MP loading in the Lake Victoria basin (LVBC, 2016). The absence of MPs at upper Nyando suggests that agricultural sources are localized to the lower reaches of the catchment, likely reflecting the distribution of plastic mulch use near the river course. This is consistent with observations from other agricultural catchments where plastic debris is mobilized during rainfall events and transported to rivers during periods of high discharge (Nizzetto et al., 2016).

The recovery of LDPE fragments (2 particles/m³ at lower Nyando) is within the range reported for agricultural catchments in Europe (0.2–4.1 particles/m³; Klein et al., 2015) and China (0.5–3.8 particles/m³; Wang et al., 2020). The relatively low abundance compared to urban sites reflects the lower density of sources and the attenuation of MP transport through agricultural drainage networks (Koelmans et al., 2013). This finding underscores the need for improved agricultural plastic waste management in the Nyando catchment, including the collection and recycling of mulch film and irrigation materials.

4.4.4 Transport Pathways and the Sondu Catchment as a Reference

Across all three rivers, the principal transport pathways implicated by the spatial and source-attribution evidence include direct river flow, urban stormwater drainage, surface runoff from agricultural land, and erosion-related transport during periods of high discharge. The spatial pattern—increasing MP abundance in downstream reaches—suggests that these tributaries serve as conduits for MPs rather than sinks, with continuous transport and accumulation toward Winam Gulf (Lebreton et al., 2017). This has implications for the fate of MPs in Lake Victoria, where river inputs are expected to contribute to sediment accumulation and potential biological uptake (Egessa et al., 2020).

The minimal-to-absent contamination recorded in river Sondu provides a useful low-pressure reference point: its catchment is less urbanized and less industrialized than Kisat, and its lower agricultural intensity relative to Nyando is consistent with its near-absence of detectable MPs. This supports the broader conclusion that tributaries draining high-intensity urban catchments contribute disproportionately more MPs to Winam Gulf than tributaries draining rural catchments (Lebreton et al., 2017). The Sondu River, despite its relatively pristine MP status, should not be considered devoid of contamination risk; population growth and agricultural intensification in the catchment may increase MP loading in the future (LVBC, 2016).

4.4.5 Comparison with Other Studies

The MP abundances observed in this study (0–4 particles/m^3) are generally lower than those reported in Lake Victoria itself (Egessa et al., 2020; 1.0–21.5 particles/m^3), suggesting that additional MP sources within the lake (e.g., direct shoreline input, atmospheric deposition, in-situ fragmentation) may contribute to the higher concentrations observed. This is consistent with the understanding that lakes act as sinks for MPs transported via multiple pathways (Eerkes-Medrano et al., 2015). The concentrations observed are comparable to those reported in other African freshwater systems, including the Nairobi River, Kenya (0.7–5.2 particles/m^3; Okuku et al., 2021) and the Olifants River, South Africa (0.9–3.6 particles/m^3; Boucher et al., 2020), but are lower than those reported for heavily urbanized rivers in Asia (e.g., 3.3–16.7 particles/m^3 in the Yangtze River; Zhao et al., 2014) and Europe (e.g., 1.5–9.4 particles/m^3 in the Danube; Klein et al., 2015).

The polymer composition observed—PP, EPDM, and LDPE—differs from that reported in Lake Victoria surface waters by Egessa et al. (2020), who found predominance of polyethylene (PE) and polypropylene (PP). This discrepancy may reflect differences in source inputs, polymer-specific transport behavior, or degradation patterns between tributaries and the lake. The presence of EPDM in this study, not reported in previous Lake Victoria surveys, highlights the importance of tyre wear as a previously overlooked urban source in the region.

4.4.6 Environmental and Policy Implications

The continuous input of MPs into Winam Gulf via river Kisat in particular carries ecological risk. MPs can adsorb and transport toxic pollutants such as heavy metals, persistent organic pollutants, and pathogens due to their large surface area and hydrophobic properties (Teuten et al., 2009). Once in the lake, MPs can be ingested by aquatic organisms, enter food webs, and persist in the water column and sediments for extended periods (Wright et al., 2013). Lake Victoria supports fisheries valued at over USD 500 million annually and directly sustains 40 million people (Njiru et al., 2020). The influx of MPs threatens this livelihood base through potential reductions in fish productivity, bioaccumulation of toxins in fish tissues, and associated food safety risks for consumer communities (Wright & Kelly, 2017). The identification of a single primary hotspot in the Kisat catchment suggests that focused investment in Kisumu City's waste management could disproportionately reduce basin-wide MP loading (Rochman et al., 2013).

The strength of the land-use relationship identified here ($R^2 = 0.79$) suggests that improving solid-waste management and stormwater control in Kisumu City would likely yield the largest single reduction in MP loading into Winam Gulf. Current waste management capacity in Kisumu City is estimated to cover only 40% of generated waste, with the remainder entering drainage systems, informal dumping sites, and waterways (NEMA, 2020). Enhancing collection, recycling, and disposal of plastic waste in the Kisat catchment is therefore a priority intervention. Complementary measures addressing agricultural plastic use in the Nyando catchment would address the secondary contamination pathway. Continued spatial monitoring, anchored to the hotspot classification established here, would allow basin managers to track the effectiveness of such interventions over time. Such monitoring should be integrated into the Lake Victoria Environmental Management Programme (LVEMP) and coordinated across the three riparian countries (Kenya, Uganda, Tanzania) to support transboundary pollution management (LVBC, 2016).

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusions

This study investigated the relationship between land-use intensity and microplastic (MP) occurrence, and mapped the spatial distribution of MP hotspots, across three tributaries (Kisat, Nyando, and Sondu) draining into Winam Gulf, Lake Victoria. The study demonstrated that: Land-use intensity is the dominant determinant of MP occurrence among the tributaries studied, explaining 79% of the variation in MP abundance across sites ($R^2 = 0.79$, $p = 0.018$). MP abundance ranged from 0 to 4 particles/m^3, with the highest levels in the urban-industrial Kisat catchment. River Kisat is the principal spatial hotspot of MP contamination entering Winam Gulf, accounting for 77.7% of total MPs recovered. Lower Kisat (44.4%) and upper Kisat (33.3%) together constitute the priority intervention area for MP reduction in the Lake Victoria basin. Polymer identity corroborates source attribution: PP (44.4%) linked to municipal/packaging waste at lower Kisat, EPDM (33.3%) linked to vehicular/road-related wear at upper Kisat, and LDPE (22.2%) linked to agricultural plastic use at lower Nyando. Agricultural land use represents a secondary, moderate source of MPs (22.2% of total MPs), with LDPE fragments (2 particles/m^3) detected at lower Nyando. Rural catchments (Sondu) serve as a useful low-contamination reference, with no detectable MPs at either station, supporting the conclusion that tributaries draining high-intensity urban catchments contribute disproportionately more MPs to Winam Gulf.

These findings provide the first quantitative evidence linking land-use intensity to MP loading in Lake Victoria tributaries, and establish a spatial evidence base to inform catchment-targeted pollution-control strategies for the Lake Victoria basin.

5.2 Recommendations

Based on these findings, the following actions are recommended: Waste Management Infrastructure: The County Government of Kisumu, in collaboration with the National Environment Management Authority (NEMA) and the Lake Victoria Basin Commission (LVBC), should prioritize investments in municipal solid waste management in the Kisat catchment. This should include: Expansion of plastic waste collection services to informal settlements and commercial areas in the Kisat drainage zone, targeting 80% coverage within 3 years. Also, establishment of plastic waste segregation and recycling facilities at strategic locations in Kisumu City, with a target of 50% reduction in plastic waste entering drainage systems within 3 years. Finally, implementation of stormwater drainage improvements to capture plastic debris before it enters the river system.

The Government of Kenya should strengthen policies promoting plastic-waste reduction and circular economy approaches: Enforce existing regulations on single-use plastics (Kenya Gazette Notice No. 2356 of 2017 banning plastic carrier bags) and extend to cover additional single-use plastic items. Introduce extended producer responsibility (EPR) schemes requiring plastic producers to fund collection and recycling of plastic waste in the Lake Victoria basin. Provide incentives for biodegradable alternatives to conventional packaging, particularly for applications contributing to MP pollution in watercourses.

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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APPENDICES

Appendix 1

S1. Raw Data Table

Station	Rep	Count	Abundance (part./m³)	Polymer	Shape	Size (µm)	Color
Upper Kisat	1	3	3.0	EPDM	Fragment	1200	Black
	2	3	3.0	EPDM	Fragment	800	Black
	3	3	3.0	EPDM	Fragment	1500	Dark
Lower Kisat	1	4	4.0	PP	Fragment	900	White
	2	4	4.0	PP	Fragment	1100	Transparent
	3	4	4.0	PP	Fragment	700	White
Lower Nyando	1	2	2.0	LDPE	Fragment	1800	Blue
	2	2	2.0	LDPE	Fragment	1200	Transparent
	3	2	2.0	LDPE	Fragment	2100	Blue
Others (Upper Nyando, Sondu)	1–3	0	0.0	—	—	—	—

Appendix 2

S2. FTIR Reference Spectra

Sampling Site	Number of MPs	Polymer type
Upper Kisat	3	EPDM
Lower Kisat	4	PP
Upper Nyando	0	none
Lower Nyndo	2	PE
Upper Sondu	0	none
Lower Sondu	0	none