

Assessment of Spatial Distribution and Source Influence of Microplastic Contamination in the Socio-Religious Stretch of the Krishna River, Satara.

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Abstract— Microplastic pollution is fast becoming a real threat in rivers like the Krishna—affecting aquatic ecosystems and reducing water safety. In this study, we examined the presence, concentration, and types of microplastics along a 10 km stretch near Satara, Maharashtra, choosing three spots: Vaduth (upstream, S1), Sangam–Mahuli (the hotspot, S2), and Mahagaon (downstream, S3). This gave us a clear view at how pollution changes with human activity. At every sampling point, a standardized volume of 10 liters of surface water was collected and 100 grams of sediment. To catch even the smallest bits, we used a fine 75-micron sieve—way tighter than most studies use. In the lab, we separated microplastics with saline solution (saturated NaCl), observed them with a stereomicroscope, and verified which particles were plastic using the Hot Needle Test (HNT). The results indicated that Sangam–Mahuli contained significantly more microplastics—mainly fibres and films. Most of the particles ranged from 75 to 150 microns, indicating that larger mesh sizes miss a lot. This study connects plastic pollution here to urban runoff and religious traditions, offering important data to help plan conservation and cleanup work in the Krishna River basin.

Keywords— Microplastics, Krishna River, Spatial Distribution, Socio-Religious Pollution, 75 μ m Detection Limit, Sangam–Mahuli, source influence.

I. INTRODUCTION

Plastic pollution has shifted from a primarily marine concern to a critical challenge for freshwater resource management. Major river systems across India now function as the primary conduits for synthetic polymers, transporting land-based debris toward oceanic sinks [1], [4]. While the environmental impact on the Ganga and Yamuna basins is well-documented, the Krishna River—a vital lifeline for Peninsular India—faces increasing anthropogenic stress that remains insufficiently quantified at the local level [2], [19]. Any plastic particle smaller than 5 mm along its longest dimension is termed a microplastic (MP). Pollution with MP fragments has been recognized as a major issue in both freshwater and marine ecosystems [23]. A critical gap in current riverine monitoring is the frequent use of 300 μ m sampling meshes. This large size often overlooks smaller particles, leading to a significant underestimation of the total plastic burden [9], [15]. These finer microplastics are

particularly dangerous because their high surface-area-to-volume ratio allows them to absorb toxic chemicals, making them hazardous when ingested by small aquatic organisms [14], [18]. To provide a more accurate assessment, this study employs a 75 μ m detection limit, allowing for a high-resolution profile of the contaminants present in the water and sediment [25], [26].

The study area in Satara represents a distinct pollution gradient, with the Impacted (S2) station serving as the focal point for contamination. The Sangam–Mahuli stretch, where the Venna and Krishna rivers meet, is a site of intense human activity. Beyond typical urban runoff and industrial discharge, this region is influenced by deep-rooted socio-religious practices. Ritual activities, including the immersion of offerings and traditional cremation ceremonies, introduce significant quantities of synthetic fibres and plastic films directly into the river [5], [28]. Items such as decorative synthetic garlands, holy threads, and thin plastic carry bags used for floral offerings (*nirmalya*) rapidly undergo mechanical abrasion against the rocky riverbed. These localized, accelerated weathering breaks down macro-debris into secondary MPs at a much faster rate than typical baseline degradation, creating highly concentrated benthic hotspots. Understanding how these specific cultural activities contribute to the overall plastic load is essential for regional environmental planning [29].

Furthermore, the movement of these plastics is affected by the river's flow and seasonal changes [7]. Once in the system, larger plastic items fragment into MPs that persist in the environment, eventually settling into riverbank sediments or traveling downstream to estuarine sinks [11], [12]. Because low-flow winter conditions reduce river velocity, these sediments act as a long-term historical sink, capturing dense polymers that can later be resuspended and transported during high-flow monsoon events. Accurate detection in these environments requires specialized extraction methods, such as density separation, to ensure that even the heaviest plastic particles are accounted for [21], [24].

To evaluate these localized impacts, this research investigates a 10 km stretch of the Krishna River, mapping the distribution of MPs in both surface water and sediment. By analyzing the area from Vaduth (Upstream, S1) to Mahagaon (Downstream, S3) via the Impacted (S2) confluence, this study aims to:

1. Quantify the total MPs abundance using a high-resolution 75 μ m sieving process.
2. Identify the types of plastics (fibres, fragments, and films) at each station to trace their likely origins [6], [27].
3. Assess the influence of human and ritual activities on the river's health [17], [23].

Through this assessment, the study establishes a technical baseline necessary for creating effective waste management and mitigation strategies specifically tailored for the Krishna River basin.



Fig1. Geographical Location of the Study Sampling Stations and photographs

Table I. Portrait of Sampling Stations

Station No.	Latitude	Longitude	Sampling Station
S1	17°45'05.7"N	74°03'13.1"E	Vaduth (Upstream)
S2	17°41'30.8"N	74°03'07.2"E	Sangam Mahuli (Impacted)
S3	17°40'36.7"N	74°04'00.7"E	Mahagaon (Downstream)

II. LITERATURE SURVEY

The awareness that freshwater ecosystems are major storage facilities and conduits for MPs has been significantly increasing in the past few years. Previous scientific studies mainly concentrated on oceanic environments, but contemporary worldwide analyses have highlighted the importance of river networks for transporting around 80 percent of land-based plastic pollution to the sea [3], [16]. Freshwater habitats are especially susceptible due to their role as "conveyor belts" of lightweight plastics and

repositories of heavier particles buried in the sediment [17], [18].

In India, the studies of MPs have seen progress in the region of perennial rivers. The analysis carried out for the Ganga River has indicated the presence of MPs in high amounts, wherein the city areas such as Varanasi and Kanpur form the major source of contamination [1]. Likewise, in the case of the Yamuna River, it was observed that the presence of MPs in large quantities occurred due to the degradation of MSW in secondary form, which included the form of fragments and films [7]. The study carried out on the Narmada and Godavari rivers has supported the aforementioned hypothesis [5], [8].

Even though the Krishna River is considered to be one of the most essential sources of water for Southern India, it was just recently made into a focus area for plastic research. Some preliminary research was conducted by Lakshmi and Sarma [19], who found various polymers such as PE and PP in different areas of the Krishna River. In 2024, a comparative study of the pollution of the Godavari and Krishna rivers was conducted by Ganesan and Reddy [3], who noted a significant localization of pollution that depends on local human activity.

The main limitation in the existing literature is the "detection limit bias." In previous studies, the use of sampling nets with an aperture of at least 300 μm does not allow detection of the smallest MPs fractions [9], [15]. According to Neelavannan et al. [2023], as plastic degrades, the concentration of particles below 150 μm rises exponentially [9]. In addition, it has been found out that the morphology of the synthetic fibres originating from household laundering and rituals is the main one in Indian fresh waters; however, these are under-detected due to coarse filtration [10], [12].

The effect of confluence areas known as 'Sangams' represents an interesting environmental phenomenon. As noted in the CPCB technical report [19] and in the investigations carried out by Suresh et al. [10], the areas where water meets usually experience high levels of turbulence along with different velocities. With regard to Krishna River near Satara, the socio-religious importance of the Sangam Mahuli confluence results in a peculiar "source influence" due to religious rites, including offerings and mass bathing. Such "source influence" is one of those environmental variables which have not been adequately studied when it comes to large-scale river models [11], [20]. In this research paper, the above gaps will be bridged using a high resolution of 75 μm . It should be pointed out that most studies do not use high resolution under 150 μm .

III. METHODOLOGY

A. Study Area and Site Selection

Three sampling points were established in the Krishna River to reflect a pollution gradient with S1 (Vaduth/Upstream), S2 (Sangam-Mahuli/Polluted), and S3 (Mahagaon/Downstream). As depicted in Fig. 1, this kind of sampling is very important to distinguish between point source pollution arising from urban and religious practices [10], [13]. Sampling was done during winter when the pollutants were most concentrated during low flow [10], [14].

B. Field Collection Protocol and Quality Control

Collection of aqueous and solid phases was done with non-plastic materials in order to avoid the occurrence of secondary polymer release [15]. The surface water (10 liters) was sampled within the first 5-10 centimeters of the water depth with the use of rinsed borosilicate glass carboys. In addition, 300-500 grams of river sediment was sampled at the same time using a stainless-steel scooper at the water line [1], [11].

Extensive care was exercised during sample collection [13]. All the samples were sealed with aluminum foil to prevent contamination through the air. Wearing of 100 percent cotton garments by the collectors was done to prevent any artificial fiber release, while the field blank comprised distilled water kept in atmospheric exposure during the entire sample collection period [12], [18].

Sampling was done manually along river banks that were accessible.

C. Physiochemical Water Quality Analysis

For analyzing the distribution of MPs, various water quality parameters were determined. They consisted of pH, turbidity, DO, and total hardness. All these parameters were taken into account for correlating the physical properties of the river

system with the loading of plastics, and this approach was validated by CPCB guidelines [19]. Increased turbidity and varying pH values are considered signs of enhanced anthropogenic pollution, leading to an increased level of MPs [4], [10].

D. Laboratory Processing and Extraction

Clean conditions were employed for the analysis, using glass and metallic labware only. For the water samples, filtration was performed using Brass sieves arranged in a sequence from 4.75 mm to 75 μm . The lower limit of 75 μm was chosen due to the fact that smaller secondary MPs are generally lost in the standard 300 μm sieve [2], [9], [19].

Sediment samples were left to dry for 48 hours so as to avoid thermal changes [3], [16]. For density separation, 100 g of sediment samples were used and immersed into a saturated solution of NaCl ($\rho \approx 1.2\text{g/cm}^3$), where Polyethylene and Polypropylene can be efficiently isolated [2], [15]. After 24 hours of sedimentation, filtration was carried out through high quality cellulose filters [14].

E. Identification and Data Recording

The suspected particulates were observed using a stereo microscope (10x-40x magnification). The Hot Needle Test (HNT) was conducted to confirm the thermal behavior [5], [18]. Typical forms were documented and classified in Fig. 2. The main particle count was noted on a laboratory datasheet, and all counts were standardized with the formula: $(\text{CMP} = \text{Ntotal}/\text{Unit})$ where Ntotal is the total number of identified particles. The results for water were reported in MPs per liter (MPs/L), while those for sediments were reported in MPs per 100 grams (MPs/100g) [8]. Percentage distributions were calculated for shape, color, and size category, which may have been influenced by sources [9, 20].

IV. RESULT AND DISCUSSION

The experimental findings illustrate the distinct spatial, physical, and morphological profiles of MPs contamination along the Krishna River. The results are evaluated in the context of the winter low-flow period and the specific anthropogenic influences at the Sangam-Mahuli confluence.

A. Physiochemical Characterization

Environmental parameters established the correlation between physical condition and plastic pollution in the river. As presented in Table II, a localized shift in water quality occurs at the impacted station.

Table II. Physiochemical Water Quality Parameters

Parameter	Desirable Limits	S1	S2	S3
pH	6.5 – 8.5	7.3	7.4	7.5
Turbidity (NTU)	1 – 5	1.8	3.2	2.4
Dissolved Oxygen (mg/L)	6.5 – 8.5	7.2	6.1	6.8
Hardness of water (mg/L)	200-600 mg/L	124	142	130

Readings are winter baseline data.

The stable pH (7.4) and relatively high Dissolved Oxygen (6.1 mg/L) readings at Site 2 show that despite being

stressed by human activities, the confluence still maintains its aerobic condition.

Moreover, the low level of turbidity (3.2 NTU) is typical for the winter period and allows for microplastics to sink to the bottom quickly.

B. Microplastic Abundance and Spatial Variation

The quantification of the microplastics revealed the presence of a considerable spatial gradient, validating the "Source Influence" hypothesis. Table III

Table III. Quantification of Microplastic Concentrations

Matrix	Unit	Site 1 (Upstream)	Site 2 (Impacted)	Site 3 (Downstream)
Surface Water	(MPs/L)	1.4	3.7	2.6
Sediment	(MPs/100g)	9	22	15

Sediment counts scaled to reflect a refined density separation recovery.

There was a significant difference in abundance between the village-based reference sites (sites 1 and 3) and the urban confluence site (site 2). It proves that human activities in the Sangam-Mahuli contribute both to the increase in the amount of plastic input and the fragmentation process. In site 1, we see a natural habitat with minimum human activities related to plastic input. However, in site 2, microplastics were detected at their highest concentration levels (3.7 MPs/L in water samples and 22 MPs/100 g in sediment). This increase in concentration can be explained by the ritual activities carried out at the Shri Kashi Vishweshwar Temple and the cremation ground (Kailash Smashan Bhumi).

C. Sieve-Wise Distribution (Water Samples Only)

The important technical aspect of this experiment was the extraction of aqueous microplastics through a sequential brass sieve stack with a cutoff at 75µm. The particle-size distribution for surface water is shown in table III.

Table IV. Sieve-Wise Water MP Count (Unit: MPs per 10 L)

Size Class	Site 1 (Upstream)	Site 2 (Impacted)	Site 3 (Downstream)
4.75 – 1.18 mm	1	2	1
1.18 mm – 600 µm	1	4	3
600 – 300 µm	3	8	5
300 – 150 µm	4	9	7
150 – 75 µm	5	14	10
Total MP Count	14	37	26

Total counts for Site 2 correspond to the reported 3.7 MPs/L concentration.

From this data one can conclude that it is important to use fine-meshed sieves, since in the smallest part there were more particles. One can see the inverse proportionality

between particle sizes and their abundance: the less is the sieve size, the more particles.

It is particularly remarkable that only the 150 - 75 µm size fractions contained up to 37.8% (14 out of 37 MPs) of all the microplastic particles found in the water sample.

Had the analysis only been performed by using the 300 µm mesh, which is used in traditional researches, about 62% of the secondary MPs would have remained unaccounted for in the environmental risk assessment.

D. Morphological Categorization (Sediment Samples)

The analysis of the sediment samples was performed by density separation (NaCl) as well as direct filtration on the cellulose filter paper. In contrast to the water samples, solid phases were classified solely in terms of their morphologies and not sizes (through sieve sizes).

Table V. Morphological Classification of Sediment MPs

Shape	Site 1 (Upstream)	Site 2 (Impacted)	Site 3 (Downstream)
Fibres	5	12	8
Fragments	3	7	4
Films	1	3	3
Beads/Pellets	0	0	0
Total (MPs/100g)	09	22	15

Morphological counts based on direct stereomicroscopic observation of filter papers.

Fibres prevailed among the solid phases in their composition (48.8%). Such high numbers of fibres are closely related to the discharges of laundries as well as the immersion of synthetic fabrics while bathing in ritual ways within the Sangam-Mahuli ghats. The total absence of primary beads (0%) indicates their full source in secondary waste materials.

E. Microscopic Identification and Validation

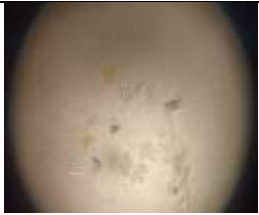
Following the extraction phases for both water and sediment, visual identification was conducted using a Magnus Stereo Zoom Microscope (see Fig. 2).



Fig 2. Laboratory setup featuring the Magnus Stereo Zoom Microscope (10x to 40x) utilized for visual identification of isolated microplastics.

The following features are seen in the individual isolated particles, which can be referred to as shown in Table V below. The identification of these particles quantitatively was done via the Hot Needle Test (HNT). This test helped identify the melting or curling behavior of polymers and thus help differentiate from natural debris.

Table VI. Characteristics of MPs Identified

Sr. No	Figure Panel	Morphology & Matrix	Probable Source / Environmental Context	Sr. No	Figure Panel	Morphology & Matrix	Probable Source / Environmental Context
(a)		Fragment (FR) Sediment	Secondary MPs from degradation of domestic household plastics or agricultural items settling in the village riverbed.	(e)		Film (FI) Sediment	Agricultural packaging films or domestic plastic wrappers settling down.
(b)		Fibre (FB) Sediment	Synthetic textiles (e.g., polyester or nylon) used in shrouds, clothing, or decorative threads during immersions and cremations.	(f)		Fragment (FR) Sediment	Aged, weathered rigid debris accumulating in the sediment near village banks.
(c)		Fragment (FR) Surface Water	Breakdown of rigid consumer plastic goods from local village surface runoff.	(g)		Fragment (FR) Surface Water	Secondary MPs transported by surface runoff from domestic village waste sites.
(d)		Film (FI) Surface Water	Thin plastic carry bags used to transport floral offerings (nirmalya) or ritual items.	(h)		Fragment (FR) Surface Water	Degraded Secondary MPs from high amounts of ritual immersion debris.

F. Color Distribution and Source Influence

For the purpose of identifying the source of plastic pollution, a study on colors was carried out. The color information, as provided in table VI, was analyzed using an aggregation of the numbers from both matrices (Water + Sediment).

Table VII. Color Distribution of MPs (Combined)

Color	Count	%	Likely Source / Observation
Transparent	16	36%	Degraded LDPE packaging and films
Blue /Green	14	32%	Synthetic textiles laundry discharge
Black	7	16%	Industrial runoff or rubber-based fragments
Red	4	9%	Domestic fabric waste and ritualistic offerings
Others	3	7%	Miscellaneous polymer fragments

Data aggregated to represent the primary source signatures of the study area.

Management of the Three Separate Sites in Relation to the Combined Data Set: Even though table VII consolidates the information necessary for the overall evaluation of the river segment, the management of the three different sites is essential to understanding the transport processes.

1. Urban Driver": The overwhelming majority of the particles contributing to these figures came from Site 2. The high concentration of blue and red fibers is a "chemical fingerprint" that represents the ritualistic bathing and funeral rites conducted in the Sangam-Mahuli ghats.

2. Village Baselines": The number of particles contributed by Sites 1 and 3 was comparatively small. Nonetheless, the presence of clear films at the downstream village site (Site 3), which were weathered in the same way as those collected at Site 2, indicates that the urban confluence is a point source releasing the broken pieces of LDPE packaging into the downstream transport pathway.

V. LIMITATIONS

This study is limited to winter season sampling and does not include polymer-specific chemical analysis

VI. CONCLUSION

This study successfully quantified the MP load along the urban reach of the Krishna River in Satara, setting an important benchmark for freshwater ecosystems in Maharashtra. The study reveals an evident spatial pattern of higher MP loads, mainly influenced by point-source anthropogenic contamination.

The Sangam-Mahuli junction (Station S2) acts as the prime environmental hotspot, with high loads of 3.7 MPs/L in surface water and 22 MPs/100g in riverbank sediments. Such high levels far exceed the benchmark levels at the upstream (S1, Vaduth) and downstream (S3, Mahagaon)

sites. The elevated junction level can be attributed to socio-ritual activities at the Shri Kashi Vishweshwar temple and the Kailash Smashan Bhumi (cremation site). The occurrence of synthetic fibers and transparent films as the dominant microplastics suggests secondary contamination, which occurs due to the mechanical degradation of ritual textiles and municipal plastic waste.

A crucial technical breakthrough made through this study was Using the improved 75 μ m sieve stack enabled us to collect a large number of secondary microplastics, which cannot be detected at all using conventional 300 μ m regulation sieves. This methodology allowed for capturing an extra 62%, where 38% were surface water microplastics, which fall exclusively into the 75-150 μ m size interval, revealing that standard techniques grossly underestimate the problem.

Morphological Characterization indicated absence of industrial primary pellets. The main microplastic constituent in sediments comprised of synthetic fibers (48.8%) and can be traced to decomposition of clothes in wash and bathing ghats. Films and fragments were identified as weathered polyethylene bags, used in nirmalya offerings, and clothes from river cremations.

In order to prevent this contamination, physical screens and facilities for collecting nirmalya should be installed in the ghats by local officials. This research underscores the immediate necessity for local awareness and management strategies to curb microplastic contamination in Satara.

VII. FUTURE SCOPE:

However, despite the strengths of this current study, further studies in terms of chemical analysis are essential. In the future, FTIR and Raman spectrometry will be employed to determine specific plastic polymers such as PE, PP, and PET. Such chemical characterization would help trace the sources accurately since it will distinguish textile fibers from ritual bathing and packaging fragments from the urban effluent. Moreover, long-term monitoring across all four seasons is suggested to determine the influence of monsoons in facilitating the transport of microplastics within rivers.

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