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**Original Article**

# Comparative assessment of microplastics in Pulicat Lagoon and adjacent coastal waters: an integrated multi-metric ecological risk evaluation

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**Abstract**
Microplastics (MP) have emerged as one of the most persistent contaminants in aquatic habitats, infiltrating even the most ecologically sensitive systems, such as lagoons and coastal waters, where ongoing anthropogenic inputs exacerbate their accumulation and biological impact. Pulicat Lake, India's second-largest brackish water lagoon, is especially vulnerable to MP loading from tidal exchange, household waste, and fishing activities. This study examined the physicochemical properties, seasonal abundance, and ecological danger of MP at three typical stations: Goonankuppam (Station I), Thonirevu (Station II), and Pulicat Beach (Station III) from 2024 to 2025. MP abundance ranged from 50 to 135 particles $L^{-1}$, peaking in Thonirevu during post-monsoon. This pattern was driven by accelerated monsoon runoff and water resuspension in the aftermath of cyclone Fengal (25 November 2024). Fibres (50.9% at Station I, 40.6% at Station II, and 51.1% at Station III) were the dominating morphotype, followed by fragments (22.60% at Station I, 27.40% at Station II, and 24.20% at Station III). The size fraction of 100–500 µm (56% at Station I, 49% at Station II, and 47% at Station III) was consistent across all locations, indicating advanced secondary fragmentation. Blue particles (40% at Station I, 30% at Station II, and 45% at Station III) predominated, highlighting the important role of fishing gear and maritime activities. This establishes a strong baseline for targeted mitigation in this ecologically sensitive lagoon-coastal interface.

**Keywords:** FESEM-EDX; microplastics; polymer composition; Pulicat Lagoon; risk assessment; surface water

## 1 | INTRODUCTION

Microplastics (MP) are synthetic plastic particles less than 5 mm in size. They are divided into two types: primary MP, which are generated on a microscale for industrial or

cosmetic use whereas secondary MP are formed due to physical, chemical, and photochemical fragmentation of larger plastic trash (Thompson *et al*. 2004). MP can be morphologically classified as fibres, fragments, films, pellets, or foams, with each having a different transport potential and bioavailability (Anderson *et al*. 2016). Low-density polymers such as polyethylene (PE) and polypropylene (PP) dominate aquatic MP assemblages due to their widespread use in packaging and fishing gear, whereas polystyrene (PS), polyamide (PA), polyurethane (PU), and polyvinyl chloride (PVC), while less abundant, have significantly higher toxicity indices due to the leaching of plasticisers, stabilisers, and reactive monomers (Ali *et al*. 2024). Filter feeders, benthic invertebrates, and larval fish can easily consume particles in the range of 100–2000 µm, posing a significant risk to their health (Lei *et al*. 2021).

In fish and invertebrates, MP consumption leads to the gastrointestinal obstruction, reduced eating, poor development, reproductive failure, and histopathological damage such as intestinal inflammation and hepatic oxidative stress (Rochman *et al*. 2013). Colour-selective ingestion increases this danger because blue and green particles, which are prevalent in fishery-influenced environments due to nets and gear, are disproportionately mistaken for prey (Athukorala *et al*. 2024). Trophic transmission amplifies these impacts across food webs, with consequences for human health from seafood consumption. In addition, MP serve as vectors for persistent organic pollutants and heavy metals adsorbed onto weathered surfaces, with FESEM-EDX analyses revealing co-adsorption of Na, Mg, Al, Si, Ti, and Fe — representing both anthropogenic and natural mineral enrichment pathways (Furfaro *et al*. 2022).

Lagoons have semi-enclosed nature, along with prolonged water residence time and restricted tidal flushing. This causes the retention and accumulation of microplastics in water (Kennish and Paerl 2010). Pulsed inputs in tropical locations are driven by monsoon and post-monsoon seasons, which intensify runoff, creek flow, and water resuspension. Pulicat Lake, India's 2nd-largest brackish water lagoon on the Andhra Pradesh-Tamil Nadu border, is a biodiversity-rich wetland that supports artisanal fishing and migratory avifauna (Jesintha *et al*. 2022), but it remains poorly assessed for MP contamination. The study period (2024–2025) also included Cyclone Fengal - 25 November 2024 (IMD, 2024), which provided a unique chance to record storm-driven MP dynamics.

Quantifying abundance alone is insufficient for determining ecological risk. The contamination factor (CF), pollution load index (PLI), polymer hazard index (PHI), and ecological risk index ($E_i$, RI) integrate concentration, polymer-specific hazard, and toxicity coefficients to distinguish sites where risk is driven by high particle loads from those where hazardous polymer compositions dominates (Dueñas-Moreno *et al*. 2024; Ranjani *et al*. 2021). Comparing lagoon and coastal stations is essential for determining local vs marine source contributions, hydrodynamic restrictions on size distribution, and the extent of lagoonal MP export to nearby coastal waters. Due to these reasons, this study was conducted with the aim to quantify seasonal MP abundance across three stations, characterisation of shape, colour and size, identification of polymer composition via ATR-FTIR, assess surface weathering and elemental associations using FESEM-EDX, and computation CF, PLI, PHI, $E_i$, and RI for establishing the first integrated, polymer-specific MP risk baseline for the Pulicat Lagoon-coastal interface.

## 2 | METHODOLOGY

### 2.1 Description of study area

The present study investigated the spatial distribution of microplastics in Pulicat Lagoon and coastal waters. The study was carried out at three selected sampling locations namely Goonankuppam (Station I) and Thonirevu (Station II) and Pulicat Beach (Station III) and the description of the study area is listed below. Samples were collected from each station from June 2024 to Aug 2025. The geographical location of the study area was noted by using a standard GPS in Android phone (Realme 12+ pro - GPS Map Camera: Geo Tagging Application).

Station I: Goonankuppam: (13.4148°N, 80.3182°E) It is a small, traditional fishing village situated close to the mouth of the Pulicat Lagoon on the southern border of Pulicat Lake. Discarded fishing nets and gear into the lagoon contributes significantly to local MP burdens. The station's proximity to the lagoon mouth exposes it to tidal backwash including marine-origin MP. Together, these features make Goonankuppam a typical inner-lagoon hotspot for diffuse, multi-source plastic contamination.

Station II; Thonirevu: (13.4235°N 80.3122°E), Thonirevu is a seaside village in the Tiruvallur District of Tamil Nadu, India, close to the southern edge of Pulicat Lake. Thonirevu is prone to plastic contamination due to fishing activities, creek inflow, and seasonal storm forcing, and its inclusion in this study allows for assessment of the cumulative influence of fishery-associated and runoff-driven MP inputs in an intermediate lagoonal setting.

Station III; Pulicat Beach: (13.4325°N 80.3190°E), This Beach is a small sandy barrier that runs along the southeast side of Pulicat Lake. Tourist activities and coastal recreational use provide additional land-based plastic inputs in the form of single-use plastics and food packaging, which are the primary sources of MP in Pulicat Beach. The choice of Pulicat Beach as Station III is crucial for determining the proportion of open marine inputs to lagoon-derived contamination, as well as determining the amount to which MP are exported from the contained

lagoon system to the broader coastal zone of the Bay of Bengal.

**2.2 Sample collection**

To assess seasonal fluctuations in microplastic presence, samples of water, sediment, and biota were gathered across five seasonal intervals: pre-monsoon 2024, monsoon 2024, post-monsoon 2025, summer 2025, and pre-monsoon 2025. Surface water samples were collected seasonally at three locations using a plankton net with a mesh size of 48 µm. To achieve uniform filtration, the net was dragged horizontally at the water's surface (2–3 m depth) for one km from the shoreline by utilising a fishing FRP boat with low towing speed. Formula of Keerthika *et al.* (2022) was used to compute the volume of water filtered during each tow: $V = \pi r^2 d$, where V is the volume of filtered water ($m^3$), r is the radius of the net mouth (m), and d is the towing distance (m). MP abundance was represented as particles per litre (particles $L^{-1}$) using the formula: MP abundance = MP counted / (V × 1000), where V in $m^3$ is converted to litres by multiplication by 1000, assuring uniform and comparable MP concentrations across all stations and seasons.

**2.3 Quantification of microplastics**

The collected water samples from the cod end at each station in triplicate were placed into pre-cleaned containers. The containers were transported to the laboratory and stored using 4% buffered formalin solution. 30% hydrogen peroxide ($H_2O_2$) was added to each sample for digestion of organic matters (Aung *et al*. 2022). Following the digestion process, water samples were subjected to density separation using a saturated zinc chloride solution, which efficiently floats low- and high-density plastics (Thomas *et al*. 2020). To get purified MP fractions, the supernatant was vacuum-filtered onto glass-fibre filters (Qiu *et al*. 2016). Procedural blanks (filtered ultrapure water) were processed concurrently for quality assurance in order to identify any contamination during filtering or laboratory work (ITRC 2021).

Potential MP were photographed for documentation, and it was visually sorted based on appearance under a stereomicroscope (magnification 40–80×) (Ferguson *et al*. 2024). Colour, shape (fragment, fibre, foam, film), and sizes (major axis length) were noted. Using image-analysis software calibrated with a micrometre scale, particles were manually quantified. Considering the filtered volume and quantity of particles found, the microplastic abundance was calculated as particles per litre (particles $L^{-1}$) (Razeghi *et al*. 2021).

**2.4 Polymer identification and surface elemental analysis**

Attenuated total reflectance Fourier transform infrared (ATR-FTIR, Nicolet iS5, Thermo Fisher Scientific, United States) spectroscopy was used to confirm the polymer type of MP (Greenshields *et al*. 2024; Nandikes *et al*. 2024). Spectra were obtained by using 32 scans with a resolution of 4 $cm^{-1}$ over a range of 4000–650 $cm^{-1}$. By comparing to reference libraries, type of polymer was identified. Based on the quantity of confirmed particles, the % composition of each polymer (such as PE, PP, PS, PA, PU, PVC) in each station and season was determined (Nandikes *et al*. 2024). Elemental composition and surface morphology a field-emission scanning electron microscope (FESEM – GeminiSEM 300, Carl Zeiss, Germany) fitted with energy-dispersive X-ray spectroscopy (EDX) was used to analyse a selection of confirmed MP (both fragments and fibres) to investigate surface weathering and adsorbed components (Randhawa 2023).

**2.5 Ecological risk assessment in water**

The indices used to evaluate ecological risk and pollution status of selected stations are polymer hazard index (PHI), pollution load index (PLI), contamination factor (CF), individual ecological risk ($E_i$) for each polymer, and total ecological risk index (RI) (Dueñas-Moreno 2024). Latest risk-assessment studies (Ranjani *et al*. 2021) provided the hazard ratings (Hi) for polymers. The lowest concentration found in all samples was defined as background ($C_o$) for CF and RI calculations, while MP concentrations (particles $L^{-1}$) from visual sorting were used as contamination values. Due to the lack of a confirmed pre-contamination or unpolluted baseline for microplastic levels in the Pulicat lagoon-coastal system, the lowest MP concentration found among the sampled stations was used as a substitute background value ($C_o$) for computing CF, $E_i$, and RI (Hakanson L 1980).

**2.5.1 Contamination factor (CF):** The contamination factor (CF) was determined using the equation by Hakanson (1980) given below, where $C_i$ is the microplastic concentration at the site and $C_{oi}$ is the background concentration. The background MP concentration value was determined by taking the lowest MP abundance found in the water samples.

$$CF_i = C_i / C_{oi}$$ (Hakanson 1980)

Values greater than 1 imply contamination enrichment at the site (Qiu *et al*. 2023; Paray *et al*. 2025).

**2.5.2 Pollutant load index (PLIi):** The Pollutant load index (PLIi), which summarises overall pollution of the study sites, was computed using the equation by Tomlinson *et al*. (1980),

$$PL_i = \sqrt{CF_i}$$

PLI values greater than 20, indicate higher pollution relative to baseline levels (Ranjani *et al*. 2021).

**2.5.3 Polymer hazard index (PHI):** The polymer hazard index (PHI) was calculated using the equation by Lithner

*et al*. (2011), which multiplies each polymer's percentage ($P_n$) by its hazard score ($S_n$), was used to calculate the PHI (Zhang *et al*. 2025).

$PHI = \sum P_n \times S_n$ (Lithner *et al*. 2011)

**2.5.4 The ecological risk index ($E_i$):** The ecological index ($E_i$) was measured using the equation by Hakanson (1980) given below, $E_i$ is the potential ecological hazard from a single MP polymer, $T_i$ is the toxicity coefficient, obtained by multiplying the hazard score of each plastic polymer, $C_i$ is the observed MP abundance at each sampling station, and $C_o$ is the background MP concentration, taken as the lowest MP abundance recorded in the current study (Shalumon *et al*. 2023; Lee *et al*. 2024).

$E_i = T_i \times C_i / C_o$ (Hakanson 1980).

**2.5.5 The Potential ecological risk index (RI):** RI is calculated using the equation by Hakanson (1980) given below with categorical grades for ecological risk (e.g. RI < 150: low; 150–300: moderate; 300–600: high; >600: extremely high) was computed as the sum of $E_i$ values for each species of microplastic (Banik *et al*. 2024; Lee *et al*. 2024).

$$RI = \sum_{i=1}^{n} Ei$$ (Hakanson 1980)

**2.6 Quality control**

To reduce background contamination, strict contamination control procedures were followed throughout the laboratory examination of water samples. All samples were promptly placed into glass vials that had been previously cleaned and tightly sealed to avoid exposure. All glassware and lab equipment were carefully cleaned and disinfected with distilled water before and after every analytical session. To avoid unintentional chemical exposure, lab coats, gloves and safety eyewear were uses during the whole analytical process. To prevent airborne particle deposition, filter papers were carefully maintained in covered Petri dishes. Procedural blank studies were carried out concurrently with sample analysis to eliminate cross-contamination of microplastics (MP). Deionised water was put in similar sample containers to create the blanks, which were then put through the same analytical process as the real water samples. This method made it possible to identify and address any airborne microplastic pollution in the lab. The results of the blank analyses verified that there were no MPs, confirming the trustworthiness of the stated findings and establishing the integrity of the analytical process.

**2.7 Data analysis**

The microplastics count in water were expressed in MP $L^{-1}$ and the shape, colour, size and polymers were expressed in percentage. The observed data was assessed using a non-parametric test. To identify the significant differences, the Kruskal-Wallis test was used. MPs distribution in terms of size, shape, and colour as well as MPs abundance in water between the sampling locations. The post hoc comparison test was used for pairwise comparisons if significant differences were found. The statistical analysis was performed using the SPSS software (Version 25), and the significance level was set to $p < 0.05$ for two analyses.

## 3 | RESULTS AND DISCUSSION

### 3.1 Seasonal microplastic (MP) abundance

In the current investigation, MP concentrations ranged from 50 to 135 particles $L^{-1}$, with a noticeable increase throughout the monsoon and post-monsoon seasons. The amount of microplastic (MP) varied spatially and temporally at Goonankuppam (Station I), Thonirevu (Station II), and Pulicat Beach (Station III). During pre-monsoon 2024, MP concentrations were relatively stable and comparable across all three stations, indicating baseline plastic loading conditions prior to the onset of seasonal hydrological disturbances, with limited runoff and calmer hydrodynamic conditions sustaining uniform distribution of microplastics throughout the study area. As the monsoon 2024 season progressed, a moderate but noticeable increase in MP abundance was observed across all stations, owing to the progressive mobilisation of land-based plastic debris via increased surface runoff, storm drain discharge, and creek-fed inflows into the coastal water body.

Due to monsoon-driven surface runoff processes that greatly increase MP loads in estuary waters, the highest MP abundance (~135 particles $L^{-1}$) was observed in Thonirevu during post-monsoon 2025 (Li *et al*. 2023). The devastating effects of cyclone Fengal, which hit the Tamil Nadu–Puducherry coast in November 2024, exacerbated this post-monsoon surge by causing heavy precipitation, storm surges, and widespread flooding. These events served as a potent plastic transport mechanism, flushing large amounts of debris from inland settlements, fishing harbours, agricultural zones, and waste disposal sites directly into Pulicat Lagoon and its neighbouring coastal waters while also breaking up larger plastic objects into microplastics through strong hydrodynamic shear forces (Lahon *et al*. 2023). Because of its location within an active estuary-creek system that serves as a natural conduit for land-based plastic transport—channelling stormwater and creek discharge laden with plastic debris from nearby residential, agricultural, and coastal areas directly into estuarine receiving waters—Thonirevu (Station II) became a consistent MP hotspot during this time.

Summer 2025 was observed to have a significant drop in MP concentrations at all three stations after this cyclone-driven post-monsoon peak. This was due to decreased hydrodynamic energy, gravitational sedimentation, and plastic inputs during the dry season, all of which encouraged the settling of suspended microplastics from

the water column into the underlying sediment. MP abundance then showed a little rebound in pre-monsoon 2025, probably due to the gradual reinstatement of land-based plastic contributions ahead of the impending monsoon cycle and the renewed wind-induced resuspension of previously deposited particles.

All five seasons recorded moderate MP concentrations of 60–100 particles $L^{-1}$ at Station I. The contained nature of the inner lagoon, which limits water exchange and allows particles to settle and persist over time, is largely responsible for this ongoing accumulation (Sarkar *et al*. 2026). Because of the restricted circulation that allows buoyant and neutrally buoyant particles to be suspended longer and go through several cycles of deposition and resuspension, lagoonal systems are well known for being effective microplastic traps (Anastasopoulou *et al*. 2018). Because of the dynamic open-coast conditions, such as wave action, tidal mixing, and longshore currents, which constantly scatter and dilute plastic particles and limit their net accumulation in the water column, Pulicat Beach (Station III) recorded relatively lower MP concentrations (~50–100 particles $L^{-1}$) throughout all seasons (Ganesan and Nallathambi 2024). Hydrodynamic mixing, which includes wind-driven circulation and tidal oscillation, generated statistically little spatial variation among the sites ($p > 0.05$) despite site-specific pressures, suggesting a generally homogeneous distribution of MP throughout the research area (Chen *et al*. 2024). In comparison to open-coast Pulicat Beach, the MP concentrations in lagoonal and estuarine stations are consistently higher, which is consistent with global trends showing that restricted-circulation water bodies acquire higher MP loads than exposed coastal habitats (Zhang *et al*. 2025). The higher MP levels at Thonirevu and Goonankuppam together highlight the compounding effects of monsoonal inflow, stormwater inputs driven by Cyclone Fengal, domestic discharges, and semi-enclosed hydrodynamics, while the lower concentrations at Pulicat Beach represent the natural self-flushing behaviour of open coastal systems.

Microplastic levels in water revealed no notable spatial variations across the three sampling locations (Kruskal–Wallis: $H = 4.622$, $p = 0.099$). Conversely, notable seasonal variation was noted ($H = 10.262$, $p = 0.036$), with the peak mean rank occurring in the post-monsoon season (13.17) and the minimum in summer (3.00). Dunn's post hoc test with Bonferroni adjustment indicated that no pairwise seasonal comparisons were statistically significant (all $p > 0.05$), though the summer and post-monsoon comparison neared significance ($p = 0.053$). Consequently, all seasons were categorized under the same significance group ("a") in Figure 1, showing the lack of statistically significant pairwise differences post multiple-comparison correction (Field 2024).

Overall, seasonal variation in MP abundance revealed a clear progressive trend across all three stations, with concentrations remaining relatively stable during pre-monsoon 2024 and increasing moderately throughout the monsoon 2024 (Figure 1). The most intense escalation was observed during post-monsoon 2025, when MP abundance reached new highs across all stations, a peak largely attributable to the disastrous impact of Cyclone Fengal.

The increase in MP abundance after the cyclone noted in this study aligns with recorded rises in coastal microplastic levels after tropical cyclones and typhoons in other regions. Typhoons and rainstorms have been demonstrated to generate 5.1 to 36.4 times and 1.9 to 11.7 times additional microplastics in beach sediment, respectively, as well as 3.5 to 6.0 times and 2.5 to 4.3 times more microplastics in surface seawater (Tsang *et al*. 2020). The Cyclone Fengal moved close to Puducherry on 30 November 2024, causing exceptionally heavy rainfall along the Tamil Nadu–Puducherry coastal area, with 24-hour rainfall amounts of approximately 50 cm at Mailam (Villupuram district) and 46 cm at Puducherry (IMD, 2024), marking the highest levels in thirty years for the region. In the Tiruvallur district, which includes the Pulicat Lagoon study region, multiple stations noted significant rainfall during the same event, such as R.K. Pet (13 cm), Thirunindravur (14 cm), and Tiruttani (12 cm) within a 24-hour period. This extensive and intense rainfall across a large area would have produced significant surface runoff into the Pulicat Lagoon transporting land-based microplastics from nearby catchments and boosting freshwater influx into the lagoon. Considering the established precedent of heightened terrestrial runoff and sediment resuspension caused by storms contributing to storm-driven MP loading, the heightened post-monsoon MP concentrations noted at the current stations may be ascribed to the impact of Cyclone Fengal and its exceptionally heavy rainfall over the Pulicat catchment.

### 3.2 Characteristics of microplastic (MP) particles

Six main polymer types were found at three stations using ATR-FTIR analysis: polyethylene (PE), polypropylene (PP), polyamide (PA), polystyrene (PS), polyurethane (PU), and polyvinyl chloride (PVC) (Figure 2). PE was the most prevalent polymer at every station (46% at Station I, 41% at Station II, and 47% at Station III). This is in line with worldwide research showing that PE is the most often produced and readily fragmentable polymer, making it the most prevalent microplastic in coastal waterways (Andrady 2011). The intense wave action and longshore currents that disperse heavier polymers offshore and accumulate floating plastics, open-coast Pulicat Beach had the largest percentage of buoyant PE (Ganesan and Nallathambi 2024). PP, the second most prevalent polymer in the study sites (39% at Station I, 36% at Station II, and 39% at Station III), is widely utilised in consumer

goods and packaging, and its low density allows for extensive transportation and deposition in nearshore systems (Andrade *et al*. 2011). Following the PP, PES (5% at Station I, 11% at Station II, and 7% at Station III) and PA (6% at Station I, 7% at Station II, and 2% at Station III), found at considerable levels, is linked to disposable containers and foam packing that easily shatter into tiny pieces when subjected to mechanical and UV stress (Prabu *et al*. 2026). Hydrodynamics explains spatial differences: semi-enclosed waterways have low circulation, fine-water trapping, and lengthy residence durations that encourage the deposition of denser polymers, which is why lagoon and creek stations (Goonankuppam, Thonirevu) preserved some proportions of PA (Sarkar *et al*. 2026). PU (3% at Station I, 3% at Station II, and 3% at Station III) most likely from foam-based fishing floats, household foam debris despite their low abundance, they disrupt hormones and limit the growth of aquatic species (Peng *et al*. 2023). Among all the polymers found, PVC was found in the least amount (1% at Station I, 2% at Station II, and 2% at Station III). Possible sources include deterioration of pipe fittings, drainage infrastructure, and synthetic ropes that are frequently utilised in and around the Pulicat Lagoon system (Martinho *et al*. 2022).

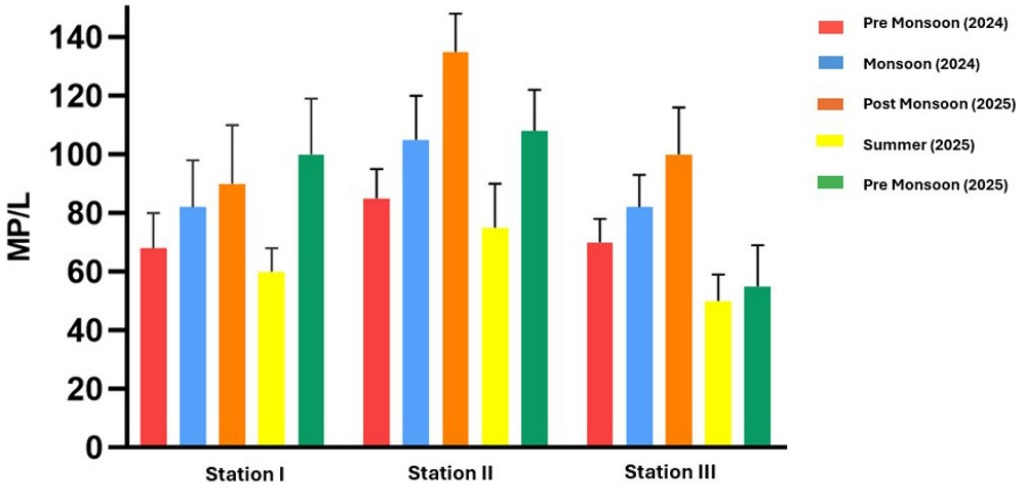
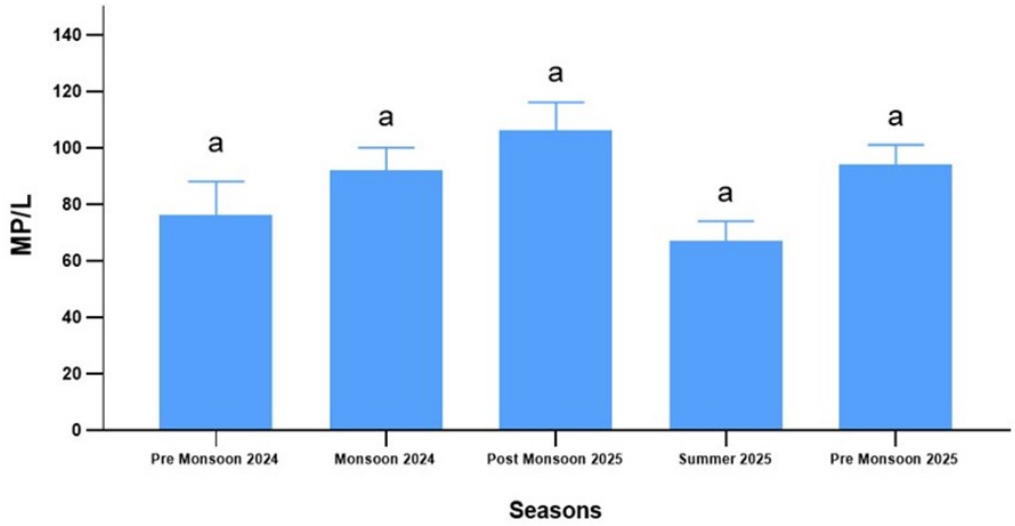



**FIGURE 1**
**(a)** Spatial variation of microplastic (MP) in water samples from three sampling sites.




**(b)** Seasonal variation of microplastic (MP) concentration in water samples from three sampling sites. Bars with the same letter (a) are not statistically different, based on Dunn's post-hoc test with Bonferroni corrections.

Fibres strongly dominated the distribution of microplastic (MP) morphotypes in Pulicat waters, accounting for 50.9% at Station I, 40.6% at Station II, and 51.1% at Station III, as shown by the pie diagrams (Figure 3). The frequency of fibres indicates that the main sources of fibrous MPs in these coastal waters are the continuous discharge of textiles, laundry effluents, fishing net abrasion, and boat-related activities. Fragments were the second most common morphotype (22.60% at Station I, 27.40% at Station II, and 24.20% at Station III), suggesting that larger plastic litter, including packaging materials, single-use plastics, and disposable cups, is broken down by UV-driven photo-oxidation and wave abrasion, processes frequently reported to produce secondary MPs in tropical coastal systems (Wang *et al*. 2022). Films (10.70% at Station I, 16.10% at Station II, and 11.20% at Station III) most likely came from decomposing carry bags, food wrappers, and agricultural mulching films that entered

through neighbourhood markets and beach dumping. These materials are known to fracture quickly because of their thin, brittle structure (Wang *et al*. 2022). Particles having irregular shapes (10.50% at Station I, 10.80% at Station II, and 8.30% at Station III) might come from composite materials and aged multi-layered polymers that fracture unevenly after extended exposure to the environment (Zhang *et al*. 2021).

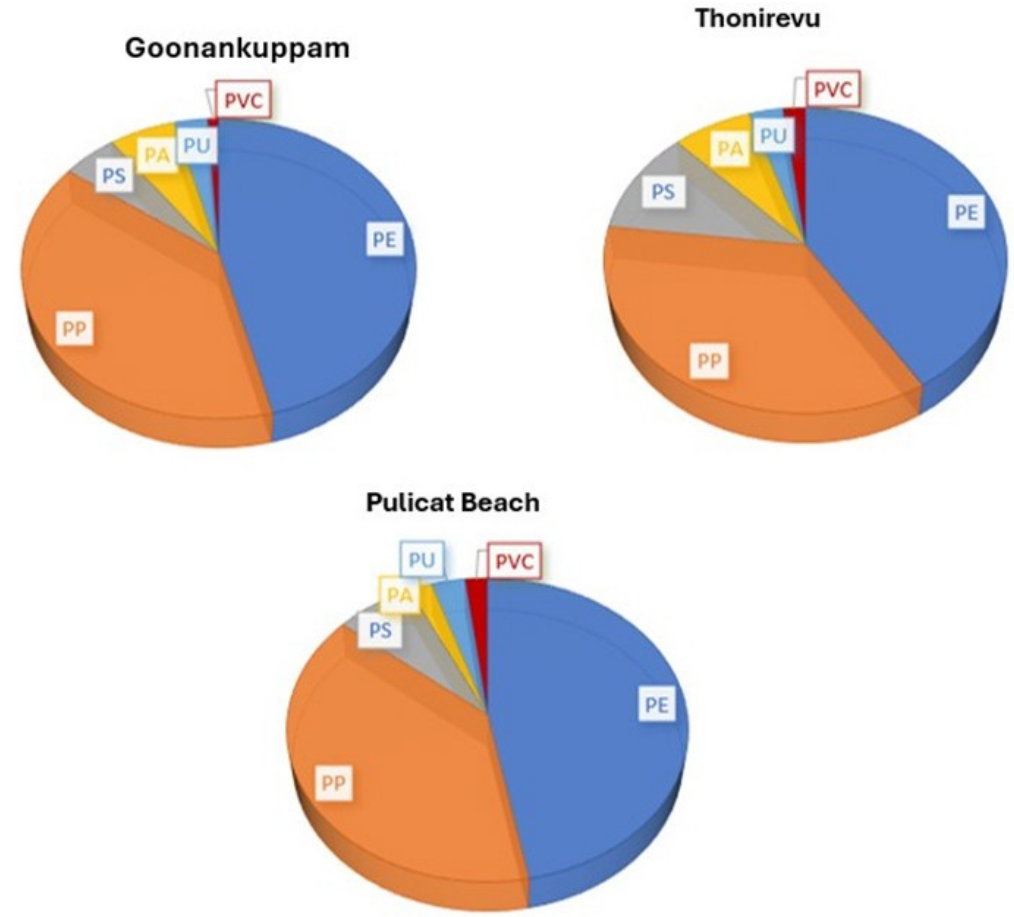



**FIGURE 2** Microplastic polymer types across the three sampling sites. PE – Polyethylene, PP – Polypropylene, PA – Polyamide, PS – Polystyrene, PU – Polyurethane, and PVC – Polyvinyl chloride.

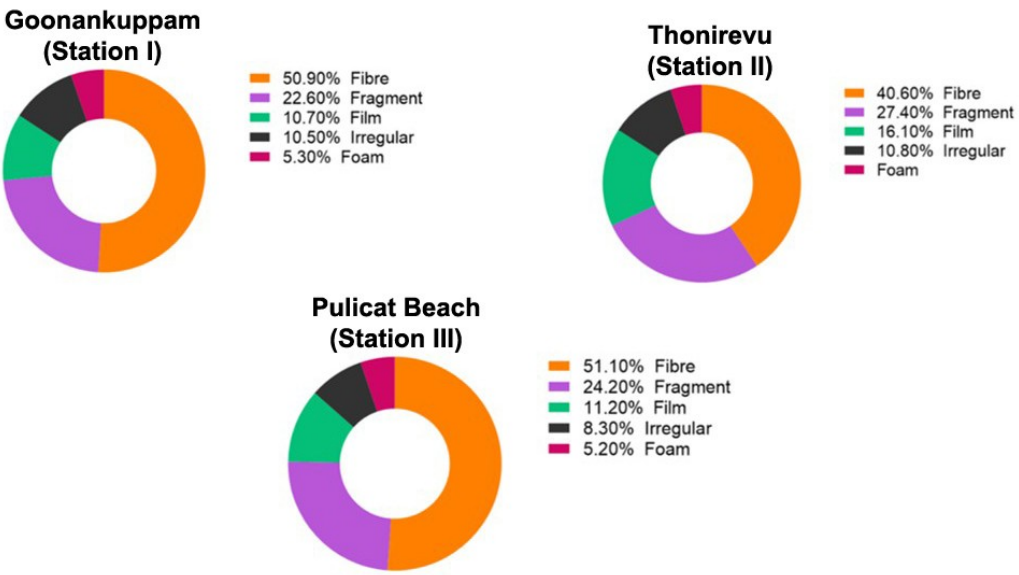



**FIGURE 3** Different microplastic shapes across the three sampling sites.

The least common morphotype was foam particles (5.30% at Station I and 5.20% at Station III), with foam being noticeably absent at Station II. This is probably because the higher hydrodynamic energy at the creek mouth speeds up the disintegration of foam; thermocol (EPS), a material used in packaging, ice box insulation, and fish landing centres, is known to fragment easily because of its delicate cellular structure (Nithin *et al.* 2023). Overall, the predominance of fibres and fragments in all three stations indicates that secondary MPs are the main contributors in Pulicat waters, indicating a strong anthropogenic influence from household wastewater, fishing, and shoreline plastic handling—a trend commonly observed in semi-enclosed Indian coastal environments (Akhter and Panhwar 2022).

Blue particles dominated the distribution of microplastics (MP) in Pulicat waters, accounting for 40% at Station I, 30% at Station II, and 45% at Station III (Figure 4). In fishing-active coastal areas, blue MPs are the most prevalent hue. They are often linked to fishing-related materials like ropes, nets, and synthetic lines, which release fibres and fragments during mechanical abrasion and use (Chandran *et al*. 2025). Transparent MPs, which come from single-use films, disposable covers, and weathered packaging plastics that progressively lose pigmentation owing to photodegradation, made up 25% of the total across all stations (Rasool *et al*. 2025). Tire particles burnt plastic residues and fishing gear coatings that enter coastal waterways through runoff are associated with black MPs (15% at Station I, 20% at Station II and 10% at Station III) (Farhan *et al*. 2024). White MPs (7% of all stations) are probably caused by food containers, oxidised household plastics, and foam materials that have been bleached by extended sun exposure (Barasarathi *et al*. 2014). Plastic bottle pieces, bottle caps, and coloured packaging materials that are thrown away close to coastal towns are often associated with green MPs (10% at Station I, 8% at Station II, and 10% at Station III) (Arivukumar *et al*. 2026). Red MPs (1% at Station I, 2% at Station II, and 2% at Station III) and yellow MPs (2% at Station I, 5% at Station II, and 2% at Station III) are indicative of coloured consumer plastics such food wrappers and buoy pieces that fade because of UV-induced oxidation (Haider *et al*. 2019). In line with worldwide patterns where blue microplastics predominate in fishing-intensive coastal ecosystems, the sustained dominance of blue MPs across all three stations indicates the substantial impact of fishing-related activities in the Pulicat system (Keerthika *et al*. 2023). Because they resemble plankton, blue and transparent MPs are more likely to be eaten by aquatic animals, which could promote trophic transfer in the Pulicat ecosystem (Kannan *et al*. 2023).

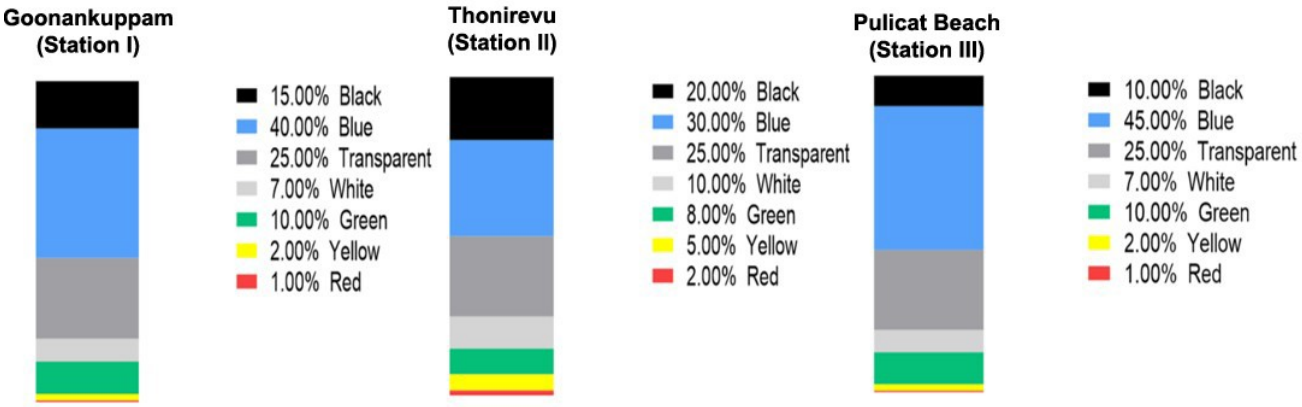



**FIGURE 4** Microplastic colors across three sampling sites.

The 100–500 µm size class (56% at Station I, 49% at Station II, and 47% at Station III) dominated the microplastic (MP) size distribution in Pulicat waters (Figure 5), indicating advanced fragmentation of larger plastic debris caused by continuous UV exposure, mechanical abrasion, and extended water residence times typical of semi-enclosed lagoonal and creek systems (Kutralam-Muniasamy *et al*. 2021). The 500–1000 µm fraction (33% at Station I, 32% at Station II, and 31% at Station III) came next. This fraction most likely represents intermediate stages of packaging film, fishing rope, and synthetic bag degradation that progressively deteriorate due to wave action and microbial activity (Athey and Erdle 2022). Fresh inputs from fishing harbours, creek openings, and beach dumping are frequently linked to the 1000–3000 µm size class (7% at Station I, 9% at Station II, and 10% at Station III), which most likely represents recently deposited plastic debris at early stages of weathering (Peñalver-Soler *et al*. 2025). Among bigger size classes, the 3000–5000 µm fraction (3% at Station I, 6% at Station II, and 5% at Station III) made up the smallest percentage. This suggests that the huge macro-fragments have just recently entered the aquatic system and have not yet experienced considerable mechanical breakdown. The <100 µm class

(2% at Station I, 4% at Station II, and 7% at Station III) exhibited a significant upward trend from the enclosed lagoon toward the open coast, indicating that extreme size reduction of particles into the finest detectable fraction is encouraged at Station III by increased hydrodynamic energy, which is driven by wave action and tidal turbulence. Because their increased surface-area-to-volume ratio increases the adsorption of hydrophobic pollutants and metal ions, increasing their potential toxicity, the higher abundance of smaller MPs (< 500 µm) across all stations is ecologically noteworthy (Li *et al*. 2019). Smaller particles are more easily consumed by plankton, filter feeders, and young fish, increasing the possibility of trophic transfer and long-term bioaccumulation within lagoon food webs (Costa *et al*. 2020). Even though they are found in smaller amounts, very small MPs (< 100 µm) are especially dangerous because of their ability to enter tissues and build up inside organs; this tendency has been increasingly shown in estuarine and coastal species exposed to microplastic contamination (Karami *et al*. 2017). All things considered, the predominance of fine-sized MPs in Pulicat waters indicates a high degree of secondary microplastic generation caused by hydrodynamic fragmentation and persistent human inputs, which is consistent with the retention dynamics of semi-enclosed lagoonal systems where extended residence times promote progressive particle weathering (Haward 2018).

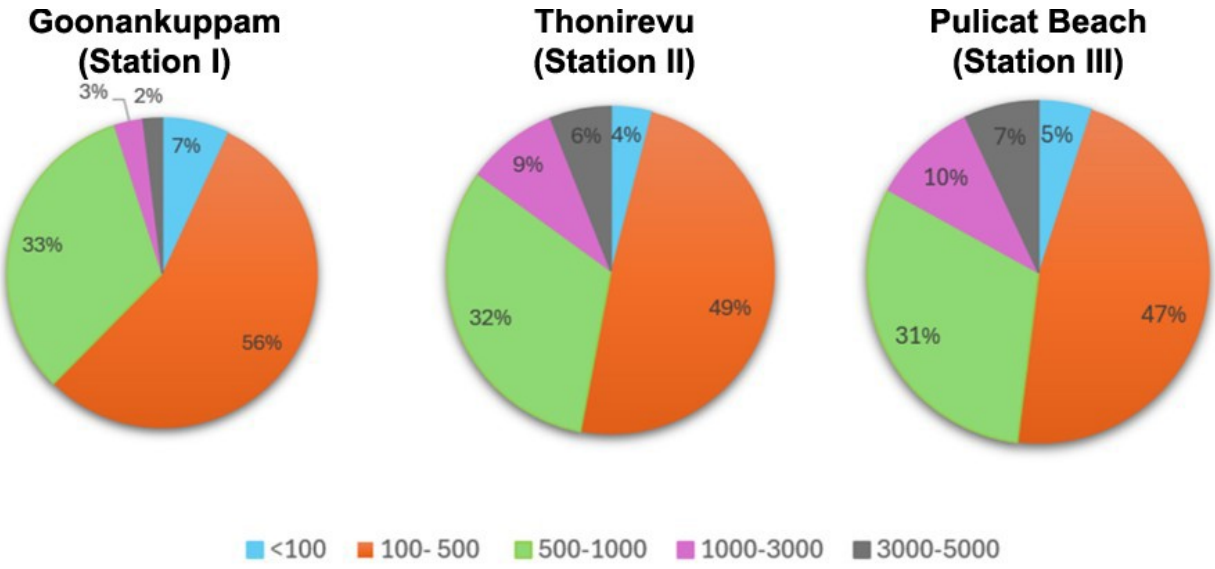



**FIGURE 5** Microplastic size composition across sampling sites (in µm).

### 3.3 Risk assessment

Using Pulicat Beach (50 particles $L^{-1}$) as the background reference, the Contamination Factor (CF) was calculated using Eq. 1, yielding values of 1.60 at Goonankuppam, 2.03 at Thonirevu, and 1.43 at Pulicat Beach (Table 1), indicating low-to-moderate contamination slightly above baseline. Thonirevu recorded the highest CF, which is consistent with intensified monsoon-driven plastic inputs and creek discharge at its active fish landing centre, while Pulicat Beach recorded the lowest, which is due to tidal dilution and open coastal flushing (Karthik *et al.* 2018; Dissanayake *et al*. 2021).

**TABLE 1** Contamination factor (CF) values obtained from triplicate sampling each station.

| Station | Mean Value ($C_i$) | CF= $C_i$/ $C_{ref}$ |
|---|---|---|
| Goonankuppam | 80 | 1.60 |
| Thonirevu | 101.6 | 2.03 |
| Pulicat Beach | 71.4 | 1.43 |

Although persistent fishing and household plastic inputs demand for ongoing monitoring, the calculated PLI of 1.26 placed all stations within pollution class I, confirming modest overall MP accumulation comparable to other hydrodynamically active coastal zones (Rakib *et al*. 2022). The hazard scores of polymers are given in Table 2. The high hazard scores of PS (30), PA (47), PU (52), and PVC (373) despite their relatively low proportional abundances were the main cause of the PHI values of 1606 at Goonankuppam, 2266 at Thonirevu, and 1902 at Pulicat Beach (Table 3). Thonirevu recorded the highest PHI because of elevated PS and PVC contributions from polystyrene packaging waste and pipe-derived fragments transported via creek discharge (Ranjani *et al*. 2021; Panahi *et al*. 2025).

The cumulative ecological risk index (RI), computed from individual polymer $E_i$ values (Table 4), was 16.06 at Goonankuppam, 22.66 at Thonirevu, and 19.02 at Pulicat Beach — all below 150, indicating minor ecological danger. The geographical gradient in RI reflects the distribu-

tion of high-hazard polymers across stations. PVC contributes an $E_i$ of 7.46 at both Thonirevu and Pulicat Beach, whereas PP consistently records the lowest $E_i$ (0.36–0.39) across all stations. Risk assessment indices and rankings are given in Table 5. These findings confirm that chemical toxicity from high-hazard polymer leaching poses a disproportionate ecological threat compared to measured particle abundance, necessitating a targeted source reduction of PVC and PS inputs in the Pulicat Lagoon-coastal system (Lithner *et al*. 2011).

**TABLE 2** Polymers observed in water samples from the Pulicat region, their sources and hazard score.

| **Polymers in beach sediments** | **Polyethylene** PE | **Polypropylene** PP | **Polystyrene** PS | **Polyamide** PA | **Polyurethane (PU)** | **Polyvinyl Chloride (PVC)** |
|---|---|---|---|---|---|---|
| g/cm³ | 0.91–0.97 | 0.89–0.92 | 1.01–1.06 | 1.13–1.15 | 1.10–1.25 | 1.30–1.45 |
| Sources | Plastic bags, packaging film, disposable caps and containers | Fishing ropes and nets, packaging items, bottle caps | Disposable cutlery, foam food containers, floats, cups | Fishing nets and lines, textile fibers, industrial pellets | Foam insulation, furniture cushions, adhesives, coatings, synthetic leather | Pipes, flooring materials, cable insulation, synthetic leather, packaging |
| Shapes observed in beach sediments | Fragments, films, pellets | Fibers, fragments, pellets | Foam pieces, fragments | Fibers, fragments | Foam particles, fragments | Fragments, films |
| Hazard score (Panahi *et al.* 2025) | 11 | 1 | 30 | 47 (higher risk category than PE/PP/PS) | 52 | 373 (very high hazard potential) |

**TABLE 3** Polymers Hazard Index (PHI) values of water samples from the Pulicat region.

| **Station** | **PHI calculation** | **PHI value** |
|---|---|---|
| Goonankuppam | (46×11) + (39×1) + (5×50) + (6×47) + (3×52) + (1×373) | 1606 |
| Thonirevu | (41×11) + (36×1) + (11×50) + (7×47) + (3×52) + (2×373) | 2266 |
| Pulicat Beach | (47×11) + (39×1) + (7×50) + (2×47) + (3×52) + (2×373) | 1902 |

**TABLE 4** $E_i$ - potential ecological hazard from a single microplastic's polymer; RI - ecological risk.

| **Station** | **$E_i$ (PE)** | **$E_i$ (PP)** | **$E_i$ (PES)** | **$E_i$ (PA)** | **$E_i$ (PU)** | **$E_i$ (PVC)** | **RI ($\Sigma E_i$)** |
|---|---|---|---|---|---|---|---|
| Goonankuppam | 5.06 | 0.39 | 2.50 | 2.82 | 1.56 | 3.73 | 16.06 |
| Thonirevu | 4.51 | 0.36 | 5.50 | 3.29 | 1.56 | 7.46 | 22.66 |
| Pulicat Beach | 5.17 | 0.39 | 3.50 | 0.94 | 1.56 | 7.46 | 19.02 |

PE = polyethylene, PP = polypropylene, PA = polyamide, PES = Polyester, PU = polyurethane, PVC = polyvinyl chloride.

### 3.4 FESEM-EDX

FESEM–EDX analysis of the predominant microplastic types (fibres and fragments) from the beach sites and Pulicat Lagoon (Figure 6) showed distinct signs of surface weathering, such as irregular depressions, rough textures, and cracked edges, indicating extended exposure to UV radiation, oxidation, and mechanical abrasion in the aquatic environment (Song *et al*. 2017). Major inorganic elements like C, O, Na, Si, Al, P, Cl, and Zn were confirmed to be present on particle surfaces by the EDX spectra; C and O predominated because of the organic polymer backbone, while mineral-associated peaks (Si, Al) indicated contact with watery particles in the lagoon system (Keerthika *et al*. 2022). Zn, Na, Al, and P were among the trace metals that were clearly adsorbed on microplastics. Zn exhibited high-intensity peaks (Figure 7), which were probably caused by antifouling coatings, tyre wear, and galvanised items that entered aquatic systems by runoff and fishing. The presence of Al and Si is consistent with their frequent use as stabilisers and fillers in the production of plastics, as well as their strong electrostatic affinity for microplastic surfaces (Rao *et al*. 2025). Additionally, peaks that correlate to P and Cl suggest that flame retardants, plasticisers, and industrial additives that are frequently used in packaging polymers may have been incorporated (Campanale *et al*. 2020). The abundance of these elements suggests both additive-related origins and environmental adsorption, supporting the concept that aged microplastics operate as efficient vectors for metal contaminants due to their weathered surfaces and enhanced binding sites (Tan *et al*. 2026). The EDX results show that microplastics from Pulicat Beach and Pulicat

Lagoon are chemically bound with environmentally generated metals contained in their polymer matrix. This highlights their increased ability to serve as mobile vectors for potentially hazardous materials throughout coastal ecosystems.

**TABLE 5** Risk assessment indices rankings and categories observed in Pulicat water samples.

| Index | Ranking system (Verbal category) | Goonankuppam | Thonirevu | Pulicat Beach |
|---|---|---|---|---|
| $CF_i$ (Contamination Factor) | <1 = Low<br>1–3 = Moderate<br>3–6 = Considerable<br>>6 = Very High | 1.60 (Moderate) | 2.03(Moderate) | 1.43 → Moderate |
| *PLI* (Pollution Load Index) | I = <10 (Low)<br>II = 10–20 (Moderate)<br>III = 20–30 (High)<br>IV = >30 (Very High) | 1.26→ Rank I (Low) | 1.42 → Rank I (Low) | 1.20 → Rank I (Low) |
| *PHI* (Polymer Hazard Index) | I = 0–1 (Very Low)<br>II = 1–10 (Low)<br>III = 10–100 (Medium)<br>IV = 100–1000 (High)<br>V = >1000 (Very High) | 1606 → Rank V (Very High) | 2266 → Rank V (Very High) | 1902 → Rank V (Very High) |
| PERI / RI (Potential Ecological Risk Index) | <150 = Minor<br>150–300 = Medium<br>300–600 = High<br>600–1200 = Danger<br>>1200 = Extreme | 16.06 (Minor) | 22.66 (Minor) | 19.02 (Minor) |

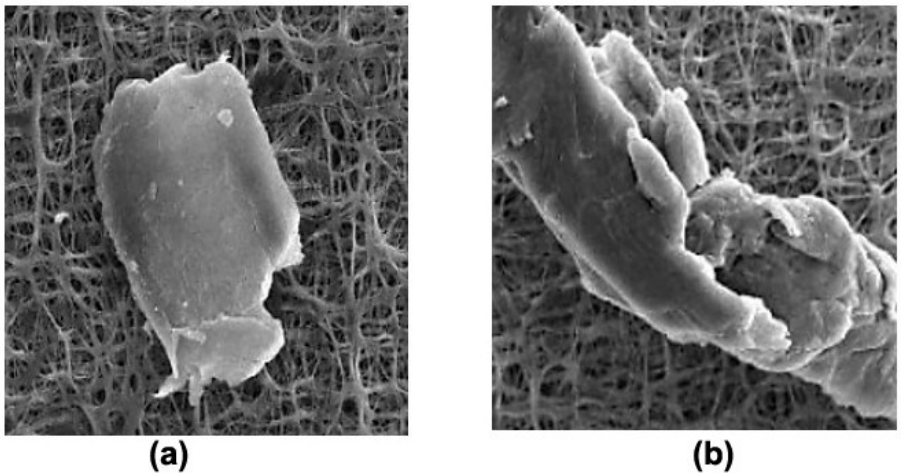



**FIGURE 6** FESEM images of fragment (a) and fiber (b) extracted from water samples.

## 4 | CONCLUSIONS

The current study thoroughly recorded the number, features, chemical composition, surface morphology, elemental composition, and risk assessment of microplastics found in water from Pulicat Beach and Pulicat Lagoon. Microplastic abundance ranged 50 to 135 particles $L^{-1}$. There was no significant spatial variation across sampling sites, indicating a homogeneous distribution of microplastics in water, unaffected by localized land-based sources. Fibre morphotype strongly dominated in the distribution of microplastic (MP) in Pulicat waters. Blue-colored microplastics were pre-dominant and microplastics ranging in size from 100–500 µm size were the most common. PE appeared as the most common polymer with sources including direct sewage intake, recreational activities, fishing operations, and inadvertent plastic loss into the coastal ecosystem. The varied polymer composition, which included polyethylene, polypropylene, polystyrene, and polyethylene terephthalate, resulted in an overall $PHI_{water}$ = 1606 at Station I, 2266 at Station II and 1902 at Station III equivalent to a hazard level of V, but the pollutant load index recorded a $PLI_{water}$ 1.26, 1.42 and 1.20 at

Stations I, II and III respectively indicating a hazard rank of I. The ecological risk posed by microplastics $RI_{water}$ 16.06, 22.66 and 19.02 at Stations I, II and III was classified as minor risk category medium emphasising the need for management measures such as proper wastewater treatment, plastic waste recycling, and responsible waste disposal practices to reduce plastic influx into this fragile coastal ecosystem. FESEM–EDX analysis confirmed that microplastics were extensively weathered and had adsorbed inorganic elements from the surrounding environment or from plastic additives, amplifying their potential toxicological impact on benthic organisms and the broader marine food web. The measured MP levels align with expectations for a semi-enclosed, human-influenced lagoon-coastal habitat, categorizing it within pollution class I (PLI) and the minor risk group, primarily influenced by residential discharge, fishing practices, and runoff from monsoons. Ongoing source-control actions, like enhanced wastewater treatment and better plastic waste management, are necessary to stop risk levels from rising any higher.

Therefore, future investigations should prioritize studying the combined effects of microplastic pollution alongside organic contaminants and heavy metal bioavailability, which would provide a more holistic and comprehensive understanding of the cumulative ecological risks posed by microplastic contamination in the Pulicat coastal ecosystem.

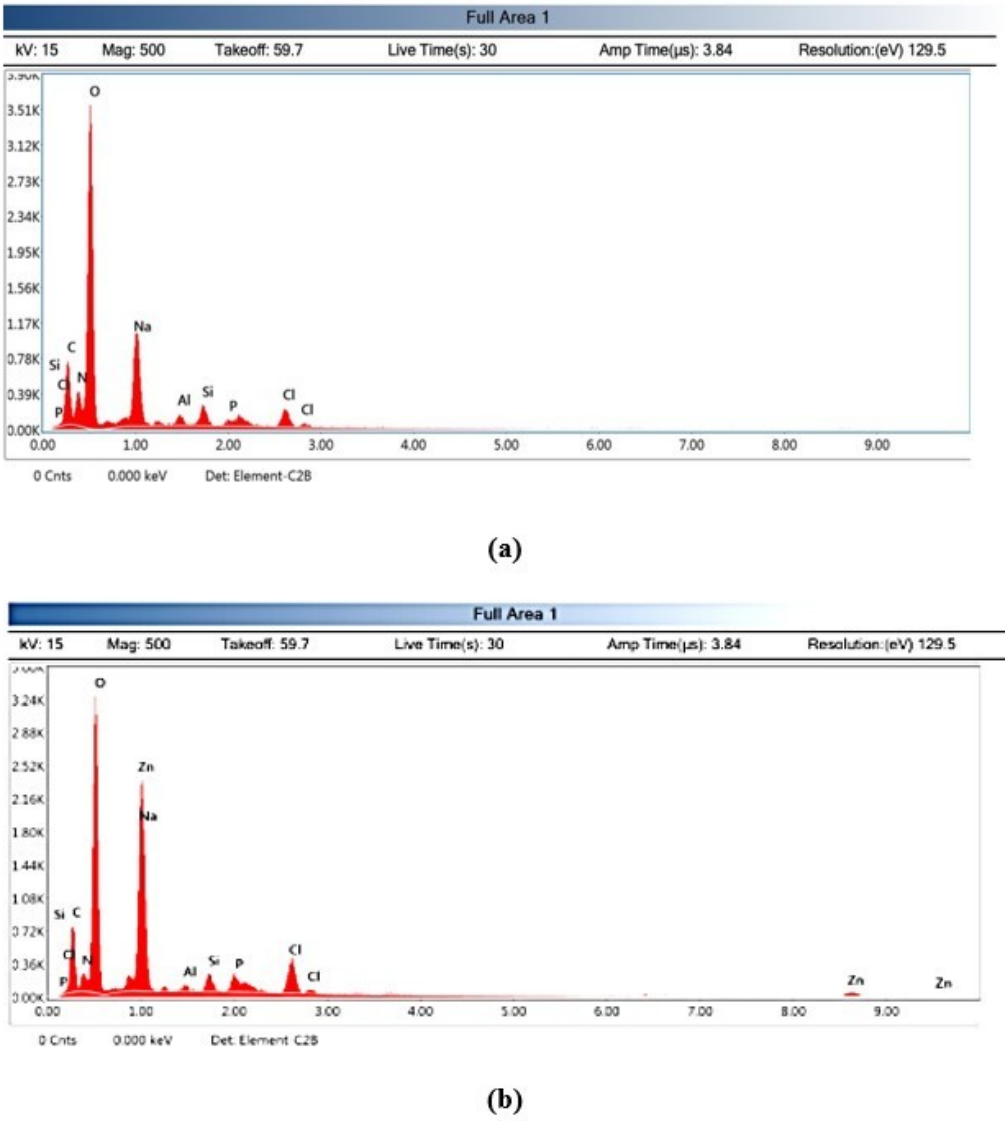



**FIGURE 7** EDAX images of fragment (a) and fiber (b) extracted from water samples.

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**ETHICAL APPROVAL**
All applicable international, national and/or institutional guidelines for the care and use of animals were followed in this study.

**CONFLICT OF INTEREST**
The author declares no conflict of interest.

**AUTHORS' CONTRIBUTION**
Credit authorship contribution statement Saleem Ashik - Conceptualization, Investigation, Sampling, Analysis & Writing; Aruna Satyapriyan - Research administration & Validation; Pandurangan Padmavathy - Supervision and guidance; Selvaraj S- Supervision and guidance. Chandran Sudhan - Data curation, Writing, Review & Editing; Kalaiselvan Keerthika -Conceptualization, Review & Editing, Gunasekaran Gobi -Conceptualization, Review & Editing.

**DATA AVAILABILITY STATEMENT**
The data that support the findings of this study are available on request from the corresponding author.

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