ASSESSMENT OF MICROPLASTIC POLLUTION LOAD INDEX IN GISIK CEMANDI RIVER ESTUARY

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Abstract

Plastic waste pollution has become a serious environmental issue in Indonesia, particularly in aquatic ecosystems where plastics degrade into microplastics. This study aims to identify the abundance, characteristics, and ecological risk of microplastics in the water and sediment of the Gisik Cemandi River Estuary, Sidoarjo. Sampling was conducted at six stations during the morning and afternoon, covering surface and mid-depth layers for water, and sediment. Microplastics were extracted using the NOAA method and observed under a stereo microscope. The results showed that microplastics were present in all samples. The abundance in water reached 339 particles/L in the morning and 356 particles/L in the afternoon. The mid-depth layer contained a higher concentration of microplastics (209 particles/L) compared to the surface layer (153 particles/L). Fibers were the most dominant shape (90-92%), while black was the most frequent color (57-60%), and the dominant size ranged from 0.1 to 0.5 mm. The ecological risk assessment using the Pollution Load Index (PLI) indicated values ranging from 11.40 to 18.03 in the morning (Moderate Risk) and up to 28.98 in the afternoon (High Risk), with Station D consistently showing the highest risk levels. These findings highlight the significant influence of domestic and fishing activities on microplastic pollution in the estuary, necessitating urgent mitigation strategies.

Keywords: Estuary, Fiber, Microplastic, Pollution Load Index, Water pollution

1. INTRODUCTION

The increasing global use of plastics has led to the release of microplastics, defined as plastic particles smaller than 5 mm, into aquatic environments, including river estuaries. Microplastics have been widely detected in water columns, sediments, and aquatic organisms, both in natural ecosystems and aquaculture systems. In aquatic environments, microplastics may act as carriers for various contaminants, including pathogens, heavy metals, persistent organic pollutants, and harmful algal species (Le et al., 2022). Furthermore, microplastics can enter the human body through the food chain, particularly via the consumption of contaminated aquatic products, and may pose potential health risks such as inflammation and immune system disruption (Wright & Kelly, 2017). In Indonesia, plastic waste management remains a major challenge, as the recycling rate is still below 10% of the total plastic waste generated (NPAP, 2020).

River estuaries are transitional zones that serve as important pathways for the transport of microplastics from terrestrial sources to marine environments. The distribution of microplastics in estuarine systems is influenced by anthropogenic activities, tidal dynamics, currents, sediment resuspension, and the physicochemical characteristics of the water. Parameters such as salinity, turbidity, total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD), and total Kjeldahl nitrogen (TKN) may affect the occurrence and behavior of microplastics through flotation, aggregation, biofouling, sedimentation, and resuspension processes. High turbidity indicates the presence of suspended particles that may interact with microplastics, while elevated BOD, COD, and TKN values reflect organic matter and nutrient inputs that may enhance biofilm formation on microplastic surfaces.

The level of microplastic contamination can be assessed using the Pollution Load Index (PLI), an index that describes pollution pressure based on microplastic abundance. Higher PLI values indicate greater levels of contamination and allow comparisons of pollution risks among sampling sites (Xu et al., 2018; Hossain et al., 2022). The Gisik Cemandi River Estuary is an area influenced by various anthropogenic activities, including port operations, fish auction activities, fishing boats, settlements, and the dynamic exchange of riverine and marine waters. These activities may contribute microplastics derived from plastic packaging, styrofoam, ropes, fishing nets, and other synthetic fishing gear. Therefore, this study is important for evaluating the abundance and characteristics of microplastics, assessing contamination levels based on PLI, and examining their relationship with the physicochemical conditions of the waters in the Gisik Cemandi River Estuary.

2. MATERIALS AND METHODS

Sample Collection and Laboratory Analysis

The Gisik Cemandi Traditional Port is in Sidoarjo Regency, East Java, Indonesia. The study was conducted from October to November 2025. In general, the study area is characterized by intensive traditional fishing activities and aquaculture ponds. Sampling locations were determined using a purposive sampling method at six stations, namely Stations A to F, which represented the environmental conditions of the study area and were recorded using a Global Positioning System (GPS) (Figure 1). River discharge was measured using an Acoustic Doppler Current Profiler (ADCP), while water depth was measured using an echo sounder to determine the hydrological conditions of the river from upstream to downstream.

Water samples were collected using a water sampler, with a volume of 1 L taken at each sampling point. Sampling was conducted at two depth layers, namely the surface layer and the mid-depth layer. Sediment samples were collected using a grab sampler, with approximately 1000 g of sediment taken from each sampling station. The collected water and sediment samples were then prepared following the NOAA method. Sample digestion was performed by adding 20 mL of H_2O_2 and 5 mL of $FeSO_4$. The samples were heated using a magnetic stirrer for 30 min at 75 °C with a stirring speed of 300 rpm. After heating, the samples were filtered, followed by density separation through flotation.

Microplastic identification was conducted using a stereo microscope at 40× magnification to observe particle shape, color, and size. The abundance of microplastics in water samples was calculated using the following equation:

$$C = n/V \quad (1)$$

where C represents microplastic abundance, n is the number of microplastic particles observed, and V is the volume of filtered water.

Figure 1. Sampling Map Location

Pollution Load Index (PLI)

The level of microplastic contamination was assessed using the Pollution Load Index (PLI). The contamination factor and PLI for each sampling station were calculated as follows:

$$CFi = Ci/Coi \quad (2)$$

$$PLIi = \sqrt{\text{Cfi}} \quad (3)$$

where Cfi is the contamination factor at station i, Ci is the microplastic abundance at station i, and C0i is the baseline microplastic abundance, represented by the lowest average microplastic frequency recorded in the study area. Higher PLI values indicate a greater level of microplastic contamination

3. RESULT AND DISCUSSION

Existing Environmental Conditions the Study Area

The estuarine area surrounding the Gisik Cemandi Traditional Port, Sidoarjo, is characterized by intensive traditional fishing activities, including regular fish capture, fishing gear maintenance, and the loading and unloading of fishery products. Along the river estuary, various types of plastic waste, including polyethylene terephthalate (PET), low-density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS), were observed floating on the water surface and accumulating along the riverbanks. Disposable diapers and face masks were also frequently found in the area. These plastic wastes are likely derived from domestic activities of nearby communities, waste generated from fishing vessels, and plastic debris transported from upstream areas by river flow.

Water depth varied between morning and afternoon observations. In the morning, the greatest water depth was recorded at Station C, reaching 195 cm, while the lowest depth was observed at Station F, with a depth of 98 cm. In the afternoon, water depth generally increased, with the highest depth recorded at Station E, reaching 216 cm. The lowest afternoon depth was observed at Station C, with a depth of 161 cm. Greater water depth is generally associated with stronger sediment deposition zones and may promote the accumulation of microplastics in bottom sediments rather than in the surface water layer.

River hydrological conditions also influence the distribution and transport of materials in the water column, particularly through variations in river discharge. The highest discharge was recorded at Station B during both morning and afternoon observations, with values of 10.684 m^3/s and 12.786 m^3/s, respectively. This indicates that Station B represents a section of the river with the greatest flow capacity. In contrast, the lowest discharge was recorded at Station D in the morning, with a value of 4.368 m^3/s. The higher discharge observed in the afternoon was likely influenced by an increase in current velocity and cross-sectional area of the river, which enhanced the overall water flow capacity during that period.

Water Quality Analysis

Water quality in the Gisik Cemandi River Estuary showed spatial variation among sampling stations, influenced by anthropogenic activities, estuarine dynamics, and the mixing of riverine and marine waters. Each sampling station exhibited different environmental characteristics, ranging from the port and fish auction area, fishing boat berthing zones, estuarine transition zones, to coastal marine waters. These differences in land use and site function affected the physicochemical characteristics of the water, including temperature, pH, salinity, turbidity, biological oxygen demand (BOD), chemical oxygen demand (COD), and total nitrogen.

Table 1 Environmental Analysis Results

Parameter	Morning	Afternoon
Temperature	25.7- 27 °C	27.2–28.7°C
pH	7.25- 7.83	6.04–8.24
Salinity (ppt)	10.1- 18	10.1–17.5
Turbidity (NTU)	852.5 – 9,410	393.9–2,460
TDS (g/L)	2.879-5.570	3.878–6.463

Water temperature ranged from 25.7 to 28.7°C, with a tendency to increase in the afternoon due to accumulated solar radiation. According to Wang et al. (2018), environmental factors such as temperature, ultraviolet radiation, and mechanical processes play important roles in the fragmentation of plastic debris into microplastics in aquatic environments. The pH values were generally within neutral to slightly alkaline conditions, ranging from 7.25 to 8.24. However, a decrease in pH to 6.04–6.50 was observed at Station A in the afternoon. This decrease was presumably associated with organic matter inputs from port activities and the Kalanganyar Fish Auction Center, which may undergo decomposition and release acidic by-products into the water column (Duarte et al., 2017).

Salinity ranged from 10.1 to 18.0 ppt, indicating brackish water conditions. Stations A and B tended to show lower salinity values due to stronger terrestrial influence and proximity to port-related activities. In contrast, Stations E and F showed greater influence from marine water masses, as reflected by relatively higher salinity values.

Turbidity showed the greatest variation among the measured parameters, with the highest value recorded at Station D in the morning, reaching 9410 NTU. The high turbidity at Station D was likely caused by turbulence and sediment resuspension resulting from the interaction between riverine and marine water masses (Liu et al., 2019). A similar condition was also observed at Station C, which serves as a transport pathway for suspended particles from the estuary toward coastal waters.

The highest TDS value was recorded at Station A in the afternoon and was likely related to port and fish auction activities, including fish washing, domestic waste discharge, and other fishery-related activities. At Stations E and F, relatively high TDS values were more strongly influenced by marine water masses, which contain higher concentrations of dissolved salts.

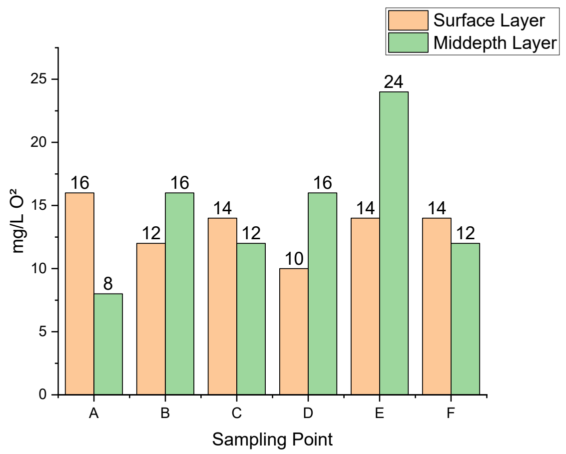


Figure 2. BOD Analysis Morning Variable

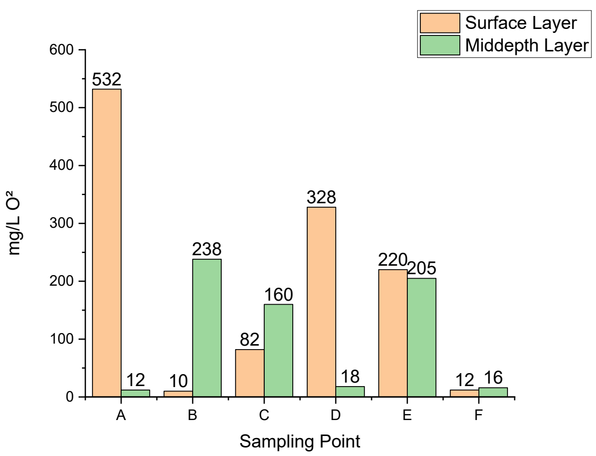


Figure 3. BOD Analysis Afrenoon Variable

BOD values in the morning ranged from 8 to 24 mg/L, while in the afternoon they increased markedly to 10–532 mg/L. The increase in BOD during the afternoon indicates a higher organic matter load, which was presumably derived from activities at the Kalanganyar Fish Auction Center, port operations, fishing boats, and domestic waste inputs. The highest BOD value was recorded at Station A, reaching 532 mg/L, which is located in the port and fish auction area. The elevated BOD at this station indicates substantial organic waste input from fishery-related activities, such as fish washing, fishery residues, and domestic wastewater discharge. Station D also showed relatively high BOD values, which may be influenced by sediment resuspension caused by tidal dynamics and the mixing of riverine and marine waters.

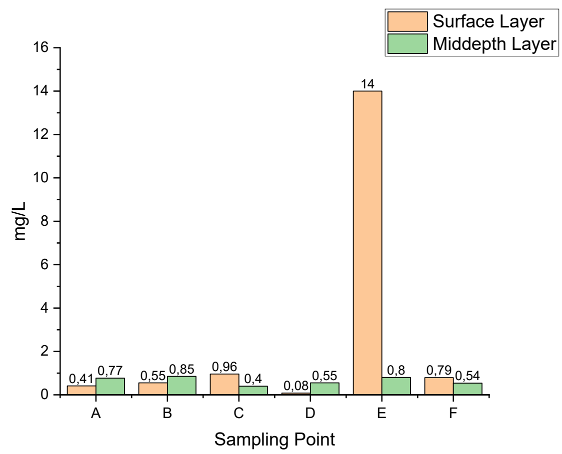


Figure 4. TKN Analysis Morning Variable

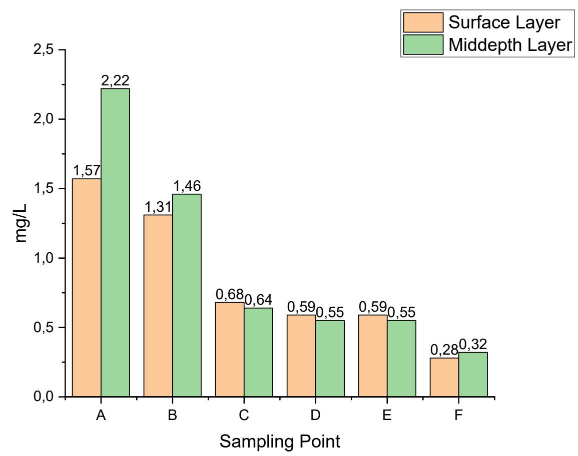


Figure 5. TKN Analysis Afternoon Variable

TKN values in the Gisik Cemandi River Estuary varied between morning and afternoon observations. In the morning, TKN ranged from

0 to 14 mg/L, with the highest value recorded at Station E1P2, reaching 14 mg/L. In the afternoon, TKN ranged from 0.28 to 4.15 mg/L, with the highest value observed at Station F, reaching 4.15 mg/L. TKN represents the concentration of organic nitrogen and ammonia in the water column, which may originate from domestic wastewater, fishery activities, port operations, and terrestrial organic matter inputs. The elevated TKN values in the marine area near the estuary indicate the transport of nitrogen compounds from the estuary toward coastal waters through currents and tidal processes. This condition suggests that the Gisik Cemandi River Estuary functions as an important pathway for nutrient input from terrestrial sources to the sea and may increase the risk of eutrophication if such inputs persist over time.

Table 2. Sedimen Analysis

Sampling Station	Sediment		
	pH	Water Content	T(°C)
A	9.1	32%	27
B	8.5	25%	27
C	8	15%	31
D	9.1	30%	27
E	9.1	39%	31
F	9.1	32%	30

The sediment conditions in the Gisik Cemandi River Estuary were generally characterized as semi-muddy to sandy, as indicated by water content values ranging from 15% to 39%. Sediment pH reached up to 9.1, indicating alkaline conditions compared with most tropical estuarine sediments, which commonly range from 7.1 to 7.8 (Firdaus et al., 2019). Sediment pH values above 8 may be influenced by seawater intrusion, photosynthetic activity, and inputs of domestic and anthropogenic waste, which can increase sediment alkalinity.

Micoplastic Types and Abundance in Estuarine Water Samples

Based on the analysis of water samples collected from the river estuary, five types of microplastics were identified, namely pellets, fragments, flakes, films, and fibers. Among these types, fiber was the dominant microplastic form in the waters of the Gisik Cemandi River Estuary, with abundances of 321 particles/L in the morning and 327 particles/L in the afternoon. The total microplastic abundance was 339 particles/L in the morning and 356 particles/L in afternoon.

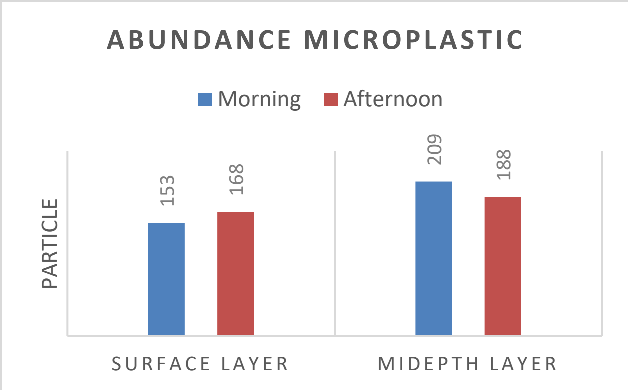
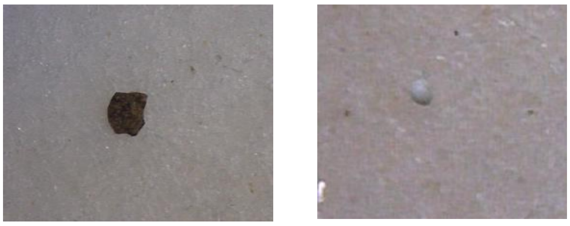


Figure 6 Microplastic Abundance

Differences in microplastic abundance were also observed between the surface layer and the mid-depth layer. The number of microplastic particles was higher in the mid-depth layer, with 188 particles/L in the morning and 209 particles/L in the afternoon. This distribution pattern may be influenced by several factors, including turbulence and water mixing processes, which allow microplastic particles to be transported from the surface into the water column. In addition, changes in particle density due to biofouling may increase the specific gravity of microplastics, causing them to sink into deeper water layers. Other factors influencing the higher abundance in the mid-depth layer include estuarine hydrodynamic conditions, particularly tidal currents and water circulation.

(a) (b)



(c) (d)

Figure 7. Type of Microplastics (a) Fiber (b) Film (c) Fragment (d) Pellet

Based on their morphology, microplastics can be classified into several types, including fibers, films, fragments, foams, and pellets. The most found microplastics in aquatic environments are secondary microplastics, which are generated from the fragmentation of larger plastic materials and are largely associated with household and anthropogenic activities (Yona D. et al., 2021). The diversity of microplastic forms identified in the Gisik Cemandi River Estuary indicates multiple potential sources of plastic pollution. The dominance of fibers, accounting for approximately 90% in the morning and 92% in the afternoon, suggests that the main sources may include polyester and nylon fibers released during clothes washing, as well as degraded fishing nets and ropes used in fishery activities.

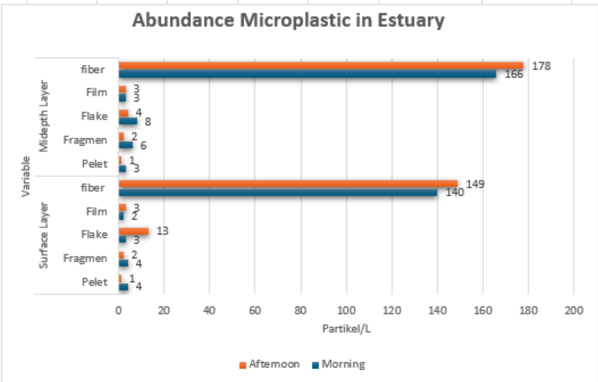


Figure 8. Microplastic Abundance in Water Estuary

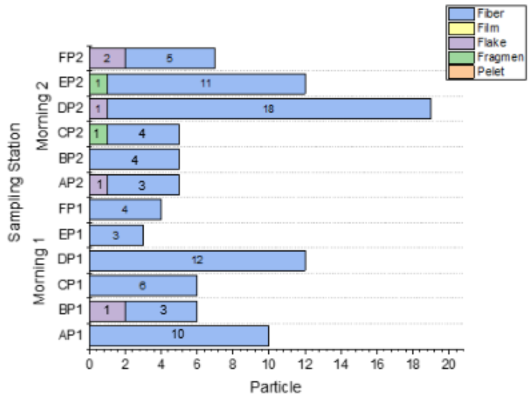


Figure 9. Microplastic Abundance in Sediment Morning Variable

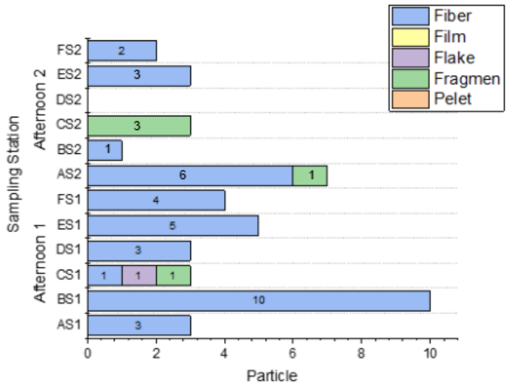


Figure 10 Microplastic Abundance in Sediment Afternoon Variable

The dominance of fiber-shaped microplastics in sediment indicates a contribution from fishery-related activities, particularly the degradation of synthetic fishing nets, ropes, and fishing gear. Fiber-type microplastics have frequently been reported as the dominant form in aquatic environments because they originate from domestic activities, textile materials, and fisheries (Wang et al., 2018). Sediments act as accumulation zones for microplastics because particles can settle through processes such as biofouling, aggregation with organic matter, and increased particle density (Horton et al., 2017). In estuarine areas, microplastic distribution is strongly influenced by tidal dynamics, currents, and sediment resuspension. As a result, microplastics that have previously settled in sediments may be resuspended into the water column Zhang, 2017; Wu et al., 2019).

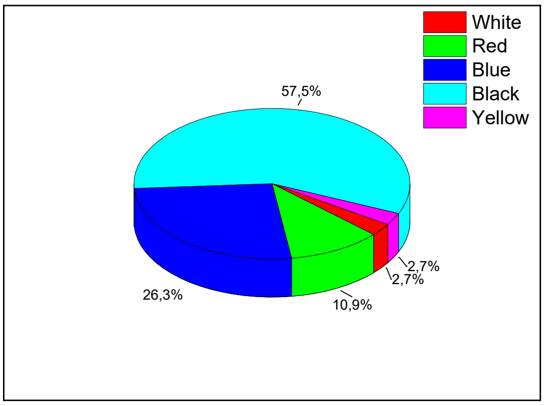


Figure 11. Microplastic Percentage Based on Color Morning Variable

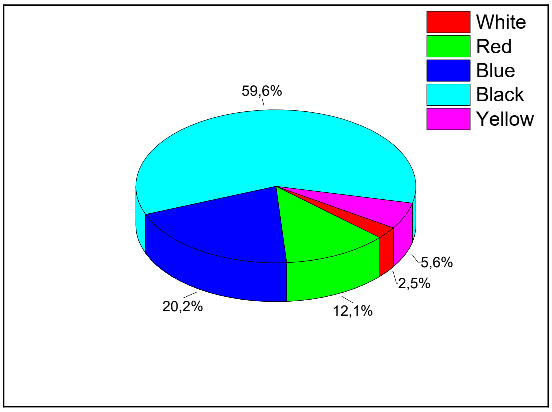


Figure 12 Microplastic Percentage Based on Color Afternoon Variable

Based on the identification results, five microplastic colors were found in water samples from the Gisik Cemandi River Estuary, namely white/transparent, red, blue, black, and yellow. As shown in Figures 3 and 4, black was the most dominant color, accounting for 57% of the total microplastics in the morning, with an abundance of 195 particles/L. In the afternoon, black microplastics increased to 60%, with an abundance of 212 particles/L.

Blue and red microplastics were also found in considerable amounts. In the morning, blue microplastics were recorded at 89 particles/L, representing 26%, while red microplastics were found at 37 particles/L. In the afternoon, blue microplastics decreased to 72 particles/L, accounting for 20%, whereas red microplastics increased slightly to 43 particles/L, representing 12%. These colors are generally associated with synthetic textile materials, plastic ropes, or packaging fragments. This finding is consistent with the previously observed dominance of fiber-shaped microplastics, as textile fibers commonly exhibit bright colors such as blue and red.

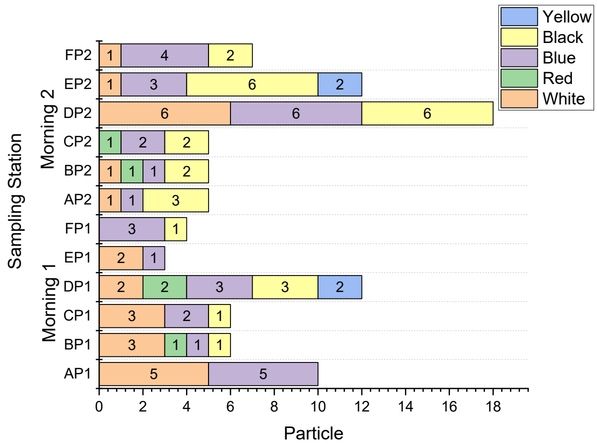


Figure 13. Microplastic Abundance in Sediment Based on Color Morning Variable

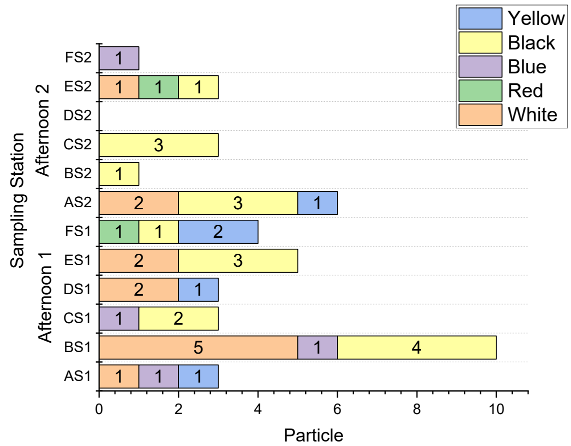


Figure 14. Microplastic Abundance in Sediment Based on Color Afternoon Variable

Based on the color distribution of microplastics in sediment samples, a contrasting abundance pattern was observed between morning and afternoon sampling periods. In the morning, sediment microplastics were dominated by blue particles (32 particles) and black particles (27 particles), followed by white particles (25 particles), while red and yellow particles were found in very limited quantities. In contrast, during the afternoon, the abundance of almost all microplastic colors decreased significantly, with black particles becoming the most dominant (18 particles), followed by white particles (13 particles). Meanwhile, blue microplastics showed a sharp decrease, with only 4 particles recorded. This difference in color distribution indicates daily dynamics in the deposition or resuspension of microplastics in estuarine sediments, which may be influenced by tidal conditions or anthropogenic activities around the study area.

The distribution of these varying sizes within the water column is heavily dictated by their physical properties and the local hydrodynamics. The dominant 0.1–0.5 mm particles possess a high surface-area-to-volume ratio and low settling velocities, allowing them to remain suspended in the water column for prolonged periods. These smaller particles are highly mobile and easily transported by even minor tidal currents, leading to their pervasive presence across all estuarine stations.

Quantitative observations from the water samples explicitly confirm this size-dependent dynamic, with total absolute abundances fluctuating between 9 and 25 particles/L across all individual replicates. Within this range, the smallest size fraction (0.1–0.5 mm) overwhelmingly dominated the samples, consistently accounting for the highest particle counts at every station during both the morning and afternoon periods. For example, during the afternoon peak at Station D's mid-depth layer which recorded the absolute maximum abundance of 25 particles/L the composition was heavily skewed toward the 0.1–0.5 mm category. Conversely, the larger fractions (0.5–1 mm and 1–5 mm) were recorded in much lower absolute frequencies. However, the persistent detection of these 1–5 mm particles alongside the dominant smaller fragments, particularly during the afternoon's high-traffic periods, provides direct evidence that the estuary's mechanical turbulence is strong enough to keep a complete spectrum of microplastic sizes suspended in the water column.

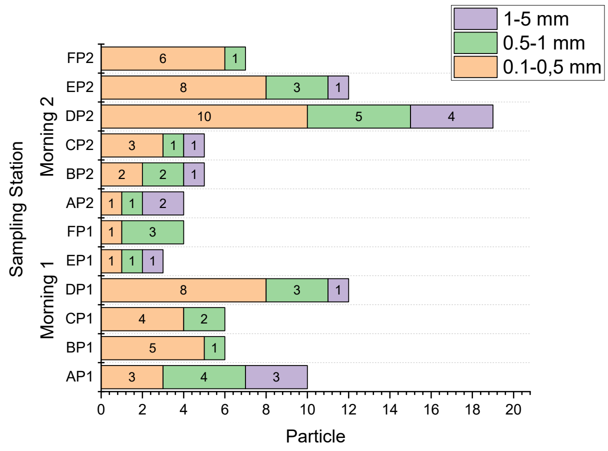


Figure 15. Microplastic Abundance in Sediment Based on Size Morning Variable

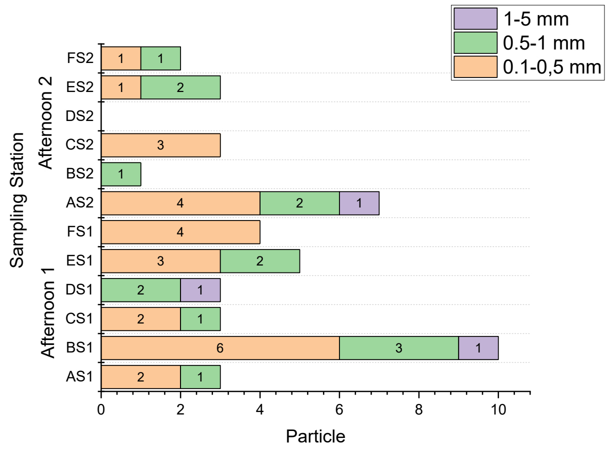


Figure 16 Microplastic Abundance in Sediment Based on Size Afternoon Variable

The size distribution of microplastics in the sediment of the Gisik Cemandi River Estuary exhibited distinct temporal and spatial variations, consistently dominated by smaller particles in the 0.1–0.5 mm range.

Morning Observations, Microplastic abundance in the sediment was relatively high, particularly during the second morning sampling (Morning 2). The 0.1–0.5 mm size class was highly dominant, peaking at Station DP2 with 10 particles/L, followed by Station EP2 (8 particles/L) and Station DP1 (8 particles/L). Medium-sized (0.5–1 mm) and larger (1–5 mm) microplastics were present in lower frequencies, with the highest occurrence of large particles (1–5 mm) recorded at Station DP2 (4 particles/L).

Afternoon Observations, a general decrease in sediment microplastic abundance was observed in the afternoon. The highest concentration was recorded at Station BS1 with 6 particles/L in the 0.1–0.5 mm size class. Notably, several stations during the second afternoon sampling (Afternoon 2), such as DS2, showed a complete absence of microplastics across all size classes.

The overall dominance of the smallest size fraction (0.1–0.5 mm) in both periods indicates that plastic debris in this estuarine environment has undergone intensive physical degradation and fragmentation over a prolonged period (Hidalgo-Ruz et al., 2012). Furthermore, the higher retention of larger particles (1–5 mm) in the sediment compared to the water column supports the role of estuarine sediments as a permanent sink for denser or biofouled microplastics (Kooi et al., 2017). The temporal decline from morning to afternoon suggests dynamic sediment resuspension and deposition processes driven by tidal cycles and vessel activities in the port area.

Pollution Load Index (PLI)

The microplastic Pollution Load Index (PLI) was calculated based on microplastic abundance data from the Gisik Cemandi River Estuary. The PLI was determined for each sampling station to identify contaminated areas and classify their risk categories according to the criteria proposed by Pan et al. (2021).

Table 3. Risk Index

Risk Index	PLI
Low (I)	<10
Moderate (II)	10-20
High (III)	20-30
Risk (IV)	>30
High Risk (V)	-

Table 4. Pollutuon Load Index Morning Variable

Station	C_{0i}	PLI	
		Surface Layer	Midepth Layer
A	0,05	17,89	13,42
B	0,05	7,75	12,65
C	0,05	7,75	10,00
D	0,05	14,14	21,45
E	0,05	12,65	14,14
F	0,05	12,65	13,42

Table 5. Pollution Load Index Afternoon Variable

Station	C_{0i}	PLI	
		Surface Layer	Midepth Layer
A	0,05	19,49	14,83
B	0,05	20,49	27,93
C	0,05	17,32	22,36
D	0,05	14,14	18,44
E	0,05	20,49	16,73
F	0,05	19,49	17,89

The microplastic PLI values in the Gisik Cemandi River Estuary showed variation among sampling stations and water depths. During the first observation, PLI values ranged from 7.75 to 21.45, with the highest value recorded in the mid-depth layer at Station D, reaching 21.45, which falls into the high-risk category. During the second observation, PLI values increased, ranging from 14.14 to 27.93, with the highest value recorded in the mid-depth layer at Station B, reaching 27.93. Overall, the PLI values indicate that most sampling points were classified within the moderate to high-risk categories.

Station A was classified as having a moderate pollution level, presumably influenced by port activities and operations at the Kalanganyar Fish Auction Center, including the use of plastic packaging, styrofoam, ropes, and fishing nets. Station B exhibited the highest PLI value, particularly in the mid-depth layer, which may be associated with fishing boat berthing activities, the use of synthetic fishing gear, and sediment resuspension caused by vessel movement. Station C functioned as a microplastic transport zone from the estuary toward the sea, whereas Station D was influenced by tidal dynamics and the mixing of riverine and marine water masses. Stations E and F indicate that microplastics from the estuary can still disperse into coastal marine waters, although dilution by marine water masses may occur at Station F.

The high PLI values observed at several stations, particularly Stations B, C, D, and E, suggest that the Gisik Cemandi River Estuary serves both as a transport pathway and an accumulation zone for microplastics originating from land-based activities before being transported into coastal marine waters.

4. CONCLUSION

This study provides a comprehensive assessment of microplastic (MP) contamination in the Gisik Cemandi River Estuary, Sidoarjo, by synthesizing environmental parameters, MP physical characteristics, and ecological risk indices.

First, water quality and hydrological analyses reveal that the estuary is highly dynamic and heavily impacted by anthropogenic activities. High organic loading indicated by elevated Biological Oxygen Demand (BOD) up to 532 mg/L and high Total Dissolved Solids (TDS) at Station A coincides with intensive port and fish auction activities. The extreme turbidity levels (up to 9,410 NTU at Station D) and fluctuating water depths between tidal cycles play a critical role in MP dynamics, facilitating the transport, aggregation, and resuspension of particles within the water-sediment interface.

Second, microplastics were ubiquitously distributed across all water and sediment samples. The total MP abundance in water reached 339 particles/L in the morning and increased to 356 particles/L in the afternoon. Hydrodynamic factors and biofouling processes heavily influenced vertical distribution, resulting in a higher MP accumulation in the mid-depth layer (209 particles/L) compared to the surface layer (153 particles/L). Morphologically, the overwhelming dominance of fibers (90–92%), black coloration (57–60%), and small-sized particles (0.1–0.5 mm) points to synthetic textiles, degraded fishing gears (nets and ropes), and domestic wastewater as the primary pollution sources. The prevalence of the smallest size class (0.1–0.5 mm) confirms intensive, long-term physical fragmentation of plastic debris in this brackish environment.

Third, the Pollution Load Index (PLI) evaluations classify the Gisik Cemandi River Estuary under a moderate to high ecological risk. The PLI values ranged from 7.75–21.45 in the morning and escalated to 14.14–27.93 in the afternoon. The mid-depth layers of Station D (morning PLI: 21.45) and Station B (afternoon PLI: 27.93) emerged as critical hotspots. These high-risk values are directly linked to localized activities, including fishing vessel operations, synthetic gear maintenance, and tidal-induced sediment resuspension.

In conclusion, the Gisik Cemandi River Estuary serves as both a major transport pathway and a critical sink for land-based and marine-derived microplastics. The strong correlation between poor water quality (high BOD, TDS, and turbidity) and elevated MP risk indices highlights the urgent need for integrated waste management strategies. Mitigating plastic inputs from domestic sewage and traditional fishing activities is imperative to prevent further ecological deterioration of this estuarine ecosystem and protect adjacent marine food webs.

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