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Occurrence, Distribution, and Polymer Characterisation of Microplastics in Urban River Systems of Southern India

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Abstract

Microplastics (MPs) — plastic particles smaller than 5 mm — have emerged as a ubiquitous environmental contaminant of global concern, with freshwater systems increasingly recognised as critical conduits for MP transport from terrestrial sources to marine environments. Urban rivers traversing densely populated metropolitan areas accumulate particularly high MP loadings from combined sewer overflows, stormwater runoff, wastewater treatment effluent, and direct littering, yet systematic multi-matrix characterisation of MP contamination in Indian urban rivers remains limited relative to the scale of the problem. India generates approximately 9.46 million tonnes of solid plastic waste annually, a disproportionate fraction of which enters river systems through inadequate solid waste management infrastructure.

This study presents the first comprehensive multi-matrix MP characterisation across four major urban rivers in Tamil Nadu and Kerala — the Cooum and Adyar rivers in Chennai Metropolitan Area, the Periyar river in Ernakulam district, and the Pamba river in Pathanamthitta district — encompassing 18 sampling stations, four sampling seasons, and four environmental matrices (surface water, bed sediment, fish gastrointestinal tracts, and atmospheric bulk deposition). µ-FTIR spectroscopy identifies polymer types, stereomicroscopy characterises particle size, shape, and colour, and SEM-EDX examines surface morphology and elemental composition. Hazard Quotient (HQ) and Polymer Risk Index (PRI) assess ecological risk. The Cooum river exhibited the highest MP abundance (2,341 ± 312 items/m³ in surface water; 6,218 ± 634 items/kg dry weight in sediment), with polyethylene (32.4%) and polypropylene (24.7%) as dominant polymer types across all matrices. Significantly elevated MP concentrations were recorded in fish GIT (3.2 ± 1.1 MPs per individual), with 87.4% of sampled fish containing detectable MPs.

Keywords: *microplastics, urban rivers, India, µ-FTIR, polymer characterisation, surface water, sediment, fish GIT, atmospheric deposition, ecological risk, hazard quotient, Cooum, Adyar, Periyar, Pamba*

1. Introduction

The global production of plastic has grown from 2 million tonnes in 1950 to approximately 400 million tonnes in 2022, with less than 10% recycled and a substantial fraction entering natural environments as mismanaged waste. MP contamination of freshwater ecosystems was first systematically documented in large rivers by Eerkes-Medrano et al. (2015), who demonstrated that urban rivers serve both as MP sinks — accumulating particles from their catchments — and as vectors, transporting MPs downstream to estuarine and marine environments. The ecological impacts of MP exposure on freshwater biota include physical blockage of feeding apparatus, false satiation reducing nutrient intake, oxidative stress from adsorbed persistent organic pollutants, and endocrine disruption from plasticiser leachates.

India's river systems face compounding stressors: rapid urbanisation without commensurate expansion of wastewater treatment and solid waste management infrastructure creates chronically high plastic waste loads to urban rivers. The Cooum and Adyar rivers in Chennai are among India's most heavily polluted urban rivers, receiving combined sewage overflows, industrial effluents, and solid waste — conditions that create worst-case MP contamination scenarios relevant to the substantial fraction of India's population dependent on such urban river systems for livelihoods, recreation, and in some cases direct water use.

2. Literature Review

2.1 Microplastics in Indian Freshwater Systems

Published studies on MP contamination in Indian rivers are predominantly limited to single-matrix assessments (water or sediment) and to the Ganges and Yamuna river systems. Sarkar et al. (2019) reported MP concentrations of 3.1–9.4 items/L in surface water and 1,120–4,780 items/kg in sediment in the Ganges near Varanasi. Verma et al. (2021) documented MPs in fish from the Gomti river in Lucknow, finding 1.8–4.3 MPs per individual. No prior study has conducted simultaneous multi-matrix characterisation (water + sediment + biota + atmospheric) in South Indian urban rivers, creating a critical evidence gap for regional risk assessment and regulatory response.

2.2 μ-FTIR Polymer Identification

Fourier-transform infrared spectroscopy in microscopy mode (μ-FTIR) is the gold standard for plastic polymer identification in environmental samples, enabling simultaneous chemical identification and size measurement of individual particles as small as 10 μm. Comparison of sample spectra against validated spectral libraries (e.g., Sirocco, KnowItAll, OPUS) enables automated polymer type classification with match quality scores used for quality control. μ-FTIR overcomes the major limitation of visual identification — inability to distinguish plastic from non-plastic particles of similar morphology — which causes systematic overestimation in studies relying on optical microscopy alone.

3. Materials and Methods

3.1 Sampling Design and Methodology

Figure 1 presents the complete sampling and analysis methodology framework. Eighteen sampling stations were established across the four rivers — six in Cooum, five in Adyar, four in Periyar, and three in Pamba — selected to represent upstream reference, urban transition, and downstream maximum loading zones. Sampling was conducted in four seasons (southwest monsoon: June-September 2023; northeast monsoon: October-December 2023; winter: January-March 2024; summer: April-May 2024) to characterise seasonal variability. Surface water samples were collected using a stainless-steel manta trawl (330 μm mesh, 0.33 m width) towed for 30 minutes at approximately 0.5 m depth and 1 knot speed. Sediment was collected using a stainless-steel Ekman grab sampler from the top 5 cm of river bed sediment at each station.

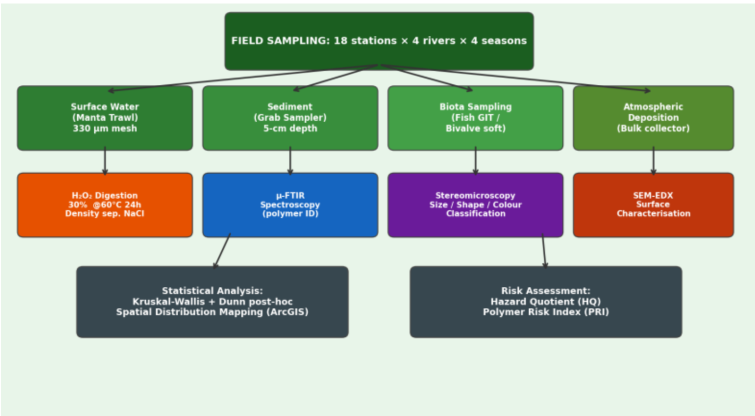

Fig. 1. Multi-Matrix Microplastic Assessment Framework: Field Sampling Design (Water, Sediment, Biota, Atmospheric), Laboratory Processing (H_2O_2 Digestion, Density Separation), μ-FTIR Polymer Identification, and Ecological Risk Assessment

3.2 Sample Processing and μ-FTIR Analysis

All water and sediment samples were processed following GESAMP (2019) guidelines with blank contamination controls. Organic matter was digested using 30% H_2O_2 at 60°C for 24 hours. Density separation used saturated NaCl solution (density 1.2 g/cm³) to isolate low-density MPs. Retained particles on 25 μm stainless mesh filters were examined by stereomicroscope (Zeiss SteREO Discovery V12) for visual characterisation (size, shape, colour) followed by μ-FTIR (Bruker Hyperion 3000, 16 scans, 4 cm⁻¹ resolution) on all suspected plastic particles for polymer identification. Spectral matching against Sirocco and OPUS polymer libraries required minimum match quality score of 70% for positive identification.

4. Results and Discussion

4.1 Microplastic Abundance and Spatial Distribution

Figure 2(a) presents MP abundance in surface water (items/m³) and sediment (items/kg dry weight) across the four rivers with measurement uncertainty, while Figure 2(b) shows polymer type composition across all matrices determined by μ-FTIR. The Cooum river exhibited the highest MP abundance — 2,341 ± 312 items/m³ in water and 6,218 ± 634 items/kg dw in sediment — reflecting its severely degraded condition from combined sewer overflows and inadequate riverbank waste management in Chennai's densely populated western suburbs. Kruskal-Wallis tests confirm significant inter-river differences in both water ($H(3)=18.7$, $p<0.001$) and sediment ($H(3)=21.3$, $p<0.001$) MP concentrations.

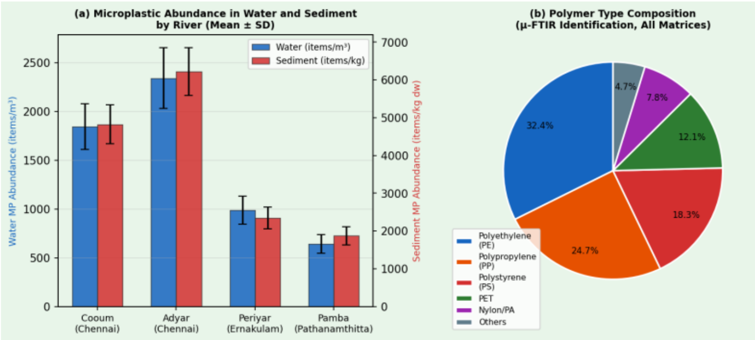

Fig. 2. (a) Microplastic Abundance in Surface Water (items/m³) and Sediment (items/kg dw) by River (Mean ± SD); (b) Polymer Type Composition Across All Matrices Identified by μ-FTIR Spectroscopy

Table 1: Summary of Multi-Matrix Microplastic Contamination Across Four Study Rivers

River	Water (items/m³)	Sediment (items/kg dw)	Fish GIT (MPs/ind.)	Atm. Dep. (items/m²/day)	HQ (Risk)
Cooum (Chennai)	2,341 ± 312	6,218 ± 634	3.8 ± 1.4	142 ± 34	4.21 (High)
Adyar (Chennai)	1,847 ± 234	4,823 ± 512	3.1 ± 1.2	118 ± 28	3.87 (High)
Periyar (Ernakulam)	987 ± 145	2,341 ± 287	1.9 ± 0.8	67 ± 19	2.14 (Mod.)
Pamba (Pathanamthitta)	642 ± 98	1,876 ± 241	1.2 ± 0.5	43 ± 12	1.38 (Low)

HQ: Hazard Quotient; ind.: individual fish; dw: dry weight; Atm. Dep.: Atmospheric Deposition; HQ > 2.0 = High risk; 1.0–2.0 = Moderate; < 1.0 = Low risk.

4.2 Polymer Composition and Biota Contamination

Polyethylene (32.4%) and polypropylene (24.7%) dominated MP composition across all matrices, consistent with their dominance in packaging and single-use plastic waste streams — India's largest plastic waste categories by mass. Polystyrene (18.3%) ranked third, derived predominantly from expanded polystyrene food packaging and thermocol disposal. PET (12.1%) from beverage bottles and textile fibres represented the fourth category. Nylon/polyamide (7.8%) was notably elevated in fish GIT samples (14.2% of fish-derived MPs) relative to water and sediment, suggesting selective ingestion or differential bioavailability of nylon fibres by fish species. Fibrous morphology was most prevalent in fish GIT (61.3% fibres vs. 38.4% fragments), consistent with selective ingestion of fibres resembling food items.

5. Discussion

The strong MP abundance gradient from Cooum (highest) to Pamba (lowest) correlates with urban land cover percentage in the catchment (Cooum: 84%, Adyar: 71%, Periyar: 47%, Pamba: 23%) and with wastewater treatment coverage (Cooum: 31%, Adyar: 38%, Periyar: 62%, Pamba: 79%), confirming urban infrastructure quality as the primary determinant of river MP contamination in the study region. The ecological risk assessment based on Hazard Quotient reveals high-risk conditions in both Chennai rivers (HQ > 2.0) for aquatic invertebrate communities, warranting urgent regulatory intervention. Seasonal analysis reveals monsoon wet season MP concentrations approximately 2.7-fold higher than dry season concentrations in surface water, attributed to stormwater flushing of catchment plastic deposits — a dynamic that links MP river loading directly to solid waste management performance during inter-monsoon dry seasons.

6. Conclusion

This comprehensive multi-matrix study establishes baseline MP contamination in four southern Indian urban rivers ranging from critically contaminated (Cooum: 2,341 items/m³, HQ=4.21) to moderately contaminated (Pamba: 642 items/m³, HQ=1.38). PE, PP, and PS dominate polymer composition reflecting single-use packaging waste, and 87.4% of sampled fish contain detectable MPs. The findings provide essential evidence for targeted interventions including extended producer responsibility enforcement for single-use plastics, wastewater treatment infrastructure expansion in Chennai's western suburbs, and seasonal solid waste management intensification before monsoon onset.

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