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Spatial Distribution Patterns and Morphological Characteristics of Microplastics in Brackish Waters of Kendari Bay Estuary, Indonesia

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Abstract: This study aimed to characterize microplastics based on variations in their physical form and size and to assess their abundance in the brackish waters of Kendari Bay. Purposive sampling was conducted at three stations representing port and shipping activities, residential areas, and mangrove habitats. Three biological replicates and three technical replicates were collected, yielding 18 samples comprising nine surface-water samples and nine sediment samples. The data were analyzed using descriptive frequency analysis, and the coordinates of all sampling locations were recorded using a Global Positioning System (GPS). The highest microplastic abundance was observed in the port and shipping zone, with 11,460 particles per 150 mL of water and 83 particles g^{-1} of sediment, indicating that this zone was the primary accumulation area. This was followed by the mangrove area, with 10,620 particles per 150 mL of water and 77 particles g^{-1} of sediment, and the residential area, with 10,200 particles per 150 mL of water and 68.4 particles g^{-1} of sediment. Four microplastic forms were identified: fibers, films, fragments, and foams. Foam was the dominant form in both environmental matrices, indicating a substantial contribution from expanded polystyrene (EPS) waste. Most particles were smaller than 0.27 mm, suggesting advanced fragmentation processes in the environment. Based on their color characteristics, the microplastics were predominantly black (37%) and transparent (31%), indicating extensive environmental weathering, followed by yellow (13%), green (13%), and blue (6%). These findings provide an evidence-based foundation for developing policies to control EPS packaging waste across upstream and coastal areas. They also highlight the urgent need to restore mangrove forests as natural filters to reduce the accumulation of microplastics in Kendari Bay.
Keywords: Abundance; characteristics; distribution; Kendari Bay; microplastics

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INTRODUCTION

Plastic pollution is widely recognized as one of the most pressing global environmental challenges of the twenty-first century. Global plastic production reached approximately 322 million tonnes in 2015 (Plastics Europe & EPRO, 2016). Rather than increasing 100-fold by 2050, as stated previously, global plastic use and plastic-waste generation are projected to nearly triple by 2060 under a business-as-usual scenario (OECD, 2022). The continued growth, persistence, and environmental accumulation of plastic materials have intensified concerns regarding their long-term ecological consequences (Rochman et al., 2015; Seltenrich, 2015). Plastic waste also constitutes a substantial proportion of municipal solid waste; approximately 242 million tonnes of plastic waste, equivalent to 12% of global municipal solid waste, were generated in 2016 (World Bank, 2018). Consequently, scientific attention has increasingly shifted from visible plastic debris to smaller particles, particularly microplastics.

Microplastics are commonly defined as solid, synthetic polymer-containing particles smaller than 5 mm (Hartmann et al., 2019; Mintenig et al., 2017; Pratiwi et al., 2025). These particles are environmentally persistent and can be transported over considerable distances through freshwater, estuarine, and marine systems. Their distribution and environmental fate are influenced not only by particle size and polymer density but also by weathering, aggregation, biofouling, turbulence, and interactions with suspended sediment. Microplastics may be ingested by aquatic organisms and transferred between trophic levels, potentially causing physical stress, altered feeding behavior, inflammatory responses, and exposure to plastic-associated chemicals (Prasetijo et al., 2025; Mokodompit & Nengsi, 2024). However, evidence of consistent biomagnification across aquatic food webs remains inconclusive, and the long-term implications for human health have not yet been fully established (Vethaak & Legler, 2021). Therefore, references to human-health risks should be framed as potential concerns rather than confirmed outcomes.

As an archipelagic country with extensive coastlines and intensive anthropogenic activities in coastal and urban areas, Indonesia is highly vulnerable to the leakage of plastic waste into aquatic environments. Rivers represent major pathways through which land-based plastic waste is transported to coastal waters and the ocean (Lebreton et al., 2017; Meijer et al., 2021). Estuarine and brackish-water ecosystems are particularly susceptible to microplastic accumulation because they receive pollutants from upstream catchments while simultaneously exchanging water and materials with adjacent marine environments (Lewaru et al., 2024). Depending on tidal circulation, river discharge, salinity gradients, particle properties, and sediment dynamics, estuaries can function both as temporary sinks that retain microplastics and as conduits that transport them to the open sea (Malli et al., 2022; Wang et al., 2022). These transitional environments are therefore characterized by complex and highly variable microplastic transport, deposition, and resuspension processes (Rochman et al., 2015; Utami, 2022).

Previous investigations in Indonesian estuaries have demonstrated substantial spatial variation in microplastic characteristics. In Benoa Bay, Bali, Suteja et al. (2021) identified microplastics predominantly within the 500–1,000 μm size range. The particles were primarily fragments (73%) and foam particles (17%), while polystyrene, polyethylene (PE), and polypropylene (PP) were among the dominant polymers. In contrast, Firdaus et al. (2020) reported that microplastics in sediments from the Jagir River estuary and adjacent coastal waters in Surabaya were dominated by fibers (57%) and films (36%). The principal polymers were polyester (56.7%), PE (24.6%), and PP (18.8%). Although these studies examined different environmental matrices and applied site-specific sampling procedures, their findings indicate that microplastic morphology and polymer composition are strongly associated with surrounding domestic, residential, commercial, and industrial activities, as well as local hydrodynamic conditions.

Although the number of studies on plastic pollution in Indonesia has increased considerably, their geographical coverage and methodological approaches remain uneven (Vriend et al., 2021). Research has been concentrated largely in western and central Indonesia, whereas eastern Indonesia, including Southeast Sulawesi Province, remains comparatively understudied. The geomorphology of Southeast Sulawesi is dominated by bays, estuaries, and river networks that interact directly with rapidly developing coastal urban areas. Kendari Bay is one of the most important coastal ecosystems in the province. It functions as an environmental buffer, supports urban mangrove habitats, and serves as a major corridor for the socioeconomic activities of Kendari City (Ningsi et al., 2019).

Kendari Bay has experienced substantial environmental pressure associated with urban development, sedimentation, and the accumulation of solid waste, including macroplastic debris. Plastic debris retained in the bay may undergo photodegradation, weathering, abrasion, and mechanical fragmentation, thereby generating secondary microplastics. The semi-enclosed configuration of the bay may further increase particle residence time and facilitate the accumulation of floating or suspended materials, although the magnitude of this process depends on local circulation, tidal exchange, and freshwater discharge.

The Wanggu River is one of the principal rivers flowing into Kendari Bay. It passes through densely populated areas and receives waste generated by urban and domestic activities. Accordingly, the river is considered a potentially important pathway for land-based pollutants entering the inner bay, rather than being assumed to contribute the majority of the pollution without quantitative evidence. In contrast, the mouth of Kendari Bay represents the principal connection between the bay and the open sea (BAPPEDA, 2022). The brackish-water zone formed by the mixing of freshwater from the Wanggu River and seawater may influence the suspension, aggregation, deposition, and subsequent transport of microplastic particles (Malli et al., 2022; Wang et al., 2022).

Previous studies have already documented microplastic contamination in selected parts of Kendari Bay. Sudia et al. (2020) examined microplastics in water and sediment from the Punggaloba, Lahundape, and Wanggu estuaries, whereas Layn et al. (2020) investigated their distribution in bay sediments. Muhsin et al. (2021) further reported microplastics in sediments and aquatic organisms collected from residential and port areas. Therefore, the research gap is not the complete absence of microplastic data for Kendari Bay. Rather, existing evidence remains fragmented across specific estuaries, sediments, and biota, and an integrated assessment of microplastic concentrations and physical characteristics in the brackish-water column along the Wanggu River–bay mouth continuum remains limited. Differences in population density, consumption patterns, waste-management practices, and coastal activities may also produce spatially distinct microplastic profiles that have not been adequately characterized.

This study was based on the hypothesis that microplastic concentrations would be higher in waters directly influenced by the Wanggu River than near the mouth of Kendari Bay because of greater exposure to land-based anthropogenic inputs. Particle morphology, size, and color were also expected to vary spatially as a result of differences in potential sources and hydrodynamic sorting. Accordingly, this study aimed to: (1) quantify microplastic concentrations in the brackish-water column of Kendari Bay; (2) characterize the particles according to morphology, size, and color; and (3) determine their spatial distribution from the Wanggu River-influenced zone to the mouth of Kendari Bay. The findings are expected to provide baseline evidence for environmental monitoring, pollution-source assessment, and the development of plastic-waste management strategies in Kendari Bay.

METHOD

Study Area and Sampling Period

This study was conducted in October 2025 in Kendari Bay, Southeast Sulawesi, Indonesia. Water and sediment samples were collected from the estuarine section of Kendari Bay. Laboratory analyses were performed at the Laboratory of the Faculty of Mathematics and Natural Sciences, Halu Oleo University, Kendari.

Sampling locations were selected using a purposive sampling approach. The study area comprised three stations with distinct environmental characteristics. At each station, three biological replicates and three technical replicates were collected, yielding a total of 18 samples, consisting of nine surface-water samples and nine sediment samples. The three sampling stations represented: (1) a port and shipping activity zone affected by vessel operations, (2) waters adjacent to a residential area, and (3) a mangrove–estuarine area. The geographical coordinates of each sampling point were recorded using a Global Positioning System (GPS) and are presented in Figure 1.

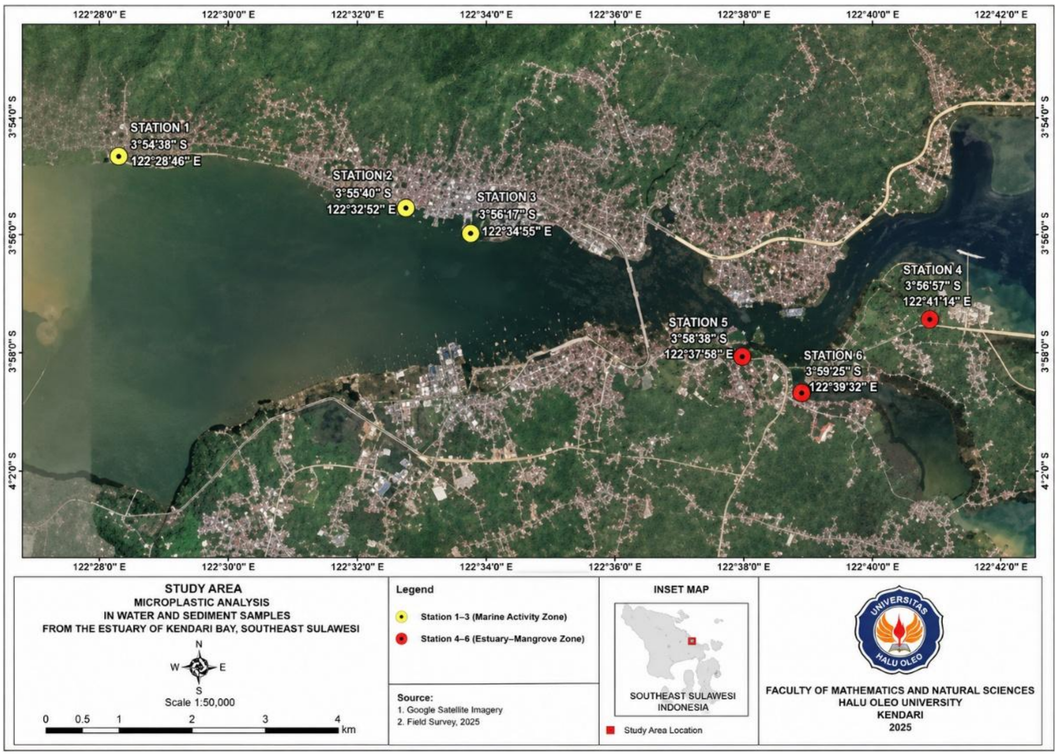

Figure 1. Study area

Water and Sediment Sampling

Before sample collection, environmental parameters were measured at each sampling station. Surface brackish-water samples were collected using a plankton net with a diameter of 30 cm and a mesh size of 300 µm. A total volume of 300 mL was collected for each water sample (Wijaya, 2024).

Sediment samples were collected from the bottom substrate at a depth of approximately 20 cm. Approximately 300 g of sediment was collected from each sampling point. The samples were wrapped in aluminum foil, placed in a cool box, and transported to the laboratory for further analysis.

Microplastic Extraction and Identification

Microplastic analysis of the water samples was conducted through five principal stages: initial filtration, organic-matter digestion, density separation, final filtration, and microscopic identification. Initially, the water samples were filtered using Whatman No. 42 filter paper with a pore size of 2.5 µm. Organic matter was subsequently degraded through oxidation by adding 20 mL of 30% H_2O_2 and heating the mixture on a hotplate stirrer at 60–75°C for 15 min (Masura et al., 2015).

For density separation, 6 g of NaCl was added to every 20 mL of sample solution. The mixture was stirred for 2 min (Masura et al., 2015) and then covered with aluminum foil and allowed to settle for 2 h, enabling microplastic particles to float to the surface. The supernatant, representing the upper layer, was subsequently filtered using

Whatman No. 42 filter paper. The filter paper was placed in a Petri dish, dried, and examined under a stereomicroscope for microplastic identification.

Sediment samples were collected from three replicate points using a shovel at a depth of approximately 20 cm (Sari et al., 2015). Approximately 300 g of sediment from each sampling point was wrapped in aluminum foil, placed in a zip-lock bag, and stored in a cool box before laboratory analysis. In the laboratory, the sediment samples were oven-dried at 60°C for 24 h (Peng et al., 2017). Aggregated samples were gently ground using a mortar and subsequently sieved using a sieve shaker to separate particles according to size (Widiyanto et al., 2025).

A 50-g sediment subsample was then mixed with saturated NaCl solution at a sediment-to-solution ratio of 3:1. The mixture was stirred for 10 min and allowed to settle for 2 h (Tsering et al., 2022). The resulting supernatant was filtered using Whatman No. 42 filter paper. The retained material was subsequently digested with 20 mL of 30% H_2O_2 in an oven at 60°C for 24 h. Finally, the sample was filtered again using Whatman No. 42 filter paper, dried, and examined under a stereomicroscope.

Data Analysis

Microplastic data were analyzed descriptively based on abundance, shape, size, color, and relative composition. Microplastic abundance was expressed as the number of particles per unit volume of water (particles mL^{-1}) or per unit mass of sediment (particles g^{-1}), following Sutanhaji et al. (2021):

$$\mathbf{K} = \frac{\mathbf{N}}{\mathbf{V}}$$

Note:
K = microplastic abundance (particles mL^{-1} or particles g^{-1});
N = number of microplastic particles; and
V = volume of the water sample or mass of the sediment sample analyzed.

Relative abundance was calculated as the proportion of each microplastic type relative to the total number of microplastic particles:

$$\text{Relative abundance (\%)} = \frac{\text{Number of particles of a given type}}{\text{Total number of microplastic particle}}\ x\ 100$$

The data were presented in tables and graphical formats to illustrate spatial variations among the sampling locations.

RESULTS AND DISCUSSION

Microplastic Morphology

Laboratory observations of samples collected from the Kendari Bay estuary identified four major microplastic morphologies: fibers, films, fragments, and foam particles (Figure 2). All four morphological categories were detected at every sampling location in both brackish-water and sediment samples. Foam particles were the most abundant category, followed by fibers, fragments, and films.

The term “foam” is used here as a morphological category. Confirmation that these particles consist of expanded polystyrene or another foamed polymer requires spectroscopic identification, such as Fourier-transform infrared or Raman spectroscopy.

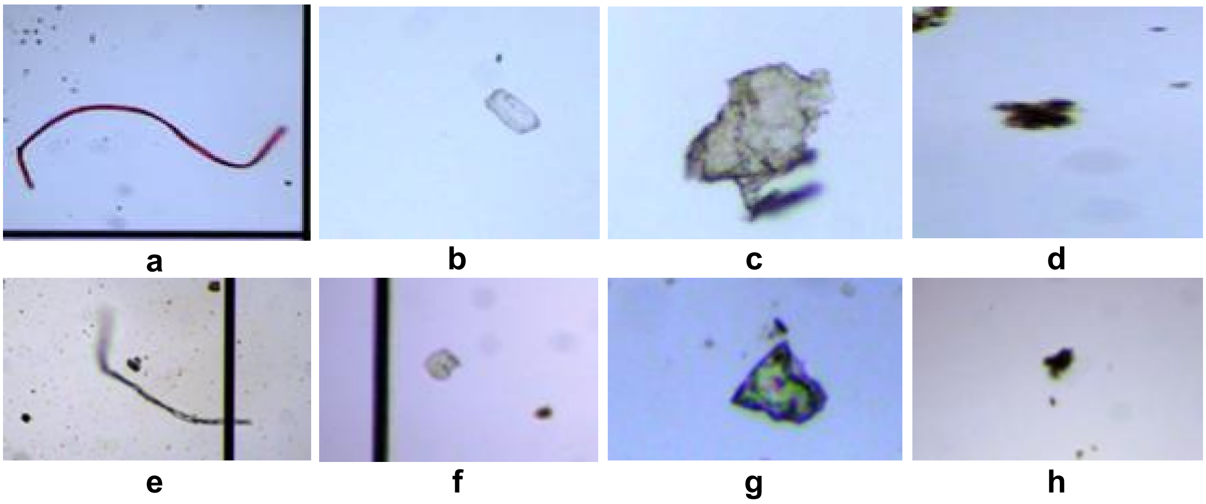

Figure 2. Microplastic morphologies observed in the study area (Microplastics in brackish-water samples: (a) fiber, (b) film, (c) fragment, and (d) foam; Microplastics in sediment samples: (e) fiber, (f) film, (g) fragment, (h) foam)

Microplastic Color Characteristics

Microplastics collected from the Kendari Bay estuary exhibited five predominant colors: black (37%), transparent (31%), yellow (13%), green (13%), and blue (6%), as shown in Figure 3. Overall, black particles were the most prevalent, followed by transparent, yellow, green, and blue particles.

Particle color was determined visually and should therefore be interpreted as a descriptive characteristic rather than direct evidence of polymer type, source, weathering stage, or contaminant content.

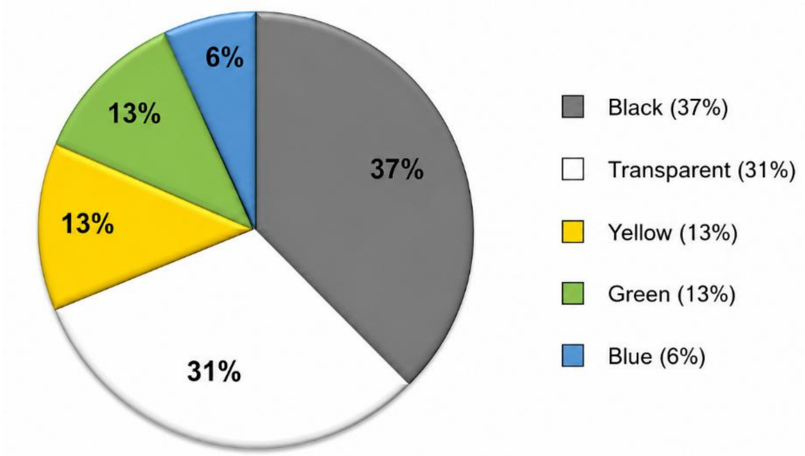

Figure 3. Percentage distribution of microplastic particle colors in the Kendari Bay estuary

Microplastic Size Distribution

Microplastic sizes varied among the sampling locations and morphological categories. In the brackish-water samples, fibers collected from the three sampling locations ranged from 0.19038 to 0.20805 mm. Films ranged from 0.04602 to 0.06241 mm, fragments measured 0.04681 mm, and foam particles ranged from 0.01840 to 0.02658 mm.

In the sediment samples, fibers ranged from 0.22726 to 0.23336 mm, films from 0.03937 to 0.05977 mm, fragments from 0.04921 to 0.05278 mm, and foam particles from 0.01061 to 0.02220 mm. Overall, fibers consistently represented the largest particles, whereas foam particles were the smallest in both brackish-water and sediment samples.

Because the smallest reported particle was approximately 0.01061 mm, or 10.61 µm, the analytical detection limit, measurement uncertainty, and polymer-confirmation procedure should be reported in the Methods section. These details are essential for evaluating the reliability and reproducibility of the size measurements.

Microplastic Abundance

Microplastic abundance varied among the three sampling locations (Figure 4 and 5). The highest numerical abundance was recorded at the Kendari Bay mouth, followed by the mangrove forest and residential locations. At the bay-mouth station, microplastic abundance was 11,460 particles/150 mL of brackish water and 83 particles/g of sediment. The mangrove station contained 10,620 particles/150 mL of brackish water and 77 particles/g of sediment, whereas the residential station contained 10,200 particles/150 mL of brackish water and 68.4 particles/g of sediment.

The sum of the station-level values was 32,280 particles across three 150-mL brackish-water samples, representing a total sampled volume of 450 mL. This value corresponds to an arithmetic mean of 10,760 particles/150 mL across the three locations. The combined value should not be reported as 32,280 particles/150 mL because the denominator would not represent the total volume analyzed.

Morphological analysis identified fibers, films, fragments, and foam particles. Foam particles were numerically more abundant than the other morphological categories. At the Kendari Bay mouth, foam abundance reached 5,280 particles/150 mL of brackish water and 39.6 particles/g of sediment. A similarly high abundance of foam particles was observed at the residential station, whereas the mangrove station had the lowest foam abundance.

Because no inferential statistical results were provided, differences among locations and morphological categories are described as numerical patterns and should not be interpreted as statistically significant. If replicate data are available, appropriate statistical analyses should be reported together with measures of variability, such as the mean ± standard deviation, confidence intervals, test statistics, and p-values.

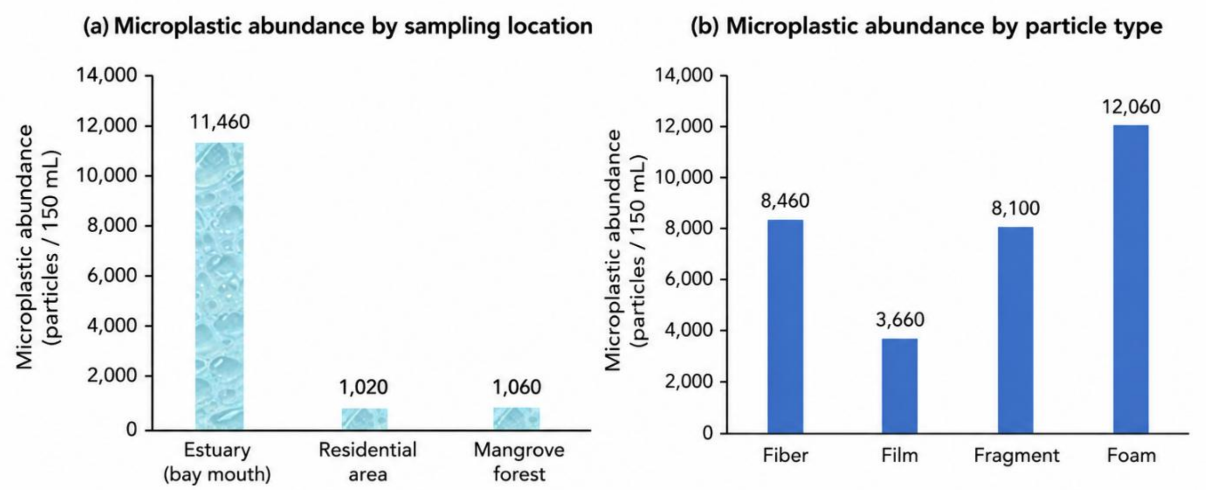

Figure 4. Microplastic abundance in brackish water in the Kendari Bay estuary: (a) abundance by sampling location; (b) abundance by microplastic type

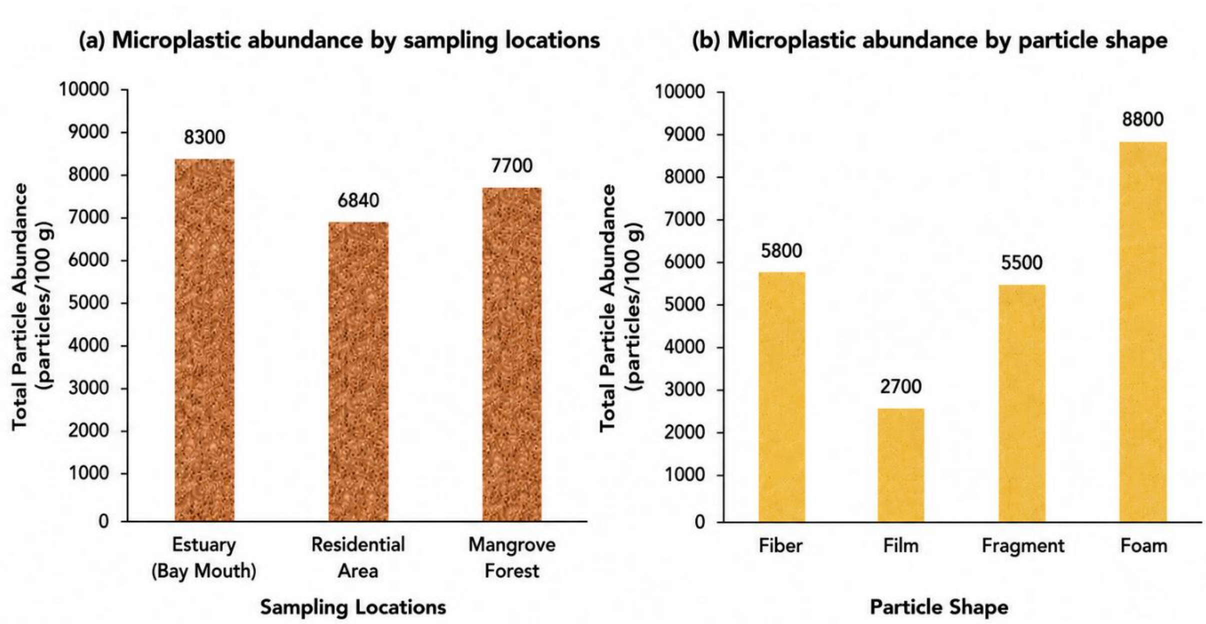

Figure 5. Microplastic abundance in sediments from the Kendari Bay estuary: (a) abundance by sampling location; (b) abundance by microplastic type.

Overall, the findings demonstrate spatial variation in microplastic morphology, color, size, and abundance across the sampling locations. These patterns may reflect differences in plastic sources, environmental degradation, hydrodynamic transport, and particle-retention processes within Kendari Bay.

The predominance of foam-shaped particles may be associated with the widespread use and disposal of foamed plastic products in domestic, fishing, and aquaculture activities. Expanded polystyrene (EPS) is commonly used in food packaging, cooling boxes, insulation materials, and fishing equipment such as floats and buoys. Its low density and high buoyancy enable it to remain near the water surface and be transported by wind, tides, and surface currents. In addition, the weak cellular structure of EPS makes it susceptible to physical abrasion and photodegradation. Prolonged exposure to ultraviolet radiation, wave action, and mechanical stress can fragment larger foam debris into smaller secondary microplastics (Song et al., 2017; Lee et al., 2023; Kuroda et al., 2024).

However, foam was identified only as a morphological category in the present study. Therefore, its classification as EPS or another foamed polymer should be confirmed using Fourier-transform infrared (FTIR) or Raman spectroscopy. Without polymer confirmation, the association between foam particles and EPS should be interpreted as a plausible explanation rather than definitive evidence of their material composition or source.

The occurrence of fragment-shaped particles may also indicate the progressive breakdown of larger and more rigid plastic materials. Exposure to sunlight, temperature fluctuations, wave action, and abrasion against sediment can weaken plastic surfaces and promote fragmentation. Similar degradation processes have been reported in coastal and estuarine environments, where prolonged environmental exposure produces increasingly smaller secondary microplastics (Y. Zhang et al., 2020; Kusniat et al., 2025). Therefore, the coexistence of foam, films, fibers, and fragments in Kendari Bay suggests contributions from multiple plastic sources and degradation pathways.

Black and transparent particles were the dominant color categories. Black particles were mainly associated with fibers and foam, whereas transparent particles were commonly observed among films and fibers. Particle color may reflect the original pigments and additives used during manufacturing, subsequent discoloration, biofilm formation, or exposure to environmental contaminants. Previous studies have also reported high proportions of black and transparent microplastics in coastal and aquaculture environments (W. Zhang et al., 2024; Kusniat et al., 2025).

Nevertheless, color alone cannot be used to identify polymer type, contamination level, degradation stage, or ecological toxicity. Although Massos and Turner (2017) detected metals and brominated compounds in some colored environmental microplastics, their presence depends on polymer composition, additives, weathering history, and surrounding environmental conditions. Consequently, the black particles observed in Kendari Bay should not automatically be considered more contaminated than particles of other colors without direct chemical analysis.

Differences in particle size among morphological types and environmental matrices may be related to their mechanical properties and environmental behavior. Fibers were consistently larger than the other particle types, whereas foam particles were the smallest in both brackish-water and sediment samples. The relatively small size of foam and film particles may reflect their low mechanical strength and greater susceptibility to fragmentation. Experimental studies have shown that ultraviolet exposure followed by mechanical abrasion can substantially increase plastic fragmentation, although the rate of degradation varies among polymer types (Song et al., 2017).

The presence of smaller particles in sediment may also result from aggregation, biofouling, and deposition. Initially buoyant particles can become denser after being colonized by microorganisms or attached to organic matter and mineral particles, causing them to settle. Sediment grain size, water movement, and local depositional conditions may further influence their accumulation. However, particle size alone cannot determine environmental age or residence time. Polymer identity, surface oxidation, biofilm development, and local hydrodynamic conditions should also be examined before conclusions are drawn regarding the degree of degradation.

Microplastic abundance was numerically highest at the bay-mouth station, followed by the mangrove and residential stations. The bay mouth may function as a convergence zone where materials transported by terrestrial runoff, urban drainage, river discharge, tides, and seawater circulation accumulate. Estuarine environments commonly receive pollutants from both terrestrial and marine sources, and their transitional hydrodynamic conditions may promote temporary retention or redistribution of suspended particles (Di et al., 2024). Thus, the high abundance observed at the bay mouth likely reflects the combined effects of source proximity, water circulation, and particle-retention processes rather than a single pollution source.

The lower microplastic abundance in brackish water at the mangrove station may be related to the interception capacity of mangrove vegetation. Complex root systems reduce water velocity and trap suspended particles and fine sediments. Liu et al. (2022) demonstrated that mangrove systems can intercept microplastics transported between riverine and coastal environments. However, a lower abundance in the water column does not necessarily indicate a lower total microplastic burden. Mangroves may transfer particles from the water column into root-associated sediments and consequently act as long-term accumulation zones. Assessment of both water and sediment is therefore necessary to determine the overall role of mangroves in microplastic retention.

The relatively lower abundance recorded at the residential station may be influenced by local coastal structures, waste-disposal practices, current velocity, and sedimentation patterns. Bridges, seawalls, and breakwaters can alter water circulation and particle transport. However, their influence cannot be confirmed solely from abundance data. Hydrodynamic measurements, tidal observations, sediment characteristics, and information on local waste inputs would be required to determine whether artificial structures enhance or restrict microplastic retention.

The high proportion of foam particles indicates substantial inputs of lightweight foamed plastic debris. Their buoyancy allows them to remain in surface waters before weathering, biofouling, or aggregation causes vertical redistribution. Kuroda et al. (2024) similarly reported that floating polystyrene foam debris is strongly influenced by surface transport processes. Salinity may also affect particle aggregation by altering electrostatic interactions among microplastics, clay minerals, dissolved organic matter, and suspended particles (Yang et al., 2022). Nevertheless, the present data do not independently demonstrate a salinity effect. Such a relationship should only be claimed when supported by station-specific salinity measurements and appropriate statistical analysis.

The abundance of small microplastics in both water and sediment indicates potential exposure pathways for aquatic organisms. Buoyant particles may be available to plankton and fish larvae in the water column, whereas deposited particles may be ingested by benthic and deposit-feeding organisms. Experimental studies have demonstrated microplastic ingestion by zooplankton and transfer between planktonic trophic levels (Cole et al., 2013; Setälä et al., 2014). Microplastics have also been detected in wild fish larvae, indicating that early life stages may be exposed under natural environmental conditions (Steer et al., 2017).

Smaller particles have a higher surface-area-to-volume ratio than larger particles of the same material, potentially increasing their interactions with dissolved pollutants, metals, microorganisms, and biological tissues. Weathering may further modify surface roughness and chemical properties, thereby affecting contaminant sorption. Rochman et al. (2013) demonstrated experimentally that chemicals associated with ingested plastics can be transferred to fish and induce physiological stress. Nevertheless, the magnitude and direction of chemical transfer in natural environments depend on polymer type, contaminant concentration, water chemistry, sediment conditions, and biological factors.

Therefore, the present findings indicate potential ecological exposure but do not demonstrate adverse biological effects in Kendari Bay. Direct analyses of plankton, benthic organisms, shellfish, and fish are required to evaluate ingestion, tissue accumulation, trophic transfer, and biological responses. Chemical analyses are also necessary to determine whether the observed particles contain or carry metals, organic contaminants, additives, or potentially pathogenic microorganisms.

The findings highlight the need for improved plastic-waste management in coastal settlements, drainage systems, river catchments, fishing areas, and aquaculture facilities surrounding Kendari Bay. Management priorities should include reducing the use and uncontrolled disposal of EPS-based products, improving waste collection, installing litter-retention systems in drainage channels, and establishing recovery programs for damaged fishing floats and buoys.

Future monitoring should combine visual identification with FTIR or Raman spectroscopy to confirm polymer composition. Studies should also report procedural blanks, recovery tests, detection limits, replicate variability, sediment characteristics, salinity, tidal conditions, and statistical comparisons among locations. Integrating source reduction, polymer-specific monitoring, hydrodynamic assessment, and biological evaluation will provide a stronger basis for reducing secondary microplastic formation and assessing long-term ecological risks in Kendari Bay.

CONCLUSION

Microplastics were detected in brackish water and sediment from the Kendari Bay estuary in four forms: fibers, films, fragments, and foams. Foam was the dominant type, while black (37%) and transparent (31%) were the most common colors. Fibers had the largest particle size, reaching 0.233 mm, whereas foam particles were the smallest, with a minimum size of 0.010 mm. The predominance of small foam particles suggests substantial degradation of expanded polystyrene waste from domestic, fishing, and coastal activities.

Microplastic abundance varied spatially, with the highest levels recorded in the estuarine port zone at 11,460 particles per 150 mL of water and 83 particles per gram of sediment. Lower concentrations in the mangrove zone may reflect the ability of mangrove roots to trap suspended particles. The high abundance of small foam particles (<0.02 mm) indicates a potential ecological risk because these particles may be ingested by aquatic organisms and may adsorb organic pollutants and heavy metals. These findings highlight the need to strengthen plastic-waste management and reduce the use and disposal of EPS-based materials in the Kendari Bay watershed and coastal areas.

RECOMMENDATION

Based on these findings, targeted management strategies are recommended to reduce microplastic inputs into the Kendari Bay estuary, particularly by controlling EPS waste generated by households, fisheries, and coastal activities. Strengthening waste-management systems in the estuarine zone and promoting environmentally sustainable alternatives to single-use polystyrene products are essential measures.

Future studies should integrate polymer identification and contaminant-adsorption analyses to provide a more comprehensive assessment of the toxicological implications of microplastics in this region. Investigations involving biotic exposure and trophic transfer are also necessary to evaluate the long-term ecological risks associated with microplastic accumulation in coastal and estuarine ecosystems.

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