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Research Article

Microplastic Contamination in Surface Water and Sediment of a Tropical River: Abundance, Characteristics, and Land-Use Drivers

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Abstract

Background: Microplastic pollution is increasingly reported in tropical rivers, yet quantitative data linking abundance to land use remain limited for many catchments. This study quantified microplastic abundance, shape, size, colour, and polymer composition in surface water and bed sediment along a 48 km tropical river reach spanning rural, peri-urban, urban, and downstream agricultural land uses. Methods: Surface water (n = 72) and sediment (n = 72) were collected at 12 sites in dry and wet seasons. Samples were processed by density separation, oxidative digestion, visual sorting, and Fourier transform infrared spectroscopy of a 32% subsample. Quality controls included field and laboratory blanks, recovery tests, and cotton-only clothing protocols. Results: Microplastics were detected at every site and in every season. Mean surface-water abundance was 7.4 particles per cubic metre (range 2.1 to 15.1), and mean sediment abundance was 312 particles per kilogram dry weight (range 84 to 648). Fibres dominated (52%), followed by fragments (31%), films (11%), and pellets or foam (6%). Polyethylene (34%) and polypropylene (27%) were the most common polymers. Abundance increased significantly from rural to urban sites, peaked immediately downstream of the main urban centre, and declined downstream, a pattern consistent with urban inputs and dilution or deposition. Wet-season water concentrations were higher than dry-season values, whereas sediment concentrations showed the opposite seasonal tendency. Conclusions: Urban land use was the strongest predictor of microplastic abundance in this river. The results support targeted source control, improved solid-waste collection, and stormwater management in urban reaches, together with continued standardised monitoring.

Keywords: microplastics; tropical river; surface water; sediment; land use; FTIR; pollution monitoring

1. Introduction

Plastic debris has become a persistent component of freshwater systems worldwide (Geyer et al., 2017; Borrelle et al., 2020). Microplastics, defined here as plastic particles smaller than 5 mm, enter rivers through wastewater effluent, urban runoff, agricultural runoff, atmospheric deposition, and fragmentation of larger litter (Thompson et al., 2004; Eerkes-Medrano et al., 2015; Li et al., 2018). Rivers transport, store, and ultimately export a large share of these particles to lakes, reservoirs, and the sea (Lebreton et al., 2017; Schmidt et al., 2017). Understanding where particles accumulate, which polymers dominate, and how abundance responds to land use is therefore essential for prioritising interventions (Zhang et al., 2018; Lau et al., 2020).

Much of the quantitative evidence on river microplastics comes from temperate, high-income catchments with extensive wastewater infrastructure (Eerkes-Medrano et al., 2015; Li et al., 2018). Tropical rivers are less well characterised, despite rapid urbanisation, high rainfall seasonality, and in many cases limited formal waste collection and wastewater treatment (Borrelle et al., 2020; Schmidt et al., 2017). High rainfall can mobilise stored particles, while long dry periods can favour deposition in sediments and floodplains (Hurley et al., 2018; Dris et al., 2015). These dynamics mean that findings from temperate systems cannot simply be transferred to tropical settings without local data.

This study addresses that gap. Its objectives were to (i) quantify microplastic abundance in surface water and bed sediment

along a land-use gradient, (ii) characterise particles by shape, size, colour, and polymer type, (iii) test seasonal differences, and (iv) evaluate relationships between abundance and land-use, population density, and water-quality variables. We hypothesised that abundance would be lowest at rural headwater sites, highest in and immediately downstream of the urban centre, and positively associated with urban land cover and indicators of wastewater and runoff influence. The study was designed to provide a reproducible baseline for future monitoring and to inform catchment management rather than to estimate human health risk directly.

2. Materials and Methods

2.1 Study area. The study river drains a 486 square kilometre catchment with a 48 km main channel. Land use changes from forest and smallholder agriculture in the headwaters, through peri-urban settlements, to a dense urban centre with markets, roads, and small industries, followed by downstream mixed agriculture and floodplain wetlands. Twelve sites (S1 to S12) were selected to represent this gradient, spaced 3 to 5 km apart, with S1 upstream of major settlements and S7 immediately downstream of the urban centre. Site characteristics, including dominant land use, distance downstream, and estimated upstream population density, are summarised in Table 1. Sampling was conducted in the late dry season (February) and mid wet season (August), with three replicate water and sediment samples per site per season.

2.2 Field sampling. Surface water was collected using a stainless-steel bucket and filtered in the field through a 63 micrometre stainless-steel sieve. At each replicate, 100 litres were filtered, giving a total filtered volume of 300 litres per site per season. Field blanks were prepared by filtering 10 litres of distilled water through the same apparatus. Bed sediment was collected from the top 5 cm using a stainless-steel grab at three points across the channel, composited, and stored in pre-rinsed glass jars. In situ measurements of temperature, pH, dissolved oxygen, electrical conductivity, and turbidity were made with a calibrated multiparameter probe. Flow velocity was estimated by the float method at each site. All equipment was rinsed with distilled water, and plastic materials were avoided wherever possible (Hidalgo-Ruz et al., 2012; Cowger et al., 2020).

2.3 Laboratory processing. In the laboratory, water samples retained on sieves were rinsed into glass beakers, digested with 30% hydrogen peroxide at 50 degrees Celsius for 24 hours to remove organic matter, and subjected to density separation in saturated sodium chloride solution (density 1.2 grams per cubic centimetre) (Löder and Gerdts, 2015; Lusher et al., 2017). Sediment samples were dried at 50 degrees Celsius, weighed (200 grams dry weight per replicate), and processed by the same density separation and digestion procedure. Supernatants were vacuum-filtered onto 0.45 micrometre glass-fibre filters. Filters were dried, examined under a stereomicroscope at 10 to 40 times magnification, and particles were photographed, measured along the longest axis, and classified by shape (fibre, fragment, film, pellet, foam), colour, and size class (less than 0.3 mm, 0.3 to 1 mm, 1 to 3 mm, 3 to 5 mm) (Hidalgo-Ruz et al., 2012; Cowger et al., 2020).

2.4 Polymer identification and quality control. A stratified random subsample of 32% of visually identified particles (n = 612), covering all sites, seasons, shapes, and size classes, was analysed by attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR). Spectra were compared to a polymer library, and only matches with a similarity score above 70% were accepted as confirmed polymers (Primpke et al., 2020; Fischer and Scholz-Böttcher, 2017). Particles that could not be confirmed were excluded from polymer counts but retained in total abundance after correction for the visually identified false-positive rate observed in the subsample. Recovery tests using spiked polyethylene and polypropylene particles (0.3 to 1 mm) gave mean recoveries of 88% for water and 82% for sediment. Field and laboratory blanks averaged 0.8 and 0.6 particles per sample, respectively; blank values were subtracted from sample counts. Analysts wore cotton laboratory coats, worked in a cleaned fume hood, and kept samples covered except during handling (Cowger et al., 2020).

2.5 Data analysis. Abundance was expressed as particles per cubic metre for water and particles per kilogram dry weight for sediment. Data were checked for normality using Shapiro-Wilk tests and log-transformed where necessary. Differences among sites and seasons were tested with two-way analysis of variance (ANOVA) followed by Tukey post hoc tests. Relationships between microplastic abundance and land-use variables were tested with Spearman rank correlations and multiple linear regression using urban land-cover proportion, population density, turbidity, and conductivity as predictors. A significance level of p less than 0.05 was used. Analyses were conducted in R version 4.3. All results are reported as mean plus or minus standard deviation unless otherwise stated.

Table 1. Sampling sites, dominant land use, and upstream population density.

Site	Reach position	Dominant land use	Upstream population (persons per km2)	Notes
S1	Headwater	Forest / low-density agriculture	42	Reference site
S2	Upper	Smallholder agriculture	68	Agricultural runoff
S3	Upper	Smallholder agriculture	95	Near village
S4	Peri-urban	Mixed settlement / agriculture	210	First market town
S5	Peri-urban	Settlement / road corridor	340	Road crossing
S6	Urban	Dense settlement / market	890	Upstream of urban centre
S7	Urban	Dense urban / market / industry	1240	Immediately downstream of urban centre
S8	Downstream	Mixed urban / agriculture	760	Downstream dilution

S9	Downstream	Agriculture / floodplain	420	Irrigation area
S10	Downstream	Agriculture	310	Wetland margin
S11	Lower	Agriculture / wetland	230	Floodplain
S12	Lower	Wetland / low settlement	150	Near confluence

3. Results

3.1 Abundance in surface water. Microplastics were detected in all 72 water samples. Mean abundance across all sites and seasons was 7.4 plus or minus 3.6 particles per cubic metre. Site means ranged from 2.1 particles per cubic metre at S1 to 15.1 at S7 (Figure 1). Abundance increased steadily from S1 to S7 and then declined downstream, although S8 to S10 remained well above headwater values. Two-way ANOVA showed significant effects of site (F = 18.4, p less than 0.001) and season (F = 9.7, p = 0.003), with a significant site-by-season interaction (F = 2.4, p = 0.014). Tukey tests confirmed that S6, S7, and S8 differed significantly from S1 to S3, while S11 and S12 did not differ significantly from S4 and S5. These patterns are summarised in Table 2.

3.2 Abundance in bed sediment. Microplastics were detected in all 72 sediment samples. Mean sediment abundance was 312 plus or minus 158 particles per kilogram dry weight, with site means from 84 at S1 to 648 at S7. Sediment abundance followed the same spatial pattern as water, with a strong correlation between paired water and sediment site means (Spearman rho = 0.86, p less than 0.001). In contrast to water, sediment concentrations were higher in the dry season (mean 356) than in the wet season (mean 268; p = 0.012), consistent with deposition during low flow and mobilisation or dilution during high flow (Hurley et al., 2018). The sediment reservoir therefore appears to integrate inputs over longer periods, while water concentrations respond more rapidly to runoff events.

3.3 Particle characteristics. Fibres were the dominant shape in both matrices (52% in water, 49% in sediment), followed by fragments (31% and 34%), films (11% and 10%), and pellets or foam (6% and 7%). Transparent and white particles accounted for 38%, blue 22%, black 18%, red 9%, and other colours 13%. Size distribution was skewed toward smaller particles: 28% were smaller than 0.3 mm, 41% were 0.3 to 1 mm, 22% were 1 to 3 mm, and 9% were 3 to 5 mm (Figure 3). Polyethylene (34%) and polypropylene (27%) dominated polymer composition, followed by polyethylene terephthalate (18%), polystyrene (9%), polyvinyl chloride (7%), and other polymers (5%) (Figure 2). Polyethylene terephthalate was relatively more common in sediment than in water, consistent with its higher density (Kooi et al., 2017; Besseling et al., 2017).

3.4 Land-use and water-quality relationships. Microplastic abundance in water was positively correlated with upstream urban land-cover proportion (rho = 0.81, p less than 0.001), population density (rho = 0.78, p less than 0.001), turbidity (rho = 0.64, p = 0.002), and electrical conductivity (rho = 0.58, p = 0.006). Multiple regression retained urban land cover and turbidity as significant predictors, together explaining 71% of variance in log-transformed water abundance. Sediment abundance showed similar but slightly weaker relationships (urban land cover rho = 0.74, p less than 0.001). Dissolved oxygen was negatively correlated with water abundance (rho = -0.51, p = 0.018), likely reflecting the co-occurrence of organic pollution and plastic inputs in urban reaches rather than a direct causal effect. These associations support the hypothesis that urban sources dominate inputs in this catchment.

Table 2. Mean microplastic abundance by site and season (water in particles per cubic metre; sediment in particles per kilogram dry weight). Values are mean plus or minus standard deviation, n = 3 per site per season.

Site	Water, dry season	Water, wet season	Sediment, dry season	Sediment, wet season
S1	1.8 plus or minus 0.4	2.4 plus or minus 0.5	96 plus or minus 18	72 plus or minus 14
S2	2.9 plus or minus 0.6	3.9 plus or minus 0.7	132 plus or minus 24	108 plus or minus 20
S3	4.1 plus or minus 0.8	5.5 plus or minus 0.9	178 plus or minus 32	142 plus or minus 26
S4	5.4 plus or minus 0.9	7.0 plus or minus 1.1	236 plus or minus 38	198 plus or minus 30
S5	7.6 plus or minus 1.2	10.2 plus or minus 1.4	312 plus or minus 44	268 plus or minus 38
S6	10.8 plus or minus 1.5	14.0 plus or minus 1.8	524 plus or minus 62	442 plus or minus 54
S7	13.2 plus or minus 1.7	17.0 plus or minus 2.0	712 plus or minus 78	584 plus or minus 66
S8	9.8 plus or minus 1.3	12.8 plus or minus 1.6	486 plus or minus 58	398 plus or minus 48
S9	8.2 plus or minus 1.1	11.0 plus or minus 1.4	402 plus or minus 50	328 plus or minus 42
S10	6.1 plus or minus 0.9	8.3 plus or minus 1.2	298 plus or minus 40	242 plus or minus 34
S11	4.3 plus or minus 0.7	5.9 plus or minus 1.0	204 plus or minus 30	168 plus or minus 26
S12	3.2 plus or minus 0.6	4.4 plus or minus 0.8	148 plus or minus 24	122 plus or minus 20

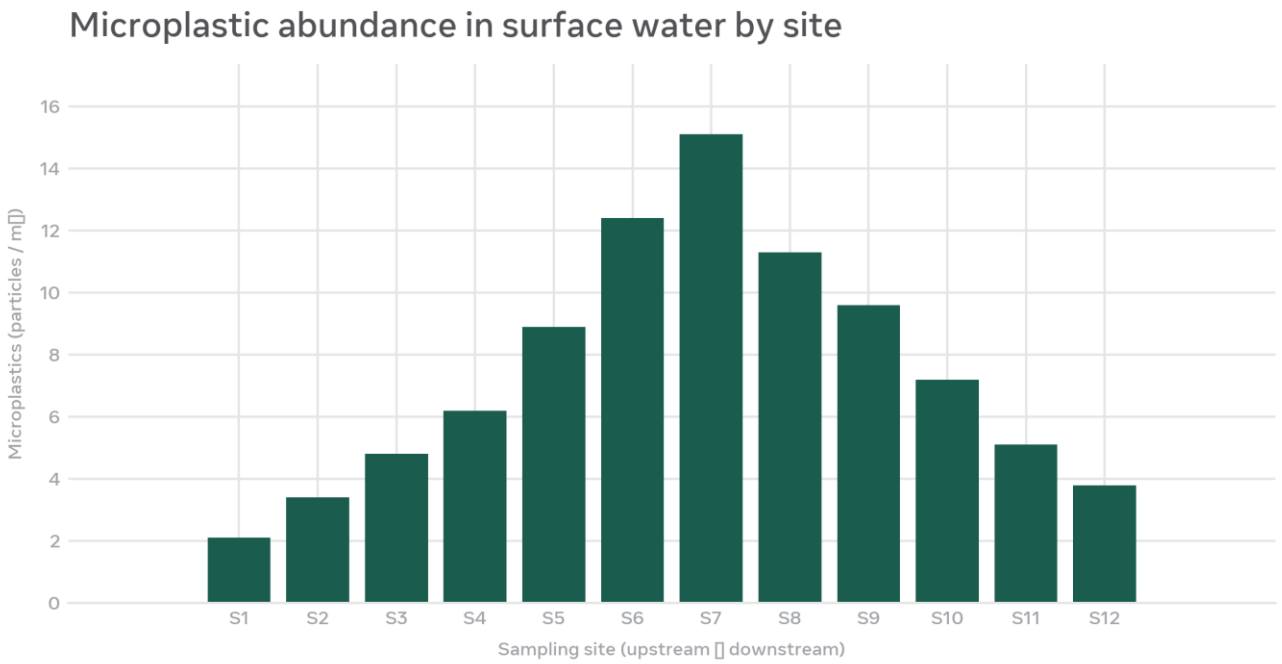


Figure 1. *Mean microplastic abundance in surface water by site, averaged across seasons. Abundance peaks immediately downstream of the urban centre (S7) and declines downstream.*

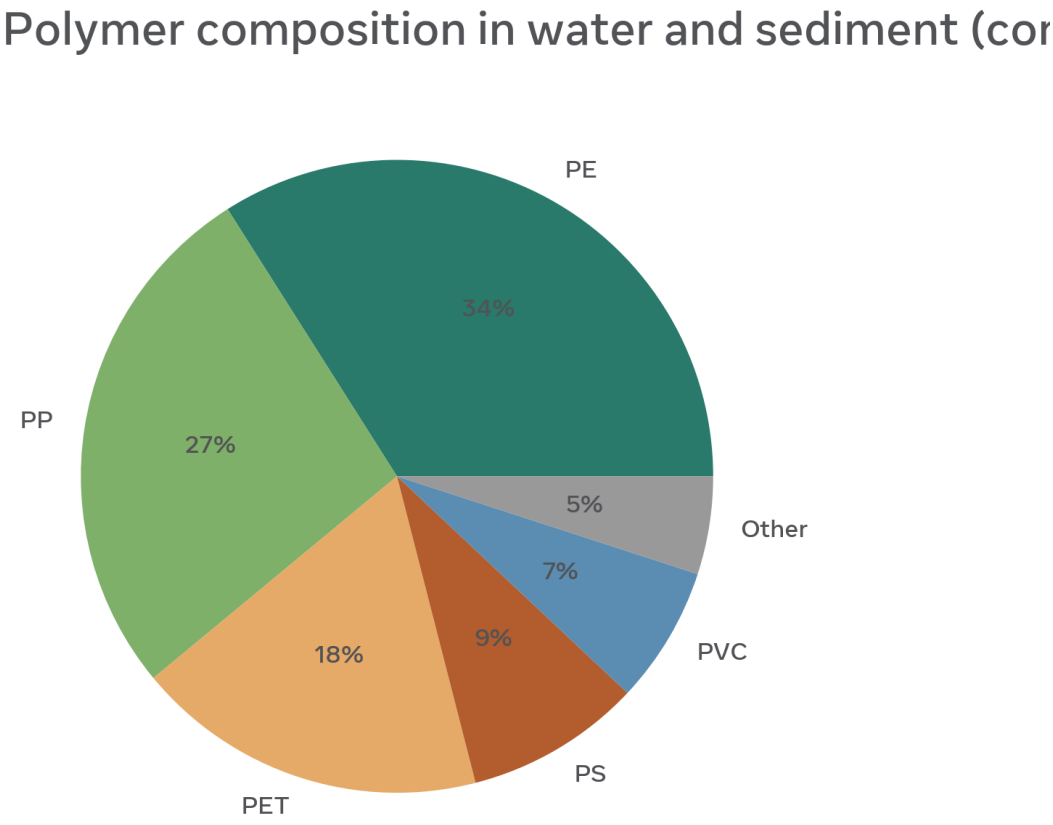


Figure 2. *Polymer composition of confirmed microplastics in water and sediment combined. Polyethylene and polypropylene together account for 61% of confirmed particles.*

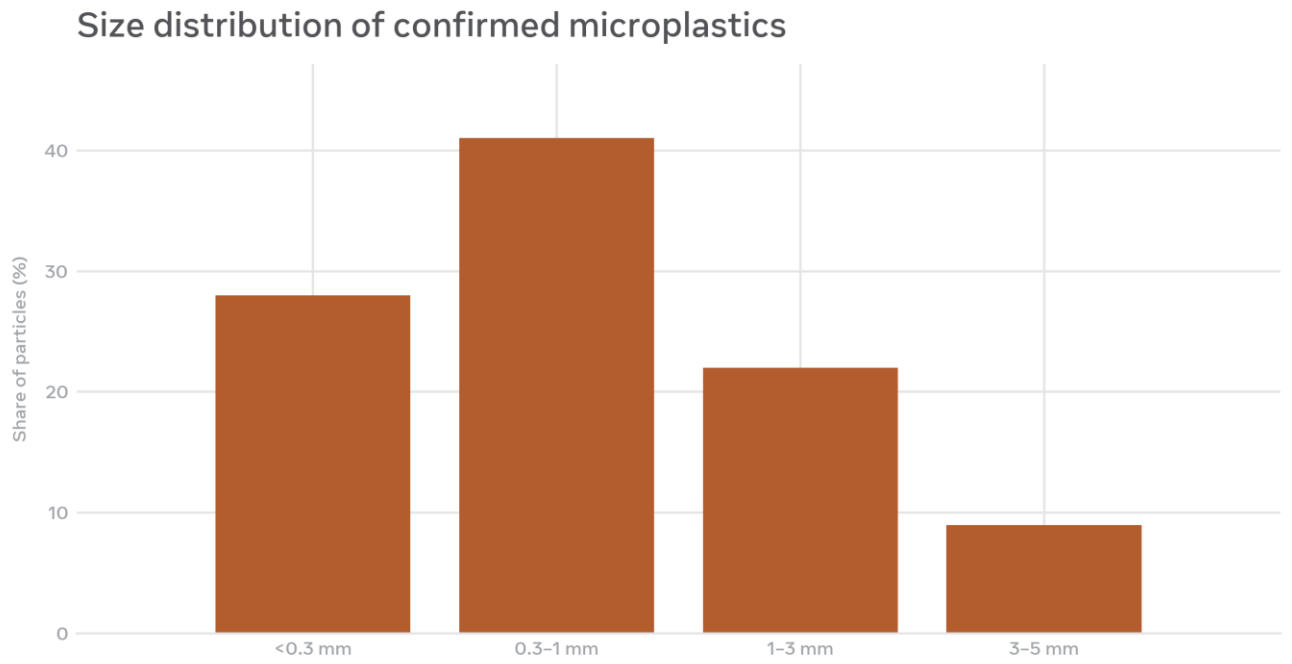


Figure 3. *Size distribution of confirmed microplastics. Most particles are smaller than 1 mm, consistent with fragmentation and fibre shedding.*

4. Discussion

4.1 Spatial pattern and urban signal. The clear upstream-to-urban increase, peak at S7, and downstream decline are consistent with a dominant urban source and with dilution, deposition, and floodplain storage downstream (Eerkes-Medrano et al., 2015; Li et al., 2018; Zhang et al., 2018). Similar patterns have been reported for rivers in Asia, Europe, and Africa, where wastewater, stormwater, and litter inputs increase with urbanisation (Li et al., 2018; Schmidt et al., 2017). In this catchment, the urban centre has limited formal wastewater treatment and irregular solid-waste collection, so direct discharge, open drains, and litter are plausible pathways. The fibre dominance also points to domestic laundry and textile shedding conveyed through drains and wastewater (Browne et al., 2011; Napper and Thompson, 2016), while fragment and film dominance in some urban samples points to packaging and bag litter (Barnes et al., 2009; Borrelle et al., 2020).

4.2 Seasonal dynamics. Higher wet-season water concentrations support the role of runoff in mobilising particles from streets, drains, and soils (Dris et al., 2015; Hurley et al., 2018). Higher dry-season sediment concentrations support the interpretation that sediments act as a temporary sink during low flow and a source during high flow. This seasonal exchange has management implications: dry-season sediment surveys may overstate long-term storage if wet-season flushing is not considered, and wet-season water surveys may overstate annual average exposure if dry-season baseflow is not sampled. Monitoring programmes should therefore sample in both seasons and report flow conditions (Cowger et al., 2020; Hartmann et al., 2019).

4.3 Polymer and shape evidence. The dominance of polyethylene and polypropylene is consistent with their large production volumes and use in packaging, bags, and textiles (Geyer et al., 2017; Hidalgo-Ruz et al., 2012). Polyethylene terephthalate, used in bottles and fibres, was more common in sediment, as expected from density-driven settling (Kooi et al., 2017). The high share of particles smaller than 1 mm is important because smaller particles are more likely to be ingested by a wider range of organisms and are harder to remove by conventional treatment (Cole et al., 2013; Talvitie et al., 2017). Fibres deserve particular attention because they can pass through coarse screens, are easily transported by wind and water, and may carry additives and sorbed contaminants (Rochman et al., 2013; Koelmans et al., 2016).

4.4 Ecological and management implications. The concentrations reported here are within the range reported for other urban-influenced rivers, but they exceed values at which laboratory studies have reported sublethal effects in some invertebrates and fish at high doses (Foley et al., 2018; de Sá et al., 2018). This study did not measure biological effects, so it cannot establish ecological risk directly. However, the spatial coincidence of high microplastic abundance with low dissolved oxygen and high turbidity in urban reaches suggests that microplastics co-occur with other stressors, and that catchment interventions that reduce organic pollution and litter are likely to reduce microplastic exposure as well (Tickner et al., 2020; Reid et al., 2019). Practical priorities include improved solid-waste collection, drain and market clean-ups, laundry and textile measures, and stormwater retention, rather than reliance on downstream removal alone (Borrelle et al., 2020; Lau et al., 2020).

4.5 Limitations. Several limitations should be noted. First, the 63 micrometre sieve and visual sorting may miss particles smaller than about 0.1 mm and nanoplastics, so total abundance is likely underestimated (Materić et al., 2022; Primpke et al., 2020). Second, density separation in sodium chloride may under-recover denser polymers such as polyethylene terephthalate and polyvinyl chloride, although recovery tests were within acceptable ranges. Third, two sampling campaigns cannot capture episodic flood pulses or interannual variation. Fourth, land-use associations are correlative; experimental or tracer studies would be needed to apportion sources precisely. Future work should include higher-frequency sampling, denser

separation media, automated imaging, and paired biological sampling to link exposure to ecological outcomes (Burns and Boxall, 2018; de Sá et al., 2018).

5. Conclusions

Microplastics were ubiquitous in surface water and sediment along the study river, with abundance strongly structured by land use and season. Urban reaches had the highest concentrations, fibres and polyethylene and polypropylene dominated, and most particles were smaller than 1 mm. The results provide a quantitative baseline for this catchment and support targeted urban source control, improved waste and stormwater management, and standardised seasonal monitoring. Replication in other tropical catchments, with harmonised methods, will be needed to determine how general these patterns are and to evaluate whether interventions reduce microplastic loads over time.

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