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Characteristics and Abundance of Large Microplastics in Sediments in Wonorejo Mangrove Tourism Area, Surabaya

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Abstract. *Microplastic (MP) pollution is a growing environmental concern due to its persistence in aquatic ecosystems. Among MPs, large microplastics (1–5 mm) originate from the degradation of larger plastic debris and pose ecological risks. However, research on their accumulation in mangrove sediments remains limited. This study investigates the characteristics, abundance, and spatial distribution of large microplastics in the Wonorejo Mangrove Tourism Area, Surabaya, which receives plastic waste transported by the Wonorejo River. Surface sediment samples were collected from three stations, followed by drying, sieving, visual inspection, and Fourier Transform Infrared (FTIR) spectroscopy for polymer identification. The results indicate that film-type microplastics were the most abundant (72%), followed by fragments (23%) and pellets (5%). Transparent microplastics (38%) were the dominant color, followed by blue (26%). The highest microplastic concentration was recorded at Station 2 (130.7 ± 73.5 particles/kg), while Station 1 had the lowest (2.7 ± 2.7 particles/kg). Despite these variations, statistical analysis showed no significant differences in microplastic distribution among stations, suggesting a relatively homogeneous spatial pattern across the study area. FTIR analysis identified two dominant polymers: polypropylene (PP) and polyethylene (PE), commonly used in consumer and industrial products. The predominance of film-type microplastics and transparent coloration suggests that the primary sources of contamination are plastic bags and food packaging waste transported by river currents. These findings underscore the role of mangrove ecosystems as critical retention zones for plastic pollution, highlighting the urgent need for improved waste management strategies to mitigate microplastic accumulation in coastal environments.*

Keywords: *pollution, polyethylene, polypropylene, retention, waste*

Citation
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INTRODUCTION

Urbanization and changing human lifestyles are major contributors to the increasing volume of waste generated and discarded annually. Plastic waste poses one of the most significant environmental threats among the various types of solid waste due to its widespread use and persistent nature. It is estimated that approximately 300 million tons of plastic waste are produced globally each year (Singh & Sharma, 2016). Plastics, synthetic polymers, are extensively utilized in various industries, including clothing, medical equipment, food packaging, electrical appliances, and construction materials. The demand for plastics continues to rise due to their affordability, durability, and ease of processing. However, poor waste management practices and the long degradation time of plastics have led to the accumulation of plastic waste in terrestrial and aquatic ecosystems. Plastics degrade extremely slowly, often persisting in the environment for decades or even centuries, where exposure to sunlight, wind, and waves gradually breaks them into smaller particles (Bajt, 2021; Albarra et al., 2024).

Plastic particles that are smaller than 5 mm are classified as microplastics (Zhang et al., 2017). These are categorized into primary microplastics, which are intentionally manufactured at a micro-scale (e.g., microbeads in personal care products or industrial pellets), and secondary microplastics, which result from the fragmentation of larger plastic debris (Zhang et al., 2017; Bajt, 2021; Hasibuan et al., 2020). Microplastics are further classified into small microplastics (<1 mm) and large microplastics (1–5 mm) based on size distribution. Large microplastics (1–5 mm) fall within the upper size range of microplastics and are of particular concern due to their unique environmental behavior and higher likelihood of entrapment in sediments. These particles originate from degraded plastic products, plastic bags, and food packaging. They are often more readily retained in sediment than smaller microplastics, making them important indicators of plastic accumulation patterns in aquatic environments. For clarity, this manuscript will refer to large microplastics simply as microplastics, as the study exclusively focuses on this size range, making additional distinctions unnecessary.

Rivers are key transportation pathways for microplastics, carrying them from land-based sources to the ocean. Microplastic concentrations tend to be higher in estuaries, where differences in salinity and turbulence influence their deposition (Firdaus et al., 2020; Xu et al., 2020). Once microplastics reach river mouths, they can become trapped in coastal sediments, particularly within mangrove ecosystems, before entering the open ocean (Anjeli et al., 2024; Yanuar et al., 2024; Yona et al., 2023).

Mangrove ecosystems within intertidal coastal zones play a vital role in coastal protection, carbon sequestration, and biodiversity conservation. These ecosystems provide wood resources, food sources, and natural barriers against hurricanes and tsunamis. However, waste pollution in mangrove forests is becoming a serious environmental concern, as plastics, textiles, glass, and other pollutants accumulate in these areas. Anthropogenic waste is transported by tidal movements and wave action, leading to its eventual deposition in mangrove sediments (Sibaja-Cordero & Gómez-Ramírez, 2022). Among the various types of waste, plastics are the most prevalent due to their buoyancy and tendency to become entangled in mangrove roots, branches, and leaves. This entrapment can significantly impact coastal flora and fauna by disrupting gas exchange and exposing organisms to harmful chemicals released from degrading plastics. Given their semi-enclosed structure and sediment-trapping capacity, mangrove ecosystems act as natural sinks for microplastics. The distribution of microplastics in mangrove sediments is influenced by multiple factors, including human activity intensity, sediment composition, tidal dynamics, and mangrove root density (Zhou et al., 2020; Zhang et al., 2020; Duan et al., 2021).

The Wonorejo Mangrove Tourism Area in Surabaya is a significant ecotourism destination on the eastern coast of Surabaya, known for its extensive mangrove forests. This area attracts both local and international visitors due to its ecological value and scenic landscape. However, despite its popularity, the site lacks proper waste management facilities, leading to the accumulation of both organic and inorganic waste. Plastic debris in this area primarily originates from tourist activities and residential waste carried by the Brantas, Jagir, and Sukolilo Rivers (Mochammad & Umilia, 2021; Sunjaya et al., 2015). The accumulation of plastic waste in mangrove areas not only threatens ecosystem health but also contributes to mangrove mortality and a decline in migratory bird populations. Given the substantial presence of plastic waste in the Wonorejo Mangrove Tourism Area, this site presents an ideal case study to examine the accumulation of microplastics in mangrove sediments.

Unlike previous studies that generally assess microplastic pollution in mangrove sediments, this research provides a focused investigation on large microplastics (1–5 mm), specifically analyzing their spatial distribution and polymer composition in a mangrove ecotourism area impacted by urban and riverine plastic waste inputs. Additionally, this study employs Fourier Transform Infrared (FTIR) analysis to determine the dominant polymer types, providing valuable insights into the sources and persistence of microplastics in sediment. Most studies on microplastics have analyzed a wide range of particle sizes, often reporting a higher abundance of smaller microplastics (<1 mm), which are more difficult to capture and identify. In contrast, research on large microplastics remains limited despite their critical role as the first fragmentation stage from larger plastic debris. As the initial breakdown products of macroplastics, large microplastics provide key insights into plastic degradation processes and sediment retention patterns, making them essential indicators of plastic pollution accumulation in aquatic environments. By examining microplastic retention in a heavily urbanized mangrove ecosystem, this research contributes to a better understanding of mangrove sediment function as a potential long-term sink for plastic waste. It emphasizes the need for targeted pollution mitigation strategies in ecologically and economically significant coastal environments.

MATERIALS AND METHODS

Study Sites

Sediment samples were collected from the Wonorejo Mangrove Tourism Area, Surabaya, East Java, near the open sea and river mouths during July 2023. Microplastic analysis, including extraction and identification, was conducted from July to September 2023. The study area was divided into three stations, selected based on differences in hydrodynamic conditions, sediment texture, and proximity to potential pollution sources (i.e., riverine input and coastal influences). These factors were considered to assess their potential role in influencing microplastic accumulation and distribution. The three stations were located along a gradient from the coastal zone to the estuary, where sediment characteristics varied, potentially affecting microplastic retention. Sediment texture is an important factor in microplastic accumulation, as fine-grained sediments (e.g., mud) tend to retain microplastics more effectively than coarser sediments (e.g., sand or rocky substrates). The coordinates of each station are as follows:

- Station 1 (7°17'42.6"S, 112°49'48.3"E) – Located on the coastal zone facing the open sea, this station is characterized by sandy and rocky sediments with sparse mangrove vegetation (mainly *Avicennia* sp.). A gazebo is present near this site, attracting frequent tourist activity.
- Station 2 (7°17'45.8"S, 112°49'51.2"E) – Positioned further inland behind Station 1, this area has muddy sediment and is dominated by *Avicennia* sp. mangroves. The station experiences periodic waterlogging due to its exposure to river inputs and tidal influences.
- Station 3 (7°17'50.3"S, 112°49'53.6"E) – Located near the Wonorejo River estuary, this site has fine-textured muddy sediments with *Rhizophora* sp. as the dominant mangrove species. It is positioned closest to riverine inputs, making it a potential hotspot for microplastic accumulation.

These three stations were selected to capture variations in sediment texture, hydrodynamic conditions, and pollution sources that may influence the distribution and abundance of microplastics. Given that mangrove ecosystems act as natural filters for microplastics, the differences in sediment characteristics and tidal exposure across these stations provide a comprehensive assessment of microplastic retention within the area (Figure 1).

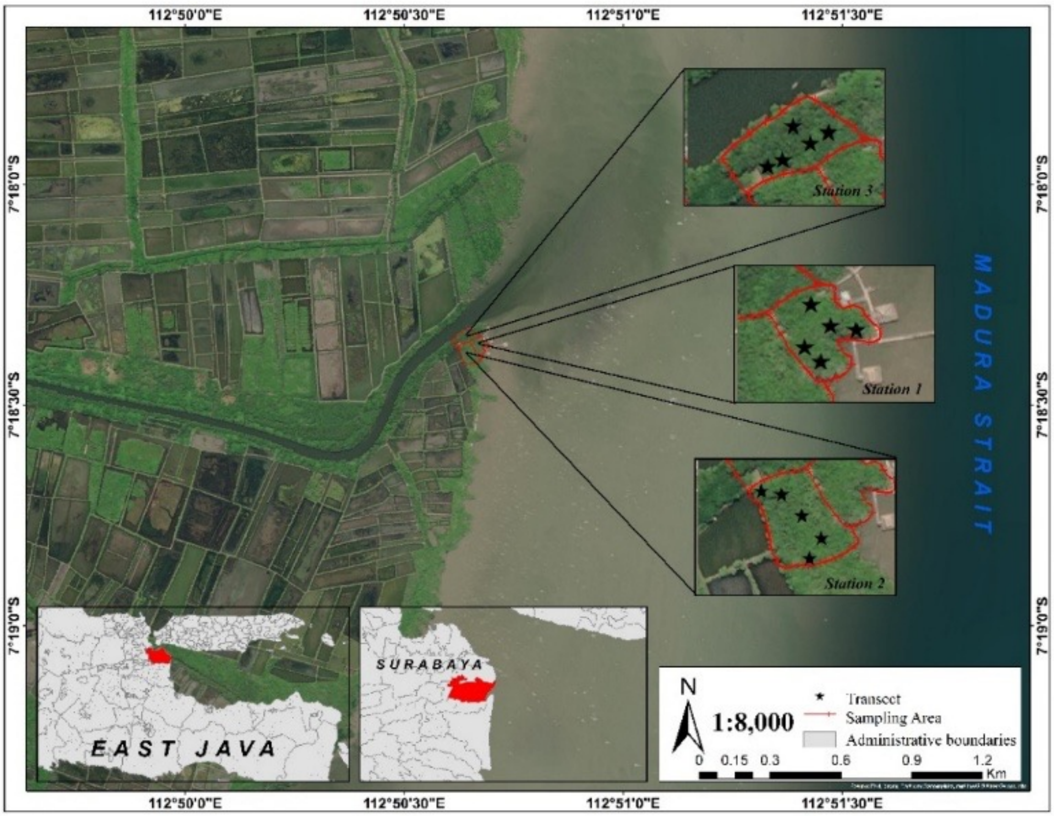

Figure 1. Map of research locations for the Wonorejo Mangrove Tourism Area

Hydrodynamic Parameters of Water

The hydrodynamic parameters of the water processed in this research are current and tidal data. These two data are used as an illustration of the hydrodynamic conditions of the water around the research location. Flow data processing refers to the method used by slight modifications (Fahmi et al., 2014). Current data is obtained from Ocean Surface Current Analysis Real-time (OSCAR) on the https: podaac.jpl.nasa.gov/. Data that has been downloaded in .nc format is extracted using Ocean Data View (ODV) software into a spreadsheet file format. Location coordinates, speed and current direction were processed using Microsoft Excel. The final stage is data processing using Surfer 10 software in grid form and a current distribution map is obtained. Raw tide data was obtained from the Geospatial Information Agency (BIG) (https://srgi.big.go.id). Tidal data processing is carried out to determine the type of tide obtained from the formzahl number (Purba et al., 2019). The data collection period is around 29 days, and it will then be processed using the admiralty method.

Sediment Collection

Sediment sampling was conducted following a modified method by Jualaong et al. (2023). Samples were collected during low tide to ensure maximum exposure of the sediment surface. 15 sediment samples were obtained using a transect-based random sampling approach to account for spatial variation within the study area. Five sediment samples were collected at each station within a 50 × 50 cm quadrat placed randomly around mangrove roots to capture potential microplastic accumulation zones. Given that mangrove sediments were often embedded in plastic waste, random quadrat placement ensured a representative sampling of microplastic distribution. To collect sediment, a metal shovel was used to excavate the top 0 – 5 cm layer of wet surface sediment within the quadrat, as this layer is most likely to accumulate microplastics due to recent deposition from tidal and riverine inputs. The excavated sediment was homogenized within the quadrat to ensure consistency, and approximately 200 – 250 g of sediment was placed into a clean, labeled glass or aluminum foil container to prevent contamination. Each sample was immediately labeled according to the station and replicate number and stored in a cool box to preserve its physical and chemical integrity before transportation to the laboratory. Prior to further analysis, sediment samples were stored in a temperature-controlled storage room (20°C) to prevent potential degradation or contamination. Maintaining the samples at 20°C helps preserve the integrity of microplastic particles by minimizing oxidative degradation and preventing physical or chemical alterations that could occur at higher temperatures. Additionally, this controlled storage condition reduces the risk of microbial activity that might influence sediment composition, ensuring the reliability of subsequent microplastic extraction and identification processes.

Microplastics Extraction and Identification

Microplastic extraction from sediment samples followed a modified method by Phuong et al. (2021) to ensure accurate identification and minimal contamination. Wet sediment samples were placed in a clean metal or aluminum baking dish, covered with aluminum foil, and dried in an oven at 50–80°C for 16–72 hours, depending on sediment composition, until completely dry. To facilitate further processing, hardened sediments were gently ground using a mortar and pestle. Each dried sediment sample was then weighed (150 g per sample) and sieved through a multi-level metal or nylon sieve with 1 mm and 5 mm mesh sizes to isolate large microplastics (1–5 mm). Larger debris was removed, while microplastic particles within the target size range were visually inspected under a stereomicroscope. Potential microplastic particles were then carefully isolated using stainless steel forceps and stored in clean, labeled Petri dishes for further analysis.

Several contamination prevention and validation procedures were implemented to maintain quality assurance (QA) and quality control (QC) during the extraction process. All glassware and equipment were rinsed with filtered deionized water before use, while cotton lab coats and nitrile gloves were worn throughout the process to minimize contamination from synthetic fibers. A plastic-free laboratory environment was maintained, and all work surfaces were thoroughly cleaned before and after sample processing. Additionally, three replicate extractions were performed on randomly selected samples to assess the reproducibility of microplastic identification and ensure consistency in abundance measurements. To further verify the accuracy of microplastic identification, suspected particles were tested for elasticity, buoyancy, and resistance to fragmentation to distinguish them from natural materials such as organic debris. These QA/QC measures ensured the accuracy, reproducibility, and contamination-free processing of sediment samples, strengthening the reliability of the microplastic abundance and characterization results.

Microplastics were categorized as films, fragments, fibers, or pellets based on type. In terms of color, they were divided into five categories: blue, transparent, white, red, and others. After determining the total number of microplastic particles, their abundance was calculated using Formula 1 (Satiyarti et al., 2022).

$$\text{Abundance} = \frac{\text{Number of microplastics (particles)}}{\text{Sediment weight (kg)}} \qquad \text{Formula (1)}$$

Polymer Identification Methods

The identified large microplastics were grouped into 10 categories based on the visual characteristics or type of microplastic of each particle, including "PE" which is pellets, "FR" which is fragments, and "FIL" which is film. Identification of polymer results in this research was carried out using two different methods, namely the manual method and using the help of a website. The manual method is carried out by identifying functional groups from the peaks of the FTIR waveforms. All wavelength peaks are identified in stages starting from zone I (single bound), namely in the range 2500 – 4000 cm-1; zone II (triple bound), namely in the range 2000 – 2500 cm-1; zone III (double-bound), namely in the range 1500 – 2000 cm-1, and zone IV (fingerprint) which is in the range of 1000 cm-1. Next, the identified wavelengths are checked for their presence and matched with a reference database (Jung et al., 2018; Veerasingam et al., 2020). To ensure a sample is a plastic polymer, at least four absorption bands or wavelengths that match the reference database are required for precise and accurate identification results (Maheswaran et al., 2022; Aslam et al., 2020).

The second method of analyzing FTIR results uses the help of the Open Specy website (openanalysis.org/openspecy/). The results of the FTIR file in CSV format were analyzed using the Open Specy website, where the website can identify polymers by comparing the peak of the sample spectrum with the peak of the existing library. To find out whether the samples identified are plastic particles, the results on the website can be read based on the plastic category, correlation coefficient, and type of polymer (Cowger et al., 2021). Next, the results of the two methods were compared and validated for the suitability of the polymer.

Statistical Analysis

This study's statistical analysis was conducted using IBM SPSS Statistics 26. The first step involved testing the normality and homogeneity of all data. For data that were not normally distributed or heterogeneous, a non-parametric Kruskal-Wallis test was performed as an alternative to ANOVA. This test was used to determine whether there were significant differences in the abundance of microplastic types and colors among stations in the Wonorejo mangrove sediments.

RESULTS AND DISCUSSION

Microplastic Characteristics

The accumulation of large microplastics in the sediments of the Wonorejo Mangrove Tourism Area resulted in a total microplastic count of 173 particles across all stations. The identified microplastic types in this area were fragments, films, and pellets (Figure 2), with film being the most dominant (72%), followed by fragments (23%) and pellets (5%) (Figure 3a). The variation in microplastic types indicates the presence of multiple sources of plastic pollution, likely originating from packaging materials, industrial waste, and degraded plastic debris. In terms of color, microplastics were categorized into six groups: blue, red, white, transparent, green, and others, with transparent being the most prevalent color of microplastics (38%) (Figure 3b). The distribution of microplastics by type and color reflects their transport pathways and accumulation patterns in the mangrove sediments. Correspondingly, the highest abundance of large microplastics was recorded for film, with a concentration of 55.1 ± 27.5 particles/kg (Figure 4a). Similarly, transparent color of microplastics exhibited the highest abundance among all color categories, reaching 28.9 ± 17.6 particles/kg (Figure 4b).

Microplastics found at each mangrove station in the Wonorejo Mangrove Tourism Area exhibited considerable variation. Fragments were present at all three stations, while films were found at stations 2 and 3 but were absent at Station 1. Pellets were exclusively detected at Station 2, accounting for 9 out of 173 particles. Film dominated Stations 2 and 3, comprising 56% and 95% of the total microplastic composition, respectively, whereas Station 1 was entirely dominated by fragments (100%) (Figure 5a). In terms of color distribution, all stations exhibited similar color trends, with Stations 1 and 3 being predominantly blue. The highest percentage of blue was observed at Station 1 (100%), followed by Station 3 (26%) (Figure 5b). Conversely, at Station 2, transparent were the most dominant, accounting for 51% of the total particles. Among the three stations, Station 3 recorded the highest microplastic abundance for both film (73.3 ± 55.4 particles/kg, Figure 6a) and transparent color of microplastics (130.7 ± 73.5 particles/kg, Figure 6b). The total accumulation of microplastics varied across the stations, with Station 2 exhibiting the highest number of microplastic particles (98 particles), followed by Station 3 (73 particles) and Station 1 (2 particles). The average microplastic abundance at Stations 1, 2, and 3 was 2.7 ± 2.7 particles/kg, 130.7 ± 73.5 particles/kg, and 97.3 ± 64.3 particles/kg, respectively, with an overall mean abundance of 76.9 ± 86.1 particles/kg across all stations (Figure 7).

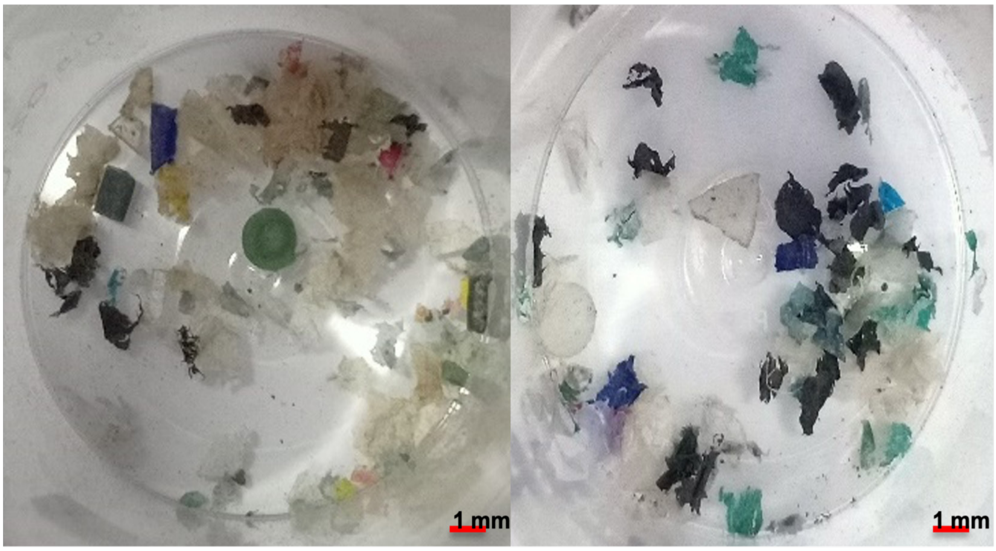

Figure 2. Type of microplastics

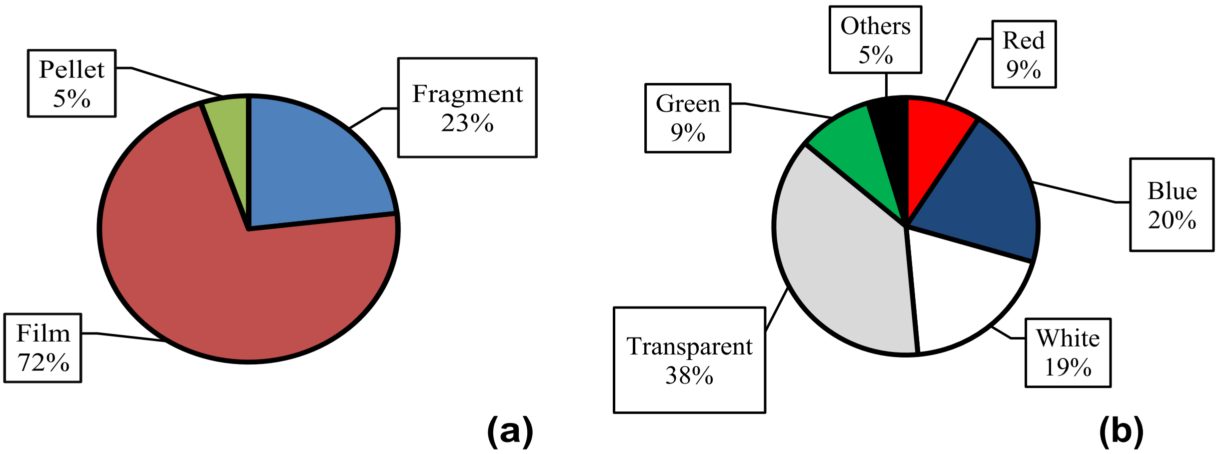

Figure 3. Percentage of microplastics in mangrove sediments: (a) type and (b) color

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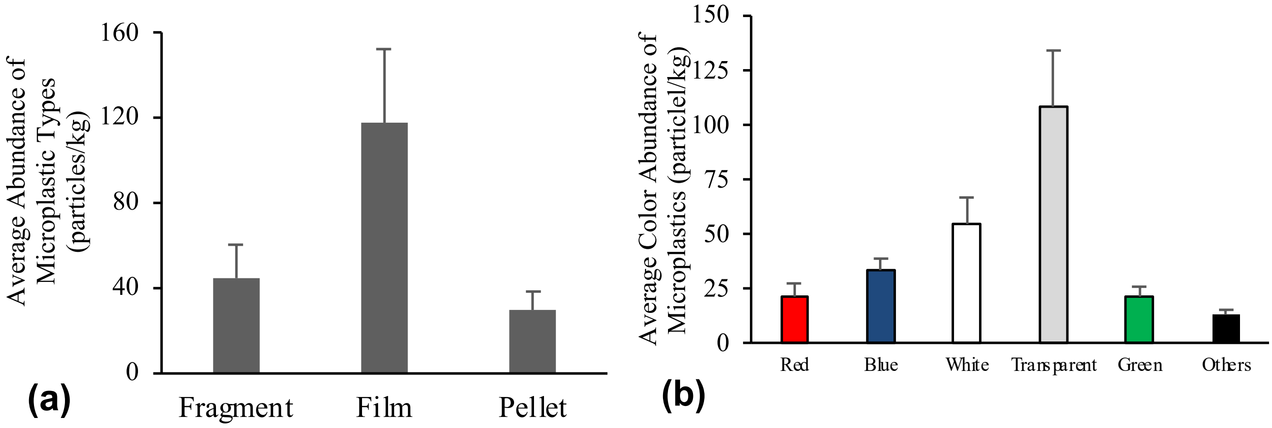

Figure 4. Average abundance of microplastics in sediment: (a) type and color

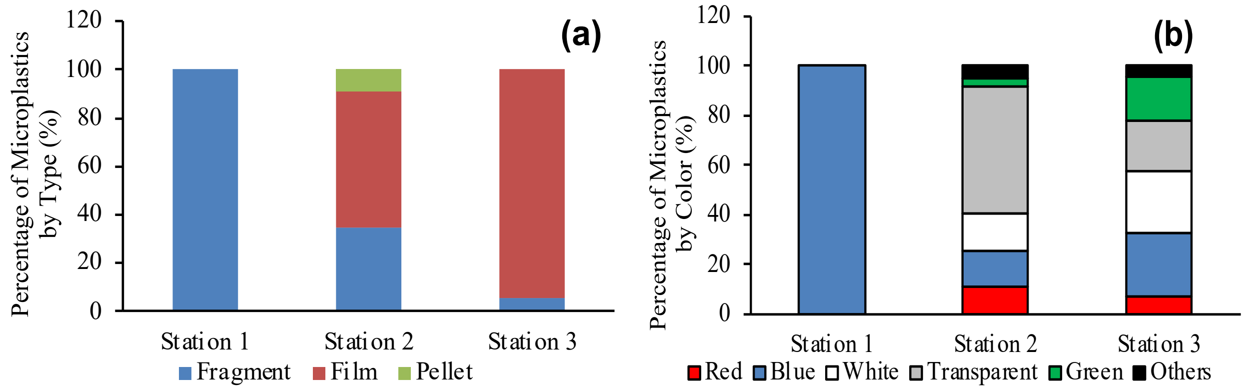

Figure 5. Percentage of microplastics in sediment at each station: (a) type and (b) color

This study found three types of microplastics found in the sediment of the Wonorejo Mangrove Tourism Area in the form of fragments, films, and pellets (Figure 4). The Kruskal-Wallis test showed no significant difference between the abundance of microplastic types in the sediment of the Wonorejo Mangrove Tourism Area (p>0.05). All the types of microplastics found in the Wonorejo mangrove sediment, film is the type of microplastic with the highest percentage (72%) (Figure 3a) and the most incredible abundance (55.1 ± 27.5 particles/kg) (Figure 4a). In addition, film is also the most dominant type of microplastic at Station 2 (56%) and Station 3 (95%) (Figure 5a) with an abundance of 73.3 ± 55.4 particles/kg and 92 ± 60.6 particles/kg, respectively (Figure 6a). The Kruskal-Wallis test showed that there was no significant difference in the abundance of film types at each station (p>0.05).

The presence of microplastics in the study areas is strongly influenced by the prevalence of plastic waste within that environment (Cauwenberghe & Janssen, 2014). The high concentration of film in the sediments of the Wonorejo Mangrove Tourism Area is likely attributed to the abundance of plastic bags and packaging waste in the region. This accumulation is primarily the result of anthropogenic waste entering the Wonorejo River, which is subsequently transported by river currents toward the estuary, where it becomes trapped in the mangrove ecosystem near the estuarine and coastal areas. This finding is supported by a waste census conducted by the Indonesian River Affairs Research Agency (BRUIN) in October 2023 in the Mangrove Ecotourism and Wonorejo Beach area of Surabaya, which revealed that unbranded plastic constituted the majority of waste accumulation. Additionally, waste from major producers was identified as a significant contributor to plastic pollution in the area (Kumparan, 2023).

The dominance of microplastic types in this study aligns with findings from the Ciénaga Grande de Santa Marta Mangrove Area, Caribbean, Colombia, where films were the most prevalent type of microplastics (Garcés-Ordóñez et al., 2019). However, these results were in contrast with previous studies conducted in the Mangrove Ecosystem in Kupang and Rote, the Banyuurip Mangrove Center, and the North Coast of the Persian Gulf, where films were reported in the lowest quantities compared to other types (Zandhi et al., 2019; Yona et al., 2019; Naji et al., 2019).

Film, which are thin and flexible type of microplastic, primarily originate from plastic bags and food packaging (Ambarsari & Anggiani, 2022). The high abundance of film at Stations 2 and 3 is likely influenced by their proximity to land-based waste sources and hydrodynamic conditions. Station 2 is closer to residential areas and aquaculture ponds, while Station 3 is directly adjacent to the river flow area. The Wonorejo River is a transportation route for plastic waste, carrying it toward the estuary, where microplastics accumulate in mangrove sediments (Imanuel et al., 2022). Additionally, due to its lower density than other microplastic types, the film is more easily transported and deposited further into the mangrove ecosystem (Astuti et al., 2014; Zhang et al., 2020). The semi-diurnal tidal cycle in the study area, characterized by two high and low tides per day, facilitates the horizontal movement of plastic bags and packaging waste, trapping them within the mangrove sediment at Stations 2 and 3.

Fragment type of microplastics were found at all three stations, with no significant differences in their abundance across locations (Kruskal-Wallis test, $p > 0.05$). The average abundance of fragments was 17.8 ± 11.2 particles/kg (Figure 4a), with Station 1 exhibiting the highest proportion (100%) but the lowest for overall abundance (2.7 ± 2.7 particles/kg). Fragments are typically generated by the degradation of larger plastic waste, such as bottles, pipes, and containers, resulting in irregularly shaped, hard, and thick particles (Dewi et al., 2015; Hiwari et al., 2019). The presence of fragments in Wonorejo Mangrove sediments is likely attributed to riverine inputs and littering by visitors. Additionally, the high number of plastic bottles found in the Wonorejo Mangrove Ecotourism area suggests low public awareness regarding proper waste disposal, further contributing to plastic fragmentation in the sediment (Fatmala et al., 2023).

Pellet type of microplastics were the least abundant in the Wonorejo Mangrove Tourism Area and were only detected at Station 2, comprising 5% of the total microplastic samples (Figure 3a). The low abundance of pellets may be due to the absence of nearby plastic manufacturing facilities, as pellets primarily originate from industrial sources, resin powder, and cosmetic products (Victoria, 2016). Since Station 2 is influenced by tidal movements from Stations 1 and 3, this location may serve as a retention zone for microplastics, causing pellets to accumulate and remain trapped rather than being dispersed to other stations.

The primary source of microplastic accumulation in the Wonorejo Mangrove sediments is believed to be the Wonorejo River, as river currents tend to be stronger than those in coastal waters. The average total abundance of microplastics in the sediments was 76.9 ± 38.5 particles/kg, with the highest concentration recorded at Station 2 (130.7 ±

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73.5 particles/kg), followed by Station 3 (97.3 ± 64.3 particles/kg) and Station 1 (2.7 ± 2.7 particles/kg) (Figure 7). However, statistical analysis showed no significant difference in total microplastic abundance across stations (Kruskal-Wallis test, $p > 0.05$). This suggests that differences in station characteristics did not significantly impact microplastic distribution. The relatively small study area may contribute to uniform microplastic transport via tidal and riverine currents, leading to homogeneous spatial distribution. Additionally, during the dry season, the reduced river flow velocity weakens hydrodynamic processes, limiting microplastic resuspension from sediments and resulting in a more uniform distribution of microplastic particle sizes along the river flow direction (Xia et al., 2021).

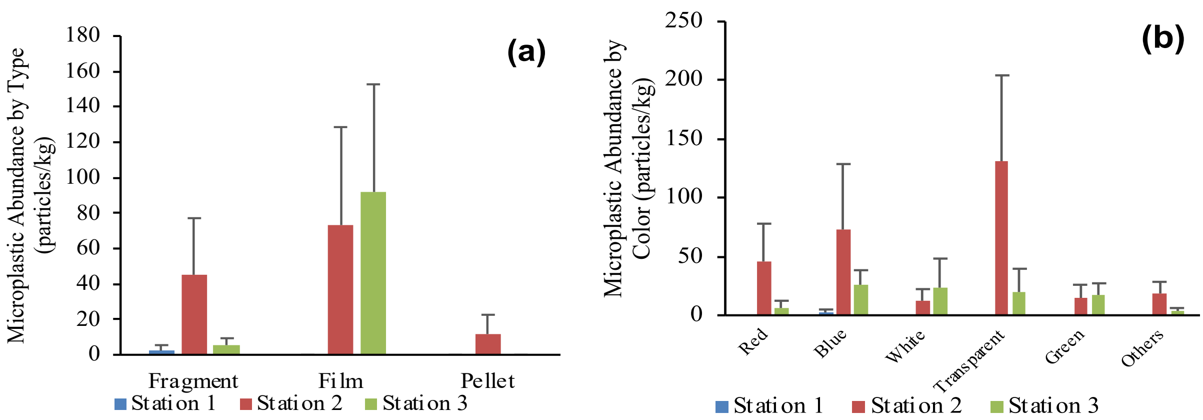

Figure 6. Abundance of microplastics at each station: (a) type and (b) color

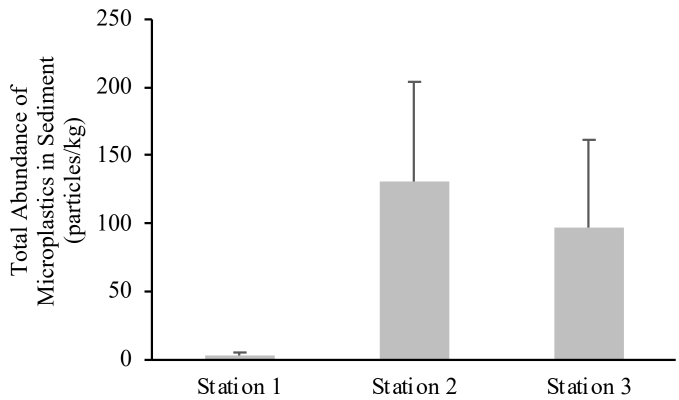

Figure 7. Average abundance of total microplastics at each mangrove station

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This study identified six microplastic color categories: red, blue, white, transparent, green, and others. The color variations were analyzed using the Kruskal-Wallis test, which revealed no significant differences in microplastic color abundance among stations (df = 5; $p > 0.05$). The diverse colors of microplastics can be attributed to various industrial sources, as different manufacturers use different colorants in plastic production (Maghsodian et al., 2021). Transparent microplastics were the most dominant, accounting for 28.9 ± 17.6 particles/kg (Figure 3b). These findings align with previous studies, where transparent microplastics were the most commonly found color in mangrove sediments in China and Brazil (Li et al., 2019; Gerolin et al., 2020).

The color of microplastics often reflects their source, with transparent microplastics primarily originating from single-use plastic bags, food packaging, and plastic containers (Pradiptaadi & Fallahian, 2022; Martí et al., 2020; Shruti et al., 2022). The dominance of transparent microplastics in this study is likely due to high plastic waste input from industrial and urban sources and color fading from weathering and photodegradation processes caused by tidal currents and prolonged environmental exposure (Gerolin et al., 2020).

The Kruskal-Wallis test showed no significant difference in microplastic color abundance among the three stations ($p > 0.05$). This indicates that microplastic colors are homogeneously distributed across the study area, suggesting that station characteristics did not significantly influence color variation. The uniform color distribution across stations implies that microplastics may originate from the same sources (Malli et al., 2023). Additionally, during environmental transport, weathering and photodegradation processes tend to be similar, leading to uniform discoloration and distribution of microplastics across all stations (Kalogerakis et al., 2017; Zahari et al., 2022; Deng et al., 2023; Yu et al., 2023). Consequently, these results indicate that mangrove ecosystems do not selectively retain microplastics based on color (Jiao et al., 2022).

Microplastic Polymer Identification

Polymer identification was conducted using Fourier Transform Infrared Spectroscopy (FTIR) both manually and through the Open Specy online platform, resulting in the detection of two plastic polymers. Among the 173 microplastic particles analyzed from 10 tested samples, the identified polymers were polypropylene (PP) and polyethylene (PE) (Table 1). PP was detected in six samples (FR1–3 and FIL3–5), while PE was found in four samples (PE1–2 and FIL1–FIL2).

In the manual identification process, both polymers were identified by matching at least four characteristic FTIR wavelengths with the reference database. The FTIR spectral analysis for PP exhibited absorption peaks at 2950 cm^{-1}, 2915 cm^{-1}, 2838 cm^{-1},1455cm^{-1}, 1377 cm^{-1}, 1166 cm^{-1}, 972 cm^{-1}, 840 cm^{-1}, and 808 cm^{-1}, whereas PE was identified by peaks at 2915 cm^{-1}, 2845 cm^{-1}, 1467 cm^{-1}, 1377 cm^{-1}, and 717 cm^{-1}. The Open Specy platform was utilized to validate the manual identification results. The spectral matching analysis on Open Specy confirmed the presence of PP and PE with Pearson correlation coefficients ranging between 0.8 and 0.9, indicating a strong correlation and reliable polymer identification.

Based on the results of FTIR graphic analysis, this research found that 173 microplastics tested by FTIR were proven to be particles originating from plastic polymers. Overall, two polymers were identified from both methods with PP dominating in six samples and PE in four samples. The results of this study are similar to several previous studies which found the dominant presence of PP and PE in mangrove sediments in China, India, Indonesia, South Africa and

Table 1. FTIR analysis results

Sample	Polymer
PE1	PE
PE2	PE
FR1	PP
FR2	PP
FR3	PP
FIL1	PE
FIL2	PE
FIL3	PP
FIL4	PP
FIL5	PP

PE - Pelet; FR - Fragment; FIL - Film

Jamaica (Zuo et al., 2020; Yu et al., 2022; Valsan et al., 2024; Cordova et al., 2021; Govender et al., 2020; Rose & Webber, 2019)

The discovery of PP and PE polymers in this study is in line with the characteristics of the samples subjected to FTIR testing. The FTIR spectrum identified PP due to absorption at wavelengths of 2950 cm^{-1} and 2838 cm^{-1} with the C-H stretch group, and 1377 cm^{-1} with the CH_3 bend group (Costa et al., 2020). PP was found in samples FR1, FR2, and FR3 which are fragment type microplastics. The HPP type is stiffer and harder which is more resistant to high temperatures than RCP (Ting, 2014). Due to its durability, HPP is commonly found in the manufacture of plastics such as food storage containers, toys, sports equipment and outdoor furniture (Wu et al., 2021). Apart from that, PP was also identified in samples FIL3, FIL4, and FIL5 which had a type of microplastic in the form of a film. Both types of PP, namely HPP and RCP, can produce plastic films such as Bi-axially Oriented Polypropylene (BOPP) and Cast Films which are usually produced as adhesive tape, food packaging and microwave containers (Wu et al., 2021; Plastic Europe, 2018).

PE was found in four samples, namely samples FIL1, FIL2, PE1, and PE2. PE is classified into several categories, but the two best known types are High Density Polyethylene (HDPE) and Low Density Polyethylene (LDPE), where LDPE is more flexible and has lower tensile and compressive strengths than HDPE (Khanam & AlMaadeed, 2015). Samples FIL1 and FIL2 have a type of microplastic film, so these samples are thought to come from the LDPE type, because LDPE is often found in making plastic bags, trash bags and food wrapping foil (Bayer et al., 2017). Samples PE1 and PE2 have a type of pelleted microplastic, namely primary microplastic whose initial form of production is in the form of complete pellets. LDPE is usually sold in pellet form, which is the easiest form of raw material to use in extrusion (Goff & Whelan, 2000). However, plastic waste recycling products can also produce plastic pellets, one of the sources of which is PE polymer, both LDPE and HDPE (Chandara et al., 2016). The assumption that the sample refers to the LDPE type is strengthened by the appearance of absorption at wavelengths of

1377 cm^{-1} and 1467 cm^{-1} with the respective groups namely CH_3 bend & CH_2 bend which are characteristic of the position of LDPE or as a differentiator from HDPE (Karlsson et al., 2020; Meyns et al., 2019).

From the results of polymer analysis, it was confirmed that microplastics did come from anthropogenic activities, the main source of which was thought to be river runoff (Kurniawan & Imron, 2019). The discovery of PP and PE plastic polymers in this research is thought to be because these two polymers have a low density so they can more easily reach the mangrove zone from river input. Transport of microplastics from rivers is likely to depend on the density of each polymer, where the movement of low density microplastics (e.g. PE and PP) can cover longer distances, while high density microplastics (e.g. PA and PET) can settle in nearby sediments point of origin (He et al., 2021).

CONCLUSION

The abundance of microplastics in the sediments of the Wonorejo Mangrove Tourism Area, Surabaya is quite diverse, where film is the type of microplastic that dominates due to the high pollution of plastic bags and packaging in the Wonorejo River area. The discovery of variations in microplastic colors comes from the initial source of the plastic waste itself until it degrades into microplastics. The abundance of microplastics based on each station tends to be homogeneous. This indicates that mangrove interception is not very selective towards different types and colors of microplastics.

AUTHOR CONTRIBUTION

E. conducted the research, wrote the manuscript, collected and analyzed the data. **D.Y**. designed the research, collected the data, and provided direction in writing the article. **S.H.J.S**. collected the data and provided direction in writing the article.

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CONFLICT OF INTEREST

The authors declare no competing interests that are relevant to the content of this article.

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