



Journal of Marine Biotechnology and Immunology

Journal homepage : <https://ejournal.immunolmarbiotech.com>



Microplastic Abundance in Water and Sediments in the Opak River Estuary, Bantul, Special Region of Yogyakarta

Muhammad Pranardho Nataruma, Bambang Yulianto*, Wilis Ari Setyati

Department of Marine Science, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Jl. Prof. Jacob Rais, Tembalang, Semarang 50275, Central Java, Indonesia.

Abstract

Microplastic pollution in estuarine environments has attracted growing attention due to the persistence, widespread distribution, and potential ecological impacts of plastic particles. This study aimed to assess the abundance and characteristics of microplastics in water and sediment at the Opak River Estuary, Bantul Regency, Special Region of Yogyakarta, Indonesia. Sampling was conducted at five stations representing different environmental gradients under ebb and flood tide conditions. Water and surface sediment samples were analyzed using particle-based approaches. Microplastics were extracted through organic matter removal, density separation, and filtration, and subsequently identified based on shape, size, and color. Microplastics were detected in all water and sediment samples. Mean microplastic abundances were 1,221.6 particles/kg in sediment and 39.8 particles/L in water. In the water samples, mean microplastic abundance was higher under the sampled flood condition (56.4 particles/L) than under the sampled ebb condition (25 particles/L); this difference describes the sampling observations and does not establish a consistent tidal pattern. Fragments were the dominant shape in both water and sediment, while black was the most frequently observed color.



Article Info

Received: August 26, 2026
Accepted: September 23, 2026
Published: September 30, 2026
Available online: September 30, 2026

Keywords:

Ebb and Flood Tide
Estuary
Microplastics
Sediment
Water

Corresponding Author email:

* bambang.yulianto@live.undip.ac.id

This is an open access article under the
CC BY-NC-SA license
(<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

Copyright ©2026 Journal of Marine Biotechnology and Immunology.

1. Introduction

Plastic pollution has become one of the most pressing environmental problems worldwide because synthetic polymers are produced and consumed on a massive scale and resist natural degradation. In marine environments, larger plastic materials gradually fragment through physical abrasion, photodegradation, and biological activity, producing microplastics generally defined as particles smaller than 5 mm (Thompson et al., 2004). Due to their persistence and widespread occurrence, microplastics are increasingly considered emerging contaminants that may adversely affect aquatic organisms and ecosystem health (Li et al., 2023). A substantial proportion of plastic waste entering coastal and marine ecosystems is transported from terrestrial sources through riverine systems, making rivers an important pathway for land-based plastic pollution (United Nations Environment Programme, 2021).

Microplastics are easily transported within aquatic systems because of their small particle size and low density. As a result, these particles can accumulate in both the water column and sediments, where they may persist for extended periods. Ecological concerns associated with microplastics include not only their ingestion by aquatic organisms but also their ability to adsorb and transport toxic contaminants (Galgani et al., 2021). In estuarine environments, hydrodynamic conditions strongly affect microplastic distribution, including tidal currents, sediment deposition, and resuspension processes (Kumar et al., 2021). These conditions make estuaries important accumulation zones while simultaneously acting as pathways that transport microplastics toward adjacent coastal waters (Pan et al., 2021).

Previous research has documented microplastic contamination in the Opak River. Lestari et al. (2025) investigated microplastics in surface water and sediment at

may contribute to microplastic pollution, making the estuary vulnerable to microplastic accumulation and transport.

2.2 Sampling Design

Sampling was conducted at five stations (MP1–MP5) distributed along the estuary from near the estuary mouth toward the upstream estuarine section. Water and sediment samples were collected under two sampled tidal conditions, ebb and flood, to describe spatial differences and differences between the two sampling observations.

Ebb-condition sampling was conducted on 13 December 2025 between 08:00 and 11:00, following the station sequence MP1 → MP2 → MP3 → MP4 → MP5. Flood-condition sampling was conducted on the same date between 14:00 and 17:00, following the same station sequence. All times are reported in Western Indonesian Time (WIB, UTC+7). Water and sediment samples were collected on the same day, with water collected first at each station under each tidal condition.

One composite water sample and one composite sediment sample were collected at each station under each sampled tidal condition, yielding 10 water samples and 10 sediment samples in total. The five bucketfuls used to prepare each water sample and the three subsamples used to prepare each sediment sample were pooled components, not independent replicates. Thus, each station-tidal condition combination provided one sample per sample type.

six sampling points spanning the upstream, middle, and downstream reaches. Although this study established the occurrence and spatial distribution of microplastics along the river, it did not compare samples collected under ebb and flood conditions. It therefore leaves unresolved how particle abundance and characteristics in the estuarine water and sediment compare between observations made under these two tidal conditions.

Accordingly, this study aimed to compare microplastic particle abundance and characteristics, including shape, size, and color, in water and sediment across five stations in the Opak River Estuary under the two sampled tidal conditions, ebb and flood. The comparison was intended to describe differences observed during sampling rather than establish a consistent tidal pattern

2. Material and methods

The study was conducted from November 2025 to February 2026, with field sampling carried out in December 2025.

2.1 Study Area

This study was conducted in the Opak River Estuary, Bantul Regency, Special Region of Yogyakarta, Indonesia. The estuary is a dynamic transitional system influenced by both riverine and marine processes. In addition to natural dynamics, human activities such as agriculture, residential settlements, tourism, and small-scale industries

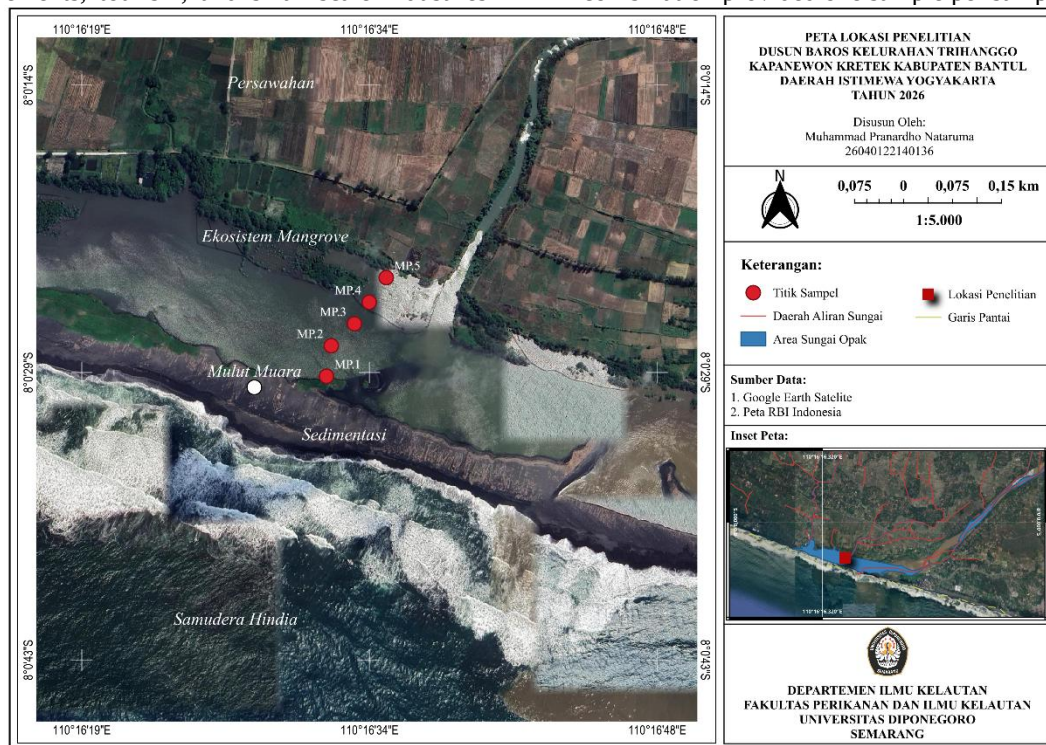


Figure 1. Map of the study area showing the Opak River Estuary in Bantul, Special Region of Yogyakarta, Indonesia, and the distribution of sampling stations (MP1–MP5) along the estuarine gradient.

Table 1. Geographic coordinates and site characteristics of sampling stations (MP1–MP5) along the Opak River Estuary.

Station	Latitude	Longitude	Description
MP1	8°0'28.99"S	110°16'31.45"E	Located on the right riverbank with sandy substrate and closer to the estuary mouth.
MP2	8°0'27.46"S	110°16'31.69"E	Sandy substrate with relatively strong currents, located near the estuary mouth.
MP3	8°0'26.36"S	110°16'32.85"E	Sandy substrate mixed with gravel and slight mud, located in the mid-channel.
MP4	8°0'25.28"S	110°16'33.59"E	Muddy substrate with an initial mangrove ecosystem and minor domestic waste.

2.3 Field Sampling

At each station under each sampled tidal condition, five bucketfuls of water were collected using a 10 L bucket and pooled into one composite sample with an approximate total volume of 50 L before filtration.

For sediment, three subsamples of approximately 150 g each were collected at each station under each sampled tidal condition from a depth of 0–20 cm using a metal digging tool. The sampling points were selected randomly and spaced approximately 2 m apart. The subsamples were pooled into one composite sediment sample of approximately 450 g and stored in a cool box prior to laboratory analysis.

2.4 Laboratory Analysis

Laboratory analysis began with sample preparation to separate microplastics from the water and sediment matrices. Water samples were concentrated by vacuum filtration, whereas 450 g sediment samples were oven-dried at 50°C to a constant weight and subjected to density separation using saturated NaCl solution. The sediment–solution mixture was stirred and allowed to settle, after which the microplastic-containing supernatant was collected and filtered (Masura et al., 2015). Material retained on the filters was digested using wet peroxide oxidation with 30% H₂O₂ at a controlled temperature of 60°C to remove organic matter, including biofilms, algae, and plant debris. Oxidation was terminated when bubbling ceased and the solution became clear. The samples were then rinsed with distilled water and oven-dried.

For microplastic shape visual analysis, particles were examined under a stereomicroscope, counted, and

classified as fragments, fibers, films, or pellets. Microplastic abundance was expressed as particles per liter (particles/L) for water and particles per kilogram of dry sediment (particles/kg) for sediment by dividing the number of particles by the filtered water volume or dry sediment mass, respectively (Masura et al., 2015).

2.5 Data Analysis

Microplastic abundance in water (particles/L) and sediment (particles/kg) was summarized descriptively for each sampling station. Microplastic shape, size, and color were also described for both sample types. Spatial patterns were assessed by examining differences among the five stations, while tidal differences were assessed by comparing the ebb and flood observations.

3. Results

3.1 Water Quality Conditions

Water Quality conditions varied among sampling stations and tidal conditions in the Opak River Estuary (Table 2). Temperature ranged from 30.3 to 36.5 °C during ebb tide and from 30.5 to 31.5 °C during flood tide. Salinity ranged from 2 to 4 ppt during ebb tide and from 2 to 5 ppt during flood tide, while pH ranged from 5.8 to 7.0 and from 6.2 to 6.5, respectively. Dissolved oxygen ranged from 1.5 to 6.6 mg/L during ebb tide and from 8.2 to 12 mg/L during flood tide. Salinity was relatively low (brackish water) and did not increase consistently toward the estuary mouth under either tidal condition.

Table 1. Water Quality parameters measured at each sampling station in the Opak River Estuary.

Station	Temperature (°C)		Salinity (ppt)		pH		DO (mg/L)	
	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood
MP1	30.3	31	3	3	7	6.5	1.5	9
MP2	30.5	30.5	4	3	6	6.3	3.6	12
MP3	31	31	4	2	6.1	6.3	4.8	11
MP4	36.5	31.3	3	2	5.8	6.3	5.2	10
MP5	33.8	31.5	2	5	6	6.2	6.6	8.2

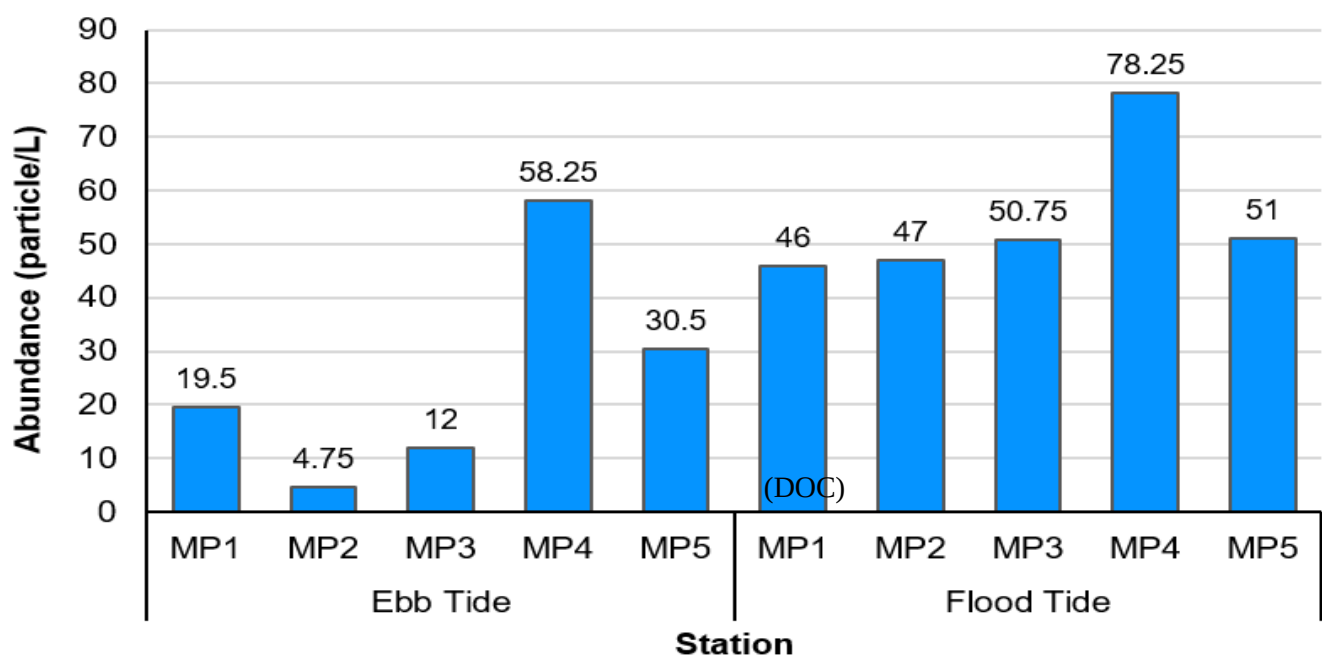


Figure 2. Microplastic abundance in water samples (particles/L) at each sampling station under different tidal conditions in the Opak River Estuary.

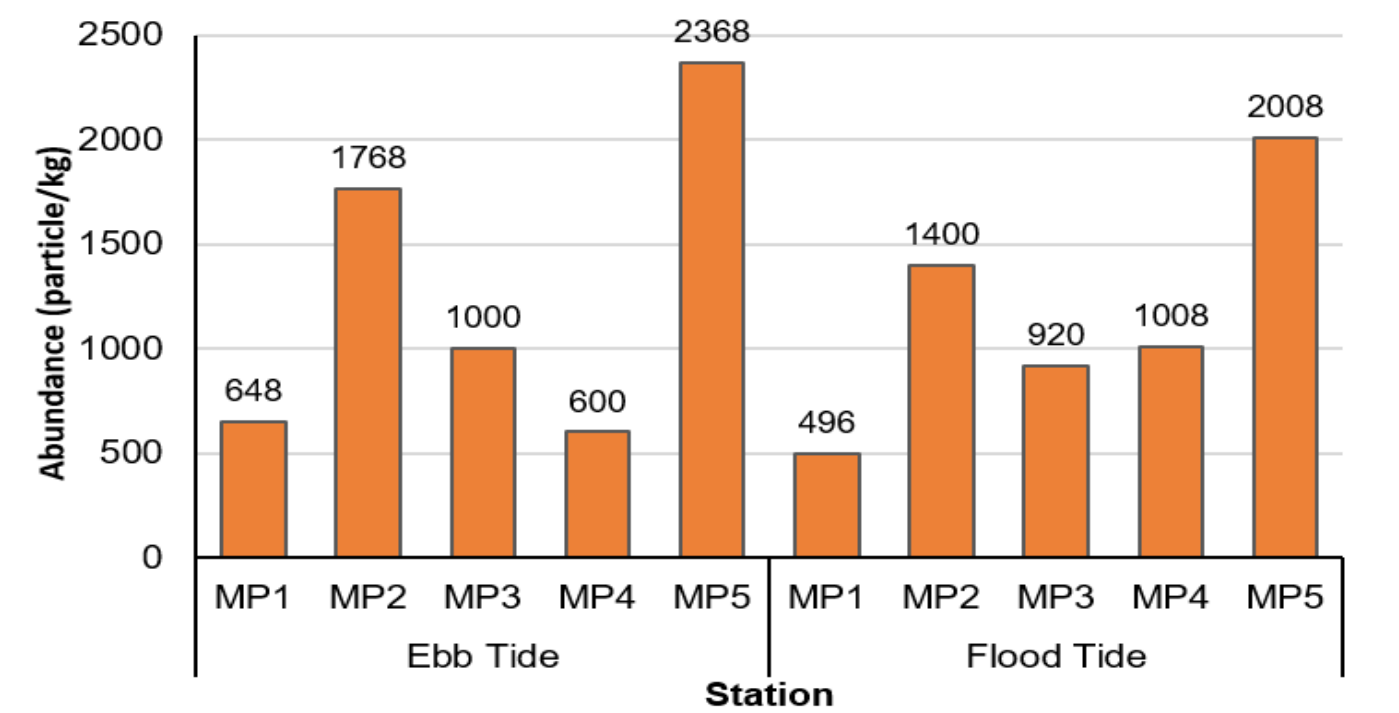


Figure 3. Microplastic abundance in sediment samples (particles/kg) at each sampling station in the Opak River Estuary.

3.2 Microplastic Abundance in Water and Sediment

Microplastics were detected at all sampling stations in both water and sediment compartments (Figure 2 and Figure 3). The average abundance of microplastics was in water (ebb tide = 25 particles/L, flood tide = 54.6 particles/L, and ebb and flood tide = 39.8 particles/L) and in sediment (ebb tide = 1276.8 particles/kg, flood tide = 1166.4 particles/kg, and ebb and flood tide = 1221.6 particles/L). The highest microplastic abundance in estuarine water was recorded at station MP4 (5.25 and 78.25 particles/L), while the highest abundance in sediment was at stations MP2 (1768

and 2368 particles/L at ebb and flood tide) and MP5 (1400 and 2008 particles/L at ebb and flood tide).

3.3 Microplastic Characteristics

3.3.1 Shape

Four microplastic shapes were identified in the water and sediment samples: fragments, fibers, films, and pellets (Figures 4 and 5). Fragments were the most abundant shape in both sample types, potentially reflecting the breakdown (fragmented) of larger plastic items used in household, automotive, and construction applications.

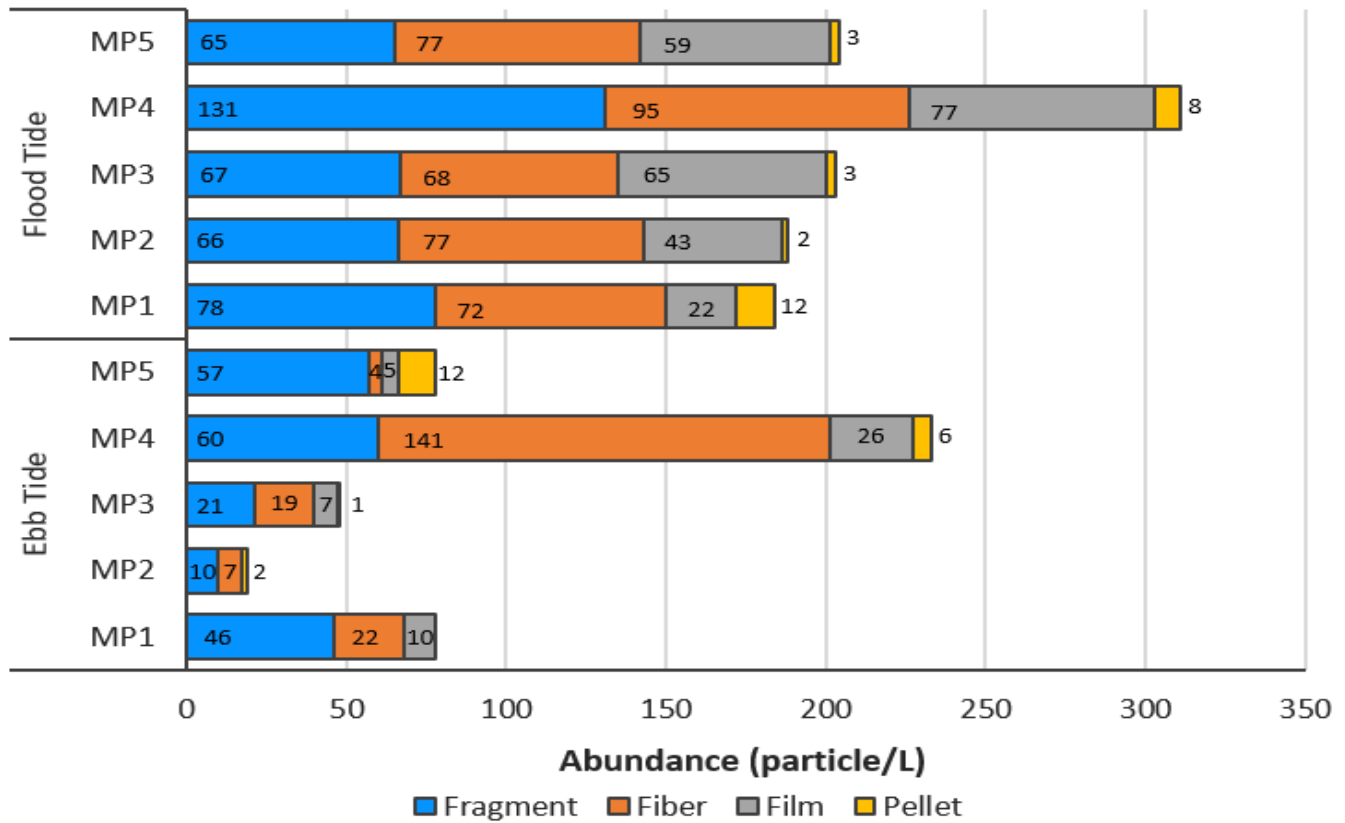


Figure 4. Distribution of microplastic shapes in water samples, including fragments, fibers, films, and pellets.

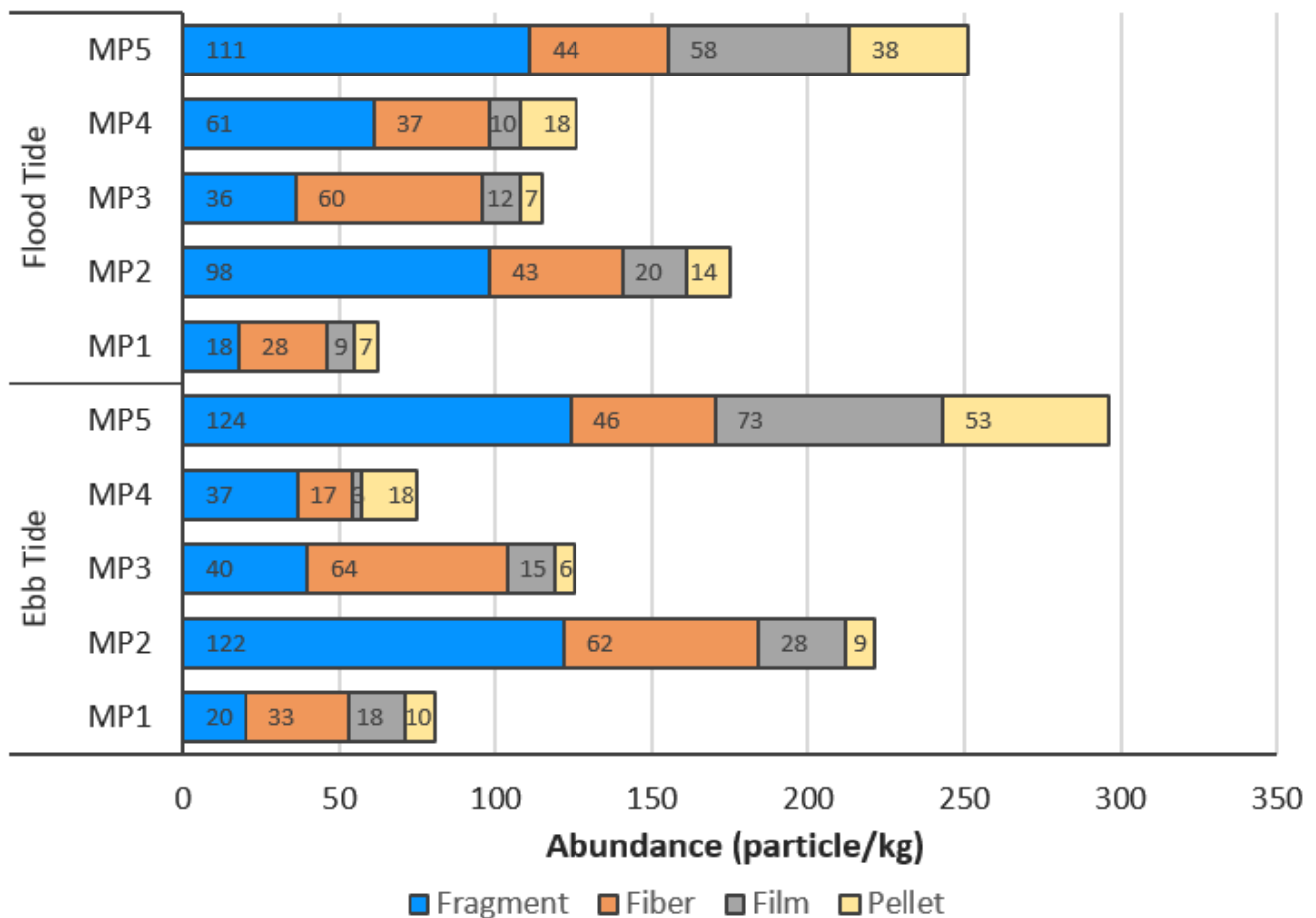


Figure 5. Distribution of microplastic shapes in sediment samples, showing the dominance of fragment-type particles

3.3.2 Size

Particle dimensions varied across shapes and between water and sediment samples (Table 3). Fibers showed the greatest maximum dimension, reaching 4,524.0

μm in water, consistent with their elongated shape, whereas pellets generally had smaller measured dimensions than the other shapes.

3.3.3 Color

Microplastics exhibited a wide range of colors, including black, white, blue, green, yellow, red, brown, and

Nataruma et. al., 2026. *Microplastic Abundance in.....* transparent (Figure 6). Black was the dominant color in both water (37.22%) and sediment (38.12%).

Table 2. Particle dimensions by shape and compartment of microplastics in water and sediment samples at the Opak River Estuary

Compartment	Condition	Type	Min (µm)	Max (µm)
Water	Ebb	Fragment	60.7	519.3
		Fiber	208.6	4524.0
		Film	87.5	804.7
		Pellet	60.0	240.0
	Flood	Fragment	67.6	1048.0
		Fiber	78.0	2599.5
		Film	66.6	738.7
		Pellet	54.6	169.9
Sediment	Ebb	Fragment	76.6	727.6
		Fiber	89.1	2484.2
		Film	119.7	943.5
		Pellet	56.4	312.4
	Flood	Fragment	62.2	1165.6
		Fiber	51.5	2350.1
		Film	56.2	420.5
		Pellet	48.6	94.6

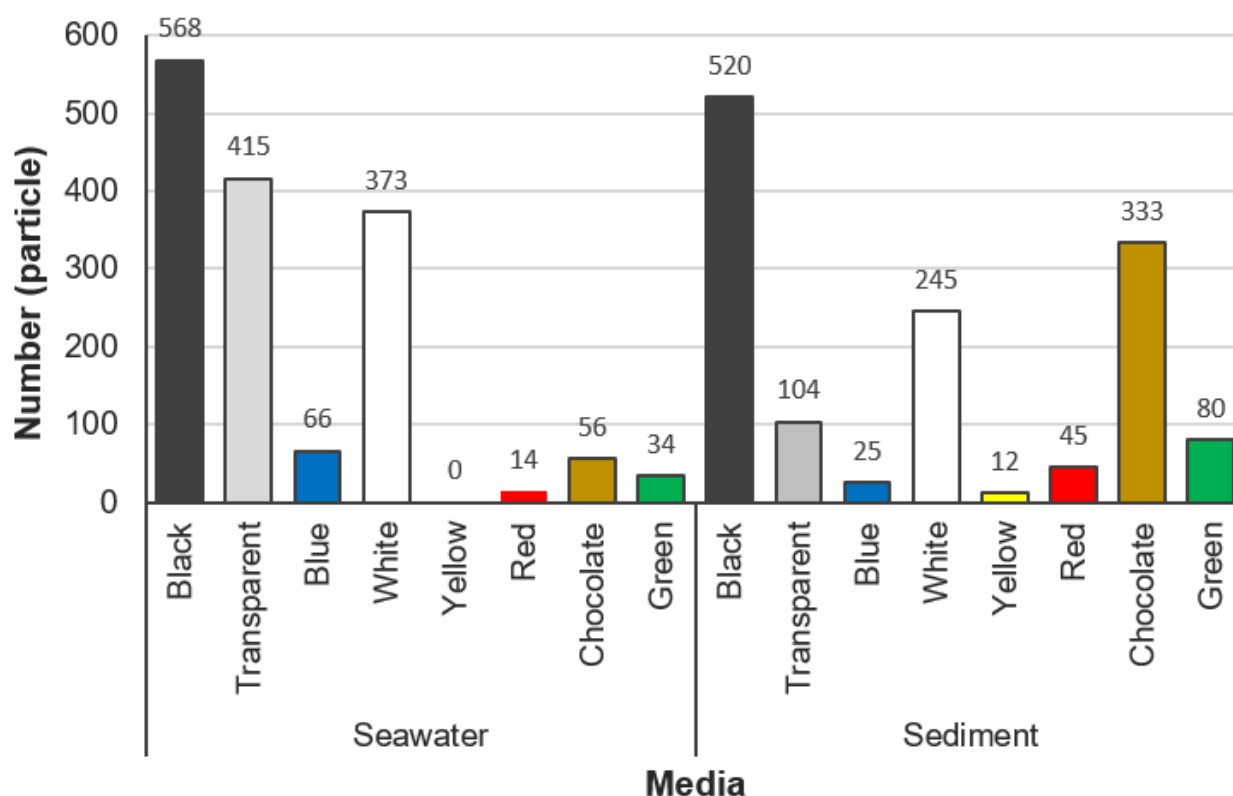


Figure 6. Color composition of microplastics in water and sediment samples, highlighting the predominance of black-colored particles.

4. Discussion

Microplastic-like particles were observed in water and sediment at all five sampling stations in the Opak River Estuary. Mean waterborne abundance was 25.0 particles/L during ebb tide and 54.6 particles/L during flood tide, while mean sediment abundance was 1,276.8 and 1,166.4 particles/kg dry weight, respectively. A previous study of the Opak River reported 4.15–12.3 particles/L in surface water and 960–3,080 particles/kg dry sediment (Lestari et al.,

2025). Thus, the sediment values in the present study fall within the previously reported range, whereas the water values are higher. In the Tukad Badung River, Bali, Harmayani et al. (2025) reported 48.5–105.4 particles/L in water and approximately 225–589 particles/kg in sediment. These comparisons provide regional context, but differences in sampling location, sampled water depth, mesh size, and identification methods limit direct comparisons of pollution levels. The relatively higher abundance observed in sediments compared to water suggests that depositional

processes play a key role in controlling microplastic distribution (Galgani *et al.*, 2021). Under relatively low hydrodynamic conditions, particles tend to settle and accumulate within the sediment layer.

The spatial patterns differed between the two compartments. Waterborne abundance was highest at MP4 and MP5, whereas sediment abundance was highest at MP2 and MP5. The muddy substrate and mangrove habitat at MP4 and MP5 may contribute to local particle retention. However, the elevated sediment abundance at sandy MP2 indicates that substrate and current velocity alone do not explain the observed pattern. Local inputs and tidal redistribution may also contribute, although their individual effects were not tested in this study.

The dominance of fragment-shaped microplastics is consistent with a possible contribution from secondary microplastics formed through the breakdown of larger plastic debris (Li *et al.*, 2023). Fragment dominance was also reported by Lestari *et al.* (2025) in the Opak River and Harmayani *et al.* (2025) in the Tukad Badung River. This suggests that fragmentation processes such as mechanical abrasion, ultraviolet (UV) radiation, and chemical weathering play a significant role in shaping microplastic characteristics in estuarine environments (Payel *et al.*, 2025). Additionally, the presence of fibers suggests contributions from domestic wastewater and textile-related sources, which are commonly reported in urban-influenced aquatic systems (Miller *et al.*, 2020). Furthermore, the predominance of smaller particle sizes reflects advanced degradation stages, increasing their potential bioavailability and ecological risk.

The predominance of black particles may reflect the fragmentation of originally dark-colored plastic products, including black shopping bags commonly used by vendors in Indonesian markets and shops. Black-colored microplastics show relatively higher resistance to photodegradation than lighter-colored plastics (Han *et al.*, 2026). Black was the most frequently observed color in both water (37.22%) and sediment (38.12%) in this study. Lestari *et al.* (2025) also reported black as the dominant color in Opak River samples. However, particle color alone cannot establish their sources; these possibilities require further chemical characterization.

Particle dimensions in the present study varied substantially by shape and compartment. Fragments measured 60.7–1,048.0 μm in water and 62.2–1,165.6 μm in sediment, whereas fibers extended to 4,524.0 μm in water and 2,484.2 μm in sediment (Table 3). This broad variation is consistent with observations from other estuarine environments, although the ranges depend strongly on how dimensions are defined and which particles the sampling method retains. For example, Li *et al.* (2020) reported that more than 72% of particles in their Yangtze Estuary study were shorter than 1 mm in their longest dimension. Their finding describes a *size distribution*; Table 3 of the present study reports the shape, minimum, and maximum size of particles by shape, so it cannot yet support a claim that a particular size class predominated.

From a management perspective, these findings emphasize the importance of incorporating sediment analysis into microplastic monitoring programs, as water-based assessments alone may underestimate total pollution levels. In addition, monitoring microplastics in the Opak River Estuary and reducing land-based plastic inputs may help inform efforts to protect adjacent coastal ecosystems.

However, this study has several limitations; the absence of polymer identification limits the ability to determine specific sources and chemical characteristics of

Nataruma *et al.*, 2026. *Microplastic Abundance in.....* microplastics. Future research should incorporate long-term monitoring and advanced analytical techniques to provide a more comprehensive understanding of microplastic dynamics in estuarine environments. Overall, this study provides important baseline data for understanding microplastic behavior in tropical estuarine environments and supports future monitoring and mitigation efforts.

5. Conclusions

Microplastic particles were found in water and sediment at all five sampling stations in the Opak River Estuary. Mean abundance in water was 25.0 particles/L during ebb tide and 54.6 particles/L under the sampled ebb and flood conditions, respectively, while mean abundance in sediment was 1,276.8 and 1,166.4 particles/kg dry weight, respectively. Fragments were the most frequently observed shape, and black was the most common color in both sample types. Abundance varied among stations and between the sampled tidal conditions, although the present sampling design does not establish the causes of these differences. Further studies should include polymer identification, repeated sampling, and complementary particle- and mass-based measurements to better characterize microplastic sources and distribution in the estuary.

Ethics approval

No need.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author contributions

Muhammad Pranardho Nataruma: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing (original draft). Bambang Yulianto: Supervision, Validation, Writing (review and editing). Willis Ari Setyati: Supervision, Validation, Writing (review and editing).

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgments

The authors thank the Marine Science Laboratory, Faculty of Fisheries and Marine Science, Universitas Diponegoro, for providing facilities and technical support during laboratory analysis. Appreciation is extended to all individuals who assisted in field sampling and data collection.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Galgani, F., O'Brien, A.S., Weis, J., Ioakeimidis, C., Schuyler, Q., Makarenko, I., *et al.*, 2021. Are litter, plastic and microplastic quantities increasing in the ocean? *Microplastics and Nanoplastics* 1(1): 1–2. <https://doi.org/10.1186/s43591-020-00002-8>

- Han, Y., Zhang, Z., Liu, Z., Wei, H., Ding, R., Zhang, T., Wang, R., Liu, P., Jia, H. 2026. Color Hierarchy in Plastic Degradation: Why Darker Colorants Fail to Protect Polypropylene Straws from Photodegradation?. *ACS EST Water*, 6 (3): 1731–1740. <https://doi.org/10.1021/acsestwater.5c01264>
- Harmayani, K. D., Hadibarata, T., Kristanti, R.A., Dayanti, P.K.P.M., Satyawati, K.L., Wiratama, P.A.A., Suari, P.P.V. 2025. *Initial Indication of Microplastics in the Water and Sediment of the Tukad Badung River in Bali, Indonesia. Water, Air, & Soil Pollution*, 236:727. <https://doi.org/10.1007/s11270-025-08365-5>
- Kumar, R., Sharma, P., Verma, A., Jha, P.K., Singh, P., Gupta, P.K., et al., 2021. Effects of hydrodynamic conditions on microplastic transport and distribution in aquatic environments. *Water* 13(19), 2710. <https://doi.org/10.3390/w13192710>
- Lestari, P., Malau, A. R., & Kumalasari, N. 2025. *Occurrence and Distribution of Microplastics Pollution in Surface Water and Sediments of Opak River, Yogyakarta. Polish Journal of Environmental Studies*, 34(5): 5195–5201. <https://doi.org/10.15244/pjoes/190918>
- Li, W., Zu, B., Yang, Q., Guo, J., and Li, J., 2023. Sources, distribution, and environmental effects of microplastics in aquatic environments: A review. *RSC Advances* 13(23): 15566–15574. <https://doi.org/10.1039/D3RA02169F>
- Li, Y., Lu, Z., Zheng, H., Wang, Y., and Chen, C. 2020. Microplastics in surface water and sediments of Chongming Island in the Yangtze Estuary, China. *Environ Sci Eur* 32: 15. <https://doi.org/10.1186/s12302-020-0297-7>
- Masura, J., Baker, J., Foster, G., and Arthur, C., 2015. Laboratory methods for the analysis of microplastics in the marine environment: Recommendations for quantifying synthetic particles in waters and sediments. *NOAA Technical Memorandum NOS-OR&R-48. National Oceanic and Atmospheric Administration, Silver Spring, MD.* <https://repository.library.noaa.gov/view/noaa/10296>
- Miller, M.E., Hamann, M., and Kroon, F.J., 2020. Bioaccumulation and biomagnification of microplastics in marine organisms: A review. *PLoS ONE* 15(10): e0240792. <https://doi.org/10.1371/journal.pone.0240792>
- Pan, Z., Liu, Q., Jiang, R., Li, W., Sun, X., Lin, H., et al., 2021. Microplastic pollution and ecological risk assessment in estuarine environments. *Chemosphere* 262: 127876. <https://doi.org/10.1016/j.chemosphere.2020.127876>
- Payel, S., Pahlevani, F., Ghose, A., et al., 2025. Microplastic pollution in aquatic environments: Sources, impacts, and remediation strategies. *Environmental Toxicology and Chemistry* 44(4): 895–915. <https://doi.org/10.1093/etojnl/vgaf037>
- Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W.G., et al., 2004. Lost at sea: Where is all the plastic? *Science* 304(5672): 838. <https://doi.org/10.1126/science.1094559>
- United Nations Environment Programme, 2021. From Pollution to Solution: A global assessment of marine litter and plastic pollution. United Nations