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Research Article

# Microplastic Distribution in Beach Sediments: Comparison Between the North and South Waters of East Java Island, Indonesia

**Defri Yona[1,2*], Fahreza Okta Setyawan[1], Sisylia Eka Narriyah Putri[1], Feni Iranawati[1,2], Muhammad Ariq Kautsar[1], and Atsuhiko Isobe[3]**

[1]Marine Science Department, Fisheries and Marine Science Faculty, Brawijaya University, Malang, East Java, 65145. Indonesia
[2]Marine Resources Exploration and Management Research Group, Brawijaya University, Malang, East Java, 65145. Indonesia
[3]Research Institute for Applied Mechanics, Kyushu University, Kasuga, 816-8580. Japan

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*) Corresponding author:
E-mail: defri.yona@ub.ac.id

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## Abstract

Microplastic pollution in beach sediments has been studied intensively worldwide, but there are limited studies in the beach areas of the eastern Java Island, Indonesia. This study aimed to identify the distribution of microplastic in four beaches in Indonesia: Bahak, Pesona, Tambakrejo, and Balekambang. The first two beaches are located in the north of Java Island and influenced by the east Java Sea, while the last two are located in the south and influenced by the Indian Ocean. Sediment samples were collected along the strandline inside the 1 × 1 m transect quadrate in the top 5 cm using a stainless-steel shovel. Microplastic and granulometry analyses were conducted to obtain microplastic and sediment grain size data, respectively. Physical parameters of the beaches, such as wind, wave, and ocean current, were calculated using Copernicus and NASA (PODAAC), respectively. The total abundance of microplastic ranged from 54.7 ± 48.6 to 103.3 ± 4.7 particles $kg^{-1}$ with the following descending order: Bahak > Pesona > Tambakrejo > Balekambang. Although there was no statistically significant difference in microplastic concentrations among the beaches, the beaches connected to the Java Sea accumulated more microplastics than the ones connected to the Indian Ocean. Fiber and blue were the dominating type and colors of microplastic. The results confirm that the distribution of microplastic is associated with the morphology of the beaches and the local source.

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## 1. Introduction

Microplastic is defined as a particle smaller than 5 mm (Andrady, 2011; GESAMP, 2015) and has been the subject of several studies about plastic pollution in the environment. Due to its very small size, it is found everywhere in the marine environment and has become a great concern for marine life as well as humans (Auta *et al*., 2017). Microplastic enters the ocean through land activities, mainly rivers, and can be deposited in marine sediments (Harris, 2020).

According to previous studies, the distribution of microplastic in marine sediments depends on the beach morphology, ocean hydrodynamic forces, physical characteristics, and environmental factors (Graca *et al*., 2017; Naji *et al*., 2017; Zhang, 2017; Pinheiro *et al*., 2019; Purba *et al*., 2020; Thepwilai *et al*., 2021; Faizal *et al*., 2022). Beach sediment is prone to the deposition of microplastic because it receives direct contact with human activities (Mauludy *et al*., 2019; Castro *et al*., 2020; Yona *et al*., 2020a). Moreover, it is also exposed to ocean currents and tidal waves that could bring microplastic from the ocean (Harris, 2020; Carvalho *et al*., 2021). Zhang (2017) emphasized that beach sediment is one of the terminal depositions of microplastic since the dynamic interaction of microplastic with the shoreline structure has a significant effect on microplastic accumulation. Pinheiro *et al*. (2019) also observed that the presence of hard structures on the coast such as beach rocks has the potential to deposit more microplastic.

According to several studies, different types of microplastic have been accumulated in the beach sediments based on the size (Thepwilai *et al*., 2021), specific density of the polymer (Graca *et al*., 2017), as well as the fragmentation process (Zhang, 2017). The type of microplastic can be differentiated into plastic fragments, pellets, filaments, films, foamed plastic, as well as granules and Styrofoam (Hidalgo-Ruz *et al*., 2012). Harris (2020) in an extensive review of the marine sedimentary environment stated that fiber is the dominating type of microplastic in the beach sediment with smaller numbers of fragments, pellets, and films. Only a few studies have found fragments (Kor *et al*., 2020), granules (Liebezeit and Dubaish, 2012), plastic film (Thepwilai *et al*., 2021), or foamed polystyrene (Kim *et al*., 2015) as the dominating type of microplastic. The domination of fiber proves that secondary types of microplastic are omnipresent in marine environments majorly due to human activities (Kor *et al*., 2020). The abundance is also related to their floatability with a greater surface area to mass ratio (Khatmullina and Isachenko, 2017). This allows them to float on the surface water and subsequently end up being deposited in the beach sediment (Harris, 2020).

Java Island is bordered by Java Sea in the north and Indian Ocean in the south. Java Sea with an average depth of 40 m is considered a semi-enclosed shallow water (Siregar *et al*., 2017) and is surrounded by Indonesia`s main islands, e.g., Java, Sumatra, Kalimantan, and Sulawesi. It is expected to experience high environmental pressure from human activities which might lead to marine pollution (Purba *et al*., 2020). Meanwhile, the eastern part of Indian Ocean bordered by Java Island is a deep ocean with an average depth of more than 1,000 m (Ma'mun *et al*., 2017). These different characteristics might influence the distribution of microplastic in the marine environment, including in the beach sediment.

Studies on microplastic have been conducted in the area of Java Sea, including in seawater, sediment, and also in marine organisms (Asadi *et al*., 2019; Cordova *et al*., 2019; Yona *et al*., 2019; 2020a; Ridlo *et al*., 2020). Compared to the study in Java Sea, there is a smaller number of microplastic investigations in the eastern part of the Indian Ocean (Syakti *et al*., 2017; Yona *et al*., 2021). Moreover, the study of microplastic in the beach sediment between the north and south part of East Java Island has also never been studied. The two study areas are experiencing microplastic pollution from human activities. Therefore, this study aims to analyze the distribution of microplastic and to compare its distribution in the beach sediment from the north (connected to Java Sea) and the south (connected to Indian Ocean) of East Java Island. The result of this study can provide insight on microplastic pollution at the regional level and can be used as a recommendation to mitigate plastic pollution.

## 2. Materials and Methods

### *2.1 Study Area and Data Collection*

This study was conducted on four beaches located in the north and south waters of East Java Island from March to June 2022 (Figure 1). The north part was represented by Bahak and Pesona Beach in Probolinggo Regency which is influenced by Java Sea. While the south part was represented by Tambak Rejo Beach (Blitar Regency) and Balekambang Beach (Malang Regency) which is affected by the Southern Ocean. A 1 x 1 m quadrate transect was placed in the strandline area, and sediment samples were collected from the top 5 cm using a stainless-steel shovel. The number of replicates for each beach was decided depending on the beach length, and in total, there were 20 samples of sediment from all the beaches (Table 1). Approximately 1 kg of sediment samples were collected and divided into two. For granulometry and microplastic analysis, sediment samples were placed in a plastic bag and a glass jar, respectively. All sediment samples were brought back to the laboratory for analysis.

Beach morphology such as beach width and gradient, sediment characteristics, wave height, and ocean current were measured. The beach slope was measured using a water pass hose and a scaling pole. The measurement started from the coastline covering the area with the highest tide to the lowest low tide with a distance of 10 m from the observation point toward the sea (Kalay *et al*., 2018). Wave height data was downloaded from http://cds.climate.copernicus.eu/ website and forecasted using wind direction and speed data considering that wind is one of the important factors in generating ocean waves (Suhana *et al*., 2018). The data used were wave height, period, and direction of the waves, as well as wind data in the form of zonal and meridional components. From the wave data obtained, the analysis was carried out by creating a graph of the wave's height and period. Afterward, the wind data was converted into wind speed and direction magnitude data. Ocean currents data were obtained from the website of http://podaac.jpl.nasa.gov/ with data resolution of 0.33° x 0.33° in the area of 37 x 37 km, and then were processed using Surfer 10 software with the kriging method.

### *2.2 Sediment Characteristic and Microplastic Laboratory Measurements*

In the laboratory, each of the sediment samples was divided into granulometric and microplastic analysis. For granulometric analysis, sediment samples were dried and sieved using a sieve shaker with mesh sizes ranging from 2, 1, 0.5, 0.25, 0.125, and 0.063 mm. Of each sample, sediment in the range of 428.72 to 896.0 g was placed in the stack and shaken for 15 minutes. The grain size percentage, according to the sieve fractions, was determined by weighing the sediment left in each sieve. The grain size sediment was then classified according to Udden-Wentworth grain size classification into granule (x > 2 mm), very coarse (2 > x > 1 mm), coarse (1 > x > 0.5 mm), medium (0.5 > x > 0.25 mm), fine (0.25 > x > 0.125), and very fine sand (0.125 > x > 0.063 mm). This method was conducted following the procedure from Alomar *et al.* (2016).

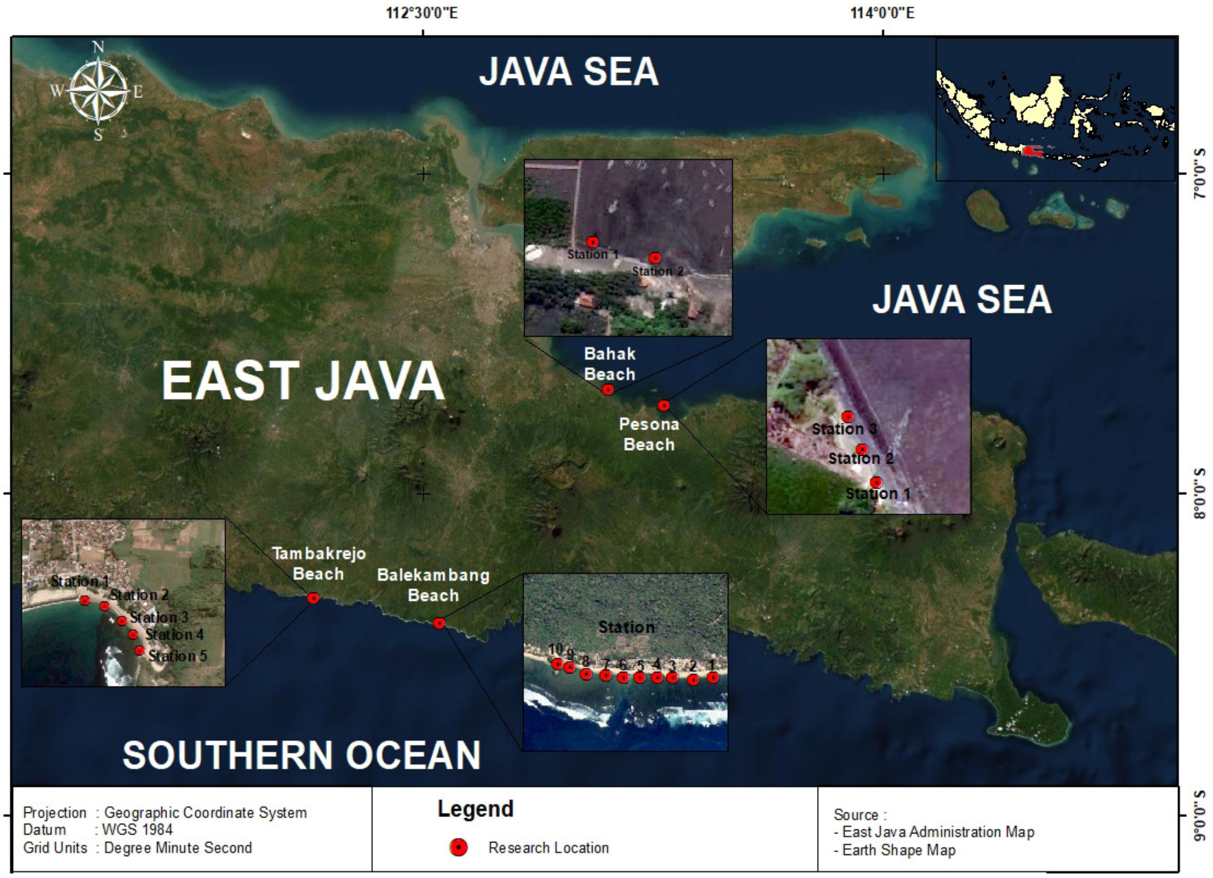


**Figure 1.** The map showing all selected beaches in the study area

Microplastic analysis was conducted by modifying section 3.5 of the NOAA method (Masura and Foster, 2015). In the laboratory, samples were oven-dried at 60°C overnight and sieved through a stainless-steel sieve with 5 mm mesh to remove larger debris. Microplastic analysis was conducted by placing 150 g of sample sediment in a beaker glass, then sodium chloride (NaCl) solution (133.3 g in 400 ml with density = 1.34 g cm$^{-3}$) was added for the density separation. The sample was mixed gently using a spatula for about five minutes and allowed to settle for one night. After the incubation process, the sample was filtered through Whatman filter papers No. 41 (pore size of 20 µm) using a vacuum filtration unit. Filter papers were placed in a closed petri dish, air dried and examined under a microscope (Olympus CX33 equipped with a camera) to identify the type of microplastic particles and their color.

Microplastic particles were classified as fiber, fragment, and film with distinct features of each type (Hidalgo-Ruz *et al*., 2012; Yona *et al*., 2019). A fiber can be identified as a thread-like particle that is equally thick throughout the entire length. Fragment has an irregular shape with sharp and broken edges due to the fragmentation process of larger plastic material. While a film is a very thin particle that is part of the plastic bags.

Contamination during microplastic examination in the laboratory was prevented by making sure all the equipment used was rinsed using filtered water. A cotton laboratory coat was worn all the time, and all samples were covered with aluminum foil when not in use. Additionally, contamination of the airborne plastic particles was observed using blank samples of ultra-pure water placed near the working area.

*2.3 Data Analysis*

All statistical tests were conducted using SPSS version 26, and non-parametric tests were used because the data did not meet the normality assumption. Furthermore, the difference between the total abundance of microplastic among the beaches was assessed with the Kruskal-Wallis's test, while the variation between the north and south waters of Java Island was tested using the Mann-Whitney U test. To assess the relationship between microplastic abundance and sediment grain particles, the Spearman`rho test was used.

## 3. Results and Discussion

*3.1 Beach Typology and Morphology*

All beaches surveyed are famous locally and receive many impacts from tourism activities. Bahak is one of the famous beaches in Probolinggo City and is visited by tourists regularly, while Tambakrejo is located in Blitar City. Additionally, Balekambang has been the iconic beach of Malang City, while the least exposed to tourist activities is Pesona Beach in Probolinggo City. According to the Bathing Area Registration and Evaluation (BARE), beaches are classified into four types based on the level of urbanization and accessibility, namely remote, rural, village, and urban (Asensio-Montesinos *et al*., 2020). Pesona Beach can be classified as a remote type considering the difficult access and limited public service. There is no public transportation to the beach due to its extremely narrow and poorly accessible road. Meanwhile, Bahak and Tambakrejo are considered village beaches because they are located in an area with a small and permanent population. It can only be accessed by private transportation, and they have a small number of public facilities such as shops and food stalls to support tourism activities. Balekambang can be considered a rural beach since it can be reached by public or private transportation. Although it is not located close to the urban area with a large population, the beach is very famous among the locals and is open to the public with very easy access.

According to the wave characteristics observed during the sampling period (wet season), the beaches in the north part of East Java Island predominantly experienced low-energy waves with wave height and period of 0.17 m and 3.53 s in Bahak Beach, respectively, while in Pesona Beach was 0.25 m and 3.71 s (Table 1). Bergillos *et al*. (2016) stated that low-energy waves are characterized by a general wave height of less than 1 m and a period below six seconds. Meanwhile, the beaches in the south part of East Java Island can be considered to experience high-energy waves. The highest current and strongest wind speed occurred in Balekambang Beach were influenced by Indian Ocean's characteristics (Figure 2). One factor that has a significant impact on microplastic deposition in the sediments is the morphology of the beach (Godoy *et al*., 2020). For example, waves energy influences the deposition of microplastic in the beach sediment. Additionally, Lo *et al*. (2018) found that higher microplastic deposition occurred in the mudflats where the wave energy is low.

Sediment grain size analysis showed that beaches in the north part were dominated by a high percentage of coarse sand (> 50 %), while the south part was dominated by coarse and medium sand (> 80%) (Table 2). Granules were higher in Bahak and Pesona Beach (north part) than in Tambakrejo and Balekambang

Beach (south part). Moreover, beach sediment in the north part was black in color, while in the south part, it was white. These characteristics might affect the deposition of microplastic in the beach sediment (Lo *et al*., 2018; Vermeiren *et al*., 2021).

microplastic was recorded in Bahak Beach (103.3 ± 4.7 particles kg-1), followed by Pesona (73.3 ± 1.0 particles kg-1), Balekambang (65.3 ± 33.1 particles kg-1), and the lowest was found in Tambakrejo Beach (54.7 ± 48.6 particles kg-1) (Figure 4). Despite the lowest number of sample replicates, Bahak Beach contained the highest number of microplastic particles per kilogram of sediment dry weight. The Kruskal-Wallis' test showed that the distribution of total abundance for microplastic was the same across the beach ($p>0.05$). In addition, based on the Mann-Whitney U test result, there was no significant difference in the abundance of microplastic between beaches in the north and south waters of East Java Island ($p>0.05$).

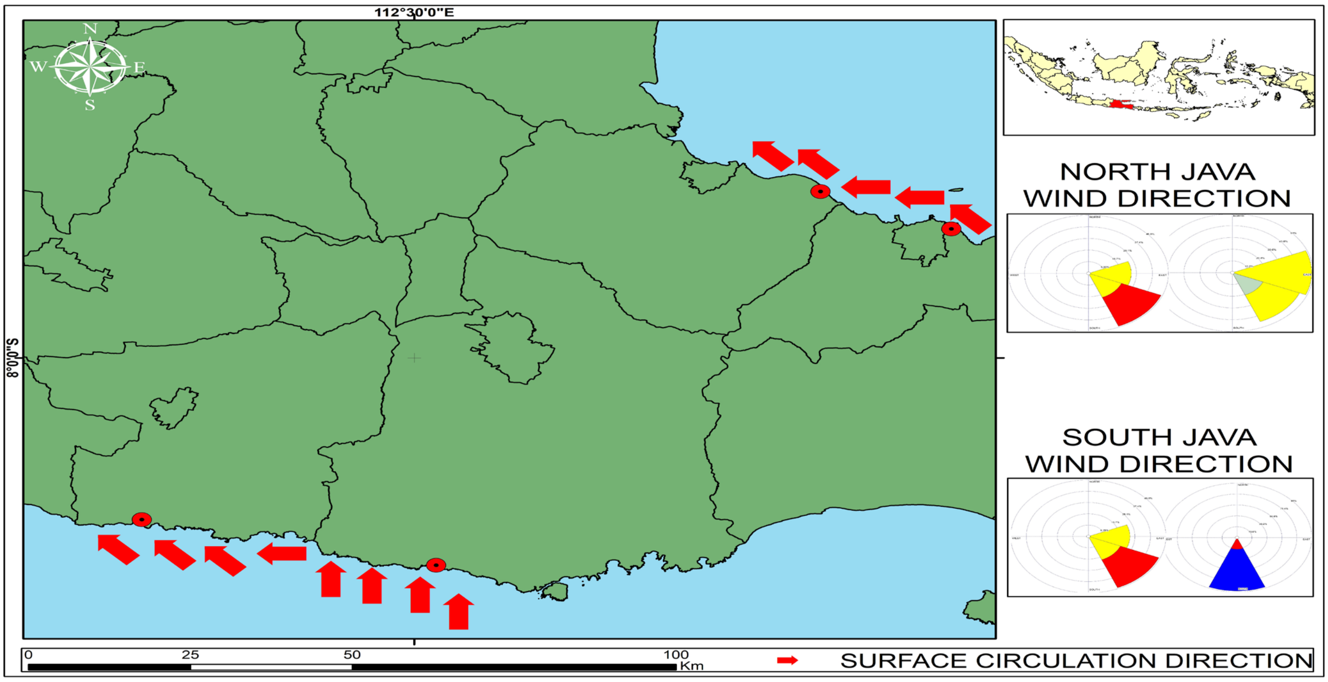


**Figure 2.** Surface circulation and wind direction of the study sites

**Table 1.** Physical and oceanographic characteristics of the surveyed beach

| Beach | Number of sample replicates | Beach length (m) | Beach slope (%) | Wave characteristics | | Currents (m/s) | Wind speed (m/s) |
|---|---|---|---|---|---|---|---|
| | | | | Height (m) | Period (s) | | |
| Northern part (Java Sea) | | | | | | | |
| Bahak | 2 | 47.5 | 11.3 | 0.17 | 3.53 | 0.04 | 2.32 |
| Pesona | 3 | 329.2 | 40.7 | 0.25 | 3.71 | 0.04 | 2.62 |
| Southern part (Indian Ocean) | | | | | | | |
| Tambakrejo | 5 | 369.9 | 28.7 | 1.79 | 8.99 | 0.01 | 2.62 |
| Balekambang | 10 | 1862.1 | 50 | 2.32 | 8.52 | 0.1 | 6.75 |

### *3.2 Microplastic Characteristics*

The occurrence of microplastic was investigated in 20 samples of beach sediment, and all samples were observed to contain microplastic. Among the 20 sediment samples, only one did not contain fiber, while 50% were observed without fragments and films. In total, 72% of the samples were fibers, 16% were fragments, and 12% were films (Figure 3). The highest number of

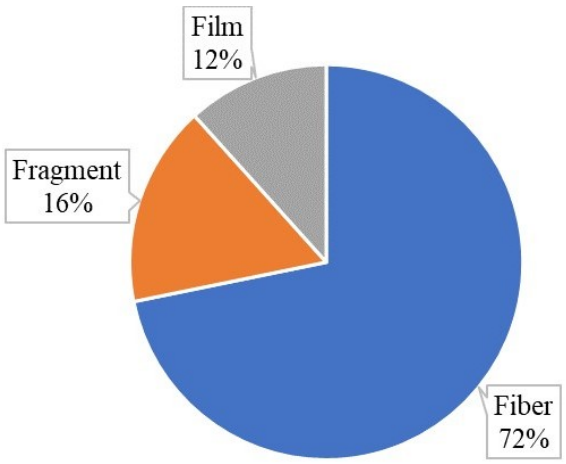


**Figure 3.** Percentage composition of microplastic particles in all sediment samples (n = 20)

(white sand). This difference might also contribute to the difference in the microplastic deposition. Moreover, dark color sand absorbs much more solar radiation than light color sand and it can increase temperature (Cardenes and Rubio, 2017). This might also lead to the variability of the microplastic present in beach sediments, although there are only a few studies on this matter. Detailed investigations are needed to observe the relationship between the color and shape of sand grains on beaches with microplastics.

The presence of microplastic is influenced by several factors, such as beach morphology, oceanographic parameters, and the distance to human activities (Godoy *et al.*, 2020). In detail, Godoy *et al.* (2020) found that enclosed beaches with finer sediment accumulated more microplastic. This is supported by Vermeiran *et al.* (2021) who reported that the abundance

**Table 2.** Percentage of sediment grain particles for each beach site according to the Udden-Wentworth grain size classification. Number inside brackets shows number of replicates Sediment grain particles (%)

| Beach | x > 2 mm | 2 > x > 1 mm | 1 > x > 0.5 mm | 0.5 > x > 0.25 mm | 0.25 > x > 0.125 mm | 0.125 > x > 0.063 mm |
|---|---|---|---|---|---|---|
| | Granule | Very coarse sand | Coarse sand | Medium sand | Fine sand | Very fine sand |
| Northern part (Java Sea) | | | | | | |
| Bahak (2) | 4.88±0.27 | 7.07±1.95 | 55.88±15.04 | 19.45±24.82 | 12.61±12.15 | 0.11±0.15 |
| Pesona (3) | 5.96±5.49 | 14.11±8.58 | 50.11±21.04 | 26.17±21.76 | 3.19±3.12 | 0.46±0.23 |
| Southern part (Indian Ocean) | | | | | | |
| Tambakrejo (5) | 0.32±0.42 | 10.77±20.14 | 44.55±15.79 | 42.09±26.58 | 2.25±2.21 | 0 |
| Balekambang (5) | 1.88±2.01 | 14.76±18.96 | 50.79±8.71 | 31.78±19.42 | 0.78±0.89 | 0.01±0.01 |

Microplastic distribution in beach sediments varies greatly in space and time, even within a single beach (Godoy *et al.*, 2020). In this study, the total concentration of microplastic on eastern Java Island was higher on the beaches in the north than in the south. The highest was found in Bahak, despite having the shortest length (47.5 m) compared to the other beaches (beach length in the range of 329.2 – 1862.1 m) (Table 1). Bahak Beach can also be considered a small semi-enclosed bay, bordered by a mangrove forest on the west side, and a hard parallel structure on the east side. These factors might contribute to the highest accumulation of microplastic in Bahak Beach. Carvalho *et al.* (2021) found a similar reason for the high accumulation of microplastics in the beach sediment of the Fernando de Noronha Archipelago, Brazil. Additionally, the sand in Bahak and Pesona Beach is darker (black sand), while in the Tambakrejo and Balekambang, it is light-colored of microplastic decreased exponentially with increasing sediment grain size. However, this study found no statistically significant association between microplastic concentrations and sediment characteristics based on Spearman`s rho test ($p > 0.05$). Sediment characteristics were observed to be almost similar among the beaches with a higher percentage of sand than granules (Table 2).

A higher number of microplastic particles was observed in Bahak and Pesona connected to the Java Sea compared to the beaches connected to the Indian Ocean. According to Handyman *et al.* (2018), Java Sea has a high potential to become the largest microplastic patch in Indonesia. It can trap marine debris and microplastic for a long time due to its reversing current characteristic. In this study, it was observed that the oceanographic parameters of the beaches might influence the accumulation process of microplastic. Low-energy beaches in the north part area (Table 1) coincided with a higher number of microplastic particles (Figure 4).

The composition of microplastic types varied significantly among the beach (Figure 4). Fiber was found to be the highest in Bahak, followed by Balekambang, Tambakrejo, and Pesona Beach. Meanwhile, fragments were found the most at Tambakrejo, followed by Pesona, and the lowest was in Balekambang. Compared to the fiber and fragment, film was found the most at Bahak, followed by Pesona, Balekambang, and Tambakrejo Beach. The dominance of fiber is consistent with the result of several studies (Table 3), and this particle is mostly coming from common products of human activities, such as fabrics and fishing gear (Browne *et al*., 2011; Kor *et al*., 2020). It also contributes the most to marine organisms from small zooplankton to bigger size fishes (Bessa *et al*., 2018; Kosore *et al*., 2018; Yona *et al*., 2020b; 2022). Therefore, it can be concluded that fiber accounts for 90% of global microplastic particles in the marine environment as suggested by Woods *et al*. (2018) and Isobe *et al*. (2021).

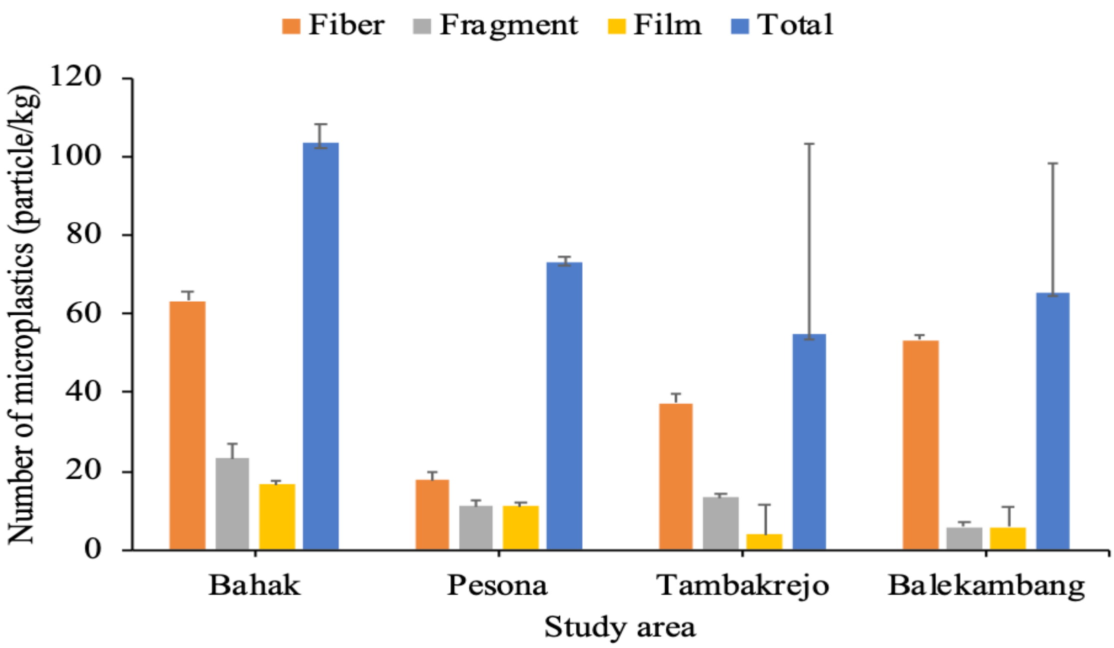


**Figure 4.** Microplastic composition in the beach sediment according to its type (fiber, fragment, and film).

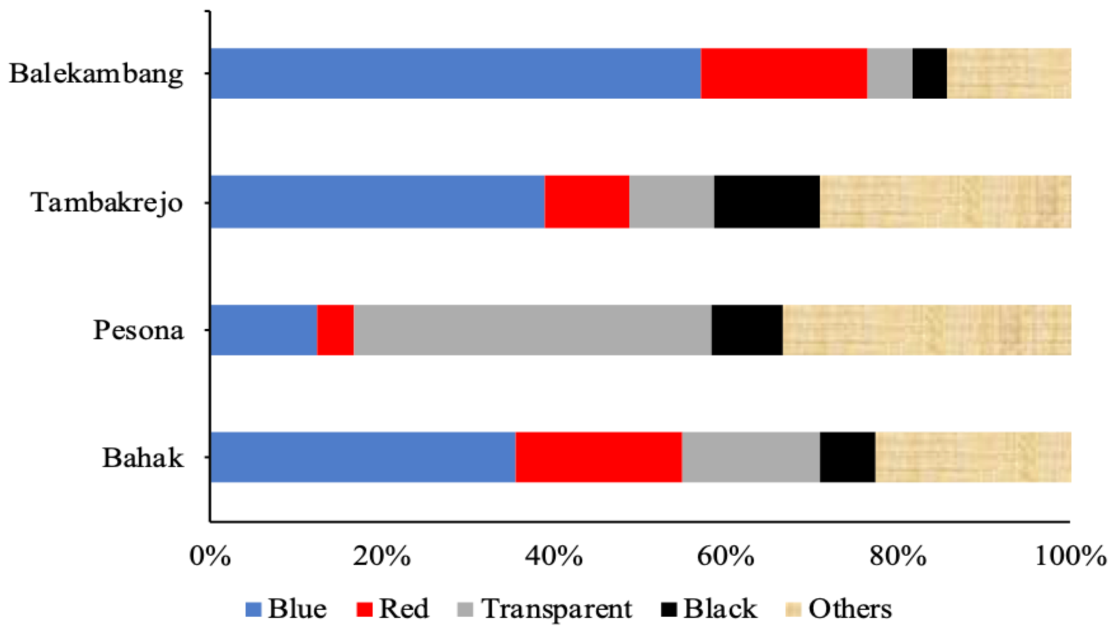


**Figure 5.** Percentage color of microplastic found on each beach

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**Table 3.** Comparison of microplastic abundance in the beach sediment of this study with other studies

| Location | Study site characteristics | Abundance (particle $kg^{-1}$) | Plastic type and color | Reference |
|---|---|---|---|---|
| Southeast coast of China | The study was conducted on 14 different beaches influenced by South China Sea and varied in tourist activities | 93.3–4433.3 | The study did not clearly state the type and color of microplastics, but the authors provided detailed information on the composition of plastic polymers | Chai *et al.* (2022) |
| Along western Gulf of Thailand | Shallow semi-enclosed bay and affected mainly by fishing industries | 20–273 | Sheets were the common type with black color in the vast majority of microplastics | Thepwilai *et al.* (2021) |
| Southern Caspian Sea | The largest inland lake in the world impacted by intensive tourism and fisheries activities | 196.67±11.58 | Fibers and blue/green colors were the dominating shape and color | Manbohi *et al.* (2021) |
| Northern part of Oman Sea, Iran | It is affected by the shipping activities to the Persian Gulf and influenced by Indian Ocean | 138±930 | Fibers and fragments were the majority of microplastic shapes with white and blue being the dominant colors | Kor *et al.* (2020) |
| Southern Baltic Sea | The study areas are classified as non-tidal or microtidal and are exposed to various anthropogenic pressure | 76±295 | Dominated by fiber and fragment; blue and black colors were found the most | Urban-Malinga *et al.* (2020) |
| Po River Delta, northeast Italy | It is affected by several river discharges and influenced by the northern Adriatic Sea which flow counterclockwise currents | 0.47±52.61 | Fragments were dominating, there was no report on colors | Piehl *et al.* (2019) |
| Badung, Bali Indonesia | The beaches are mainly affected by tourism activities | 90.7±59.1 | Fibers were the common type of microplastics and there was no report on colors | Mauludy *et al.* (2019) |
| Northern and southern waters of Java Island, Indonesia | Influenced by two different water masses, namely Java Sea in the northern part and Indian Ocean in the southern part | 20-140 | Fiber and blue color were the dominant types and color of microplastics | This study |

The method used to extract microplastic particles might also be the reason for the high dominance of fiber. Graca *et al.* (2017) found that density separation using NaCl solution probably allows better separation of fibers than the other types of plastic particles. Therefore, the presence of higher density microplastic particles (such as PVC) other than fibers might be underestimated. Hidalgo-Ruz (2012) also stated that less dense plastic particles (such as polyethylene) float better in NaCl solution with a density of 1.2 g $cm^{-3}$, while the denser one's float only in Sodium Polytungstate Solution with a density of 1.4 g $cm^{-3}$. Several studies have also used zinc chloride (ZnCl) solution with density of 1.5 g $cm^{-3}$ to extract denser polymers of microplastics (Liebezeit and Dubaish, 2012; Kor *et al.*, 2020).

Several studies have categorized microplastics into several sizes ranging from <300 µm, 300–500 µm, 500–1,000 µm, and 1,000–5,000 µm (Bridson *et al.*, 2020; Godoy *et al.*, 2020; Chai *et al.*, 2022). Most of the studies found that the concentration of microplastic increases with decreasing particle size. Van Cauwenberghe *et al.* (2015) stated that 35 to 90% of small particles (< 1 mm) contributed to the presence of microplastics in the marine environment. Although this study did not differentiate between the sizes of microplastics, larger particles (1-5 mm) that can be identified visually without the use of a microscope were not observed. Two reasons were suspected of this finding: firstly, this is due to the very thick and porous sampled sediment. A higher percentage of coarse sand (Table 2) makes the removal of substrates easier by waves, hence, the bigger plastic particles cannot stay on a surface for a long time (Bergillos *et al*., 2016; Godoy *et al*., 2020). Secondly, the extraction method used might also cause the absence of larger microplastics. As stated previously, the use of NaCl solution during the density separation allows less dense plastic particles to float better (Graca *et al*., 2017). Consequently, denser plastic particles were still trapped inside the sediment and might be missed during the calculation. In addition, the very small size of microplastic found in this study was the reason that FTIR analysis could not be conducted. It is not an easy task to retrieve the particle that can only be seen by microscope to conduct further FTIR analysis. Previous studies have also found that by using the FTIR method, it is difficult to identify very small microplastic particles because the instrument cannot produce the spectra clearly (Baalkhuyur *et al*., 2018; Sathish *et al*., 2020).

This study found varying colors of microplastic particles in all sediment samples, but they were only classified into blue, red, transparent, black, and others (Figure 5). The varied colors of microplastic indicate diverse origins in the environment (Chen and Chen, 2020). Blue is the dominating color on most of the beaches, except in Pesona which is dominated by a transparent type of microplastic. Furthermore, blue, white, and colorless plastic particles were the dominant colors in the marine environment as reported by Kor and Mehdinia (2020). The dominance of white or colorless plastic particles has also been found on Pasir Pandak Beach, Serawak (Idrus *et al*., 2022), and this might be due to the longer exposure to the sun.

The results in this study are comparable to the abundance of microplastic from other regions (Table 3). This shows that the accumulation of microplastic on beach sediments is a problem worldwide. Chai *et al.* (2022) found a very wide range distribution of microplastics in 14 beaches along the southeast coast of China between 93.3 and 4433.3 particles $kg^{-1}$, and the result was higher compared to our study. Apart from the influence of human activities, previous studies stated that the high number of microplastic particles was also caused by the technique applied in identifying the type and size. The μ-FTIR spectrometer equipped with novel Wizards software that can quickly identify all plastic particles and provide effective identification of small microplastics in the samples was used. In contrast, the lower values of microplastic concentrations observed by Piehl *et al.* (2019) in the Po River Delta, Italy, compared to our study were due to limited access of sampling areas to the beach`s visitors. Another comparison is that the previous studies only targeted large-sized microplastic particles (1-5 mm) to be calculated, while the current study targeted a wider range of microplastic particles. Although several studies stated that comparing the results of different methodologies is difficult (Laglbauer *et al*., 2014; Chai *et al*., 2022), this can still be carried out by analyzing the causes of the differences (Bridson *et al*., 2020; Carvalho *et al*., 2021).

Oceanographic parameters such as wave action, currents, and sediment composition potentially influence the deposition of microplastic in the beach sediment. However, these parameters cannot be the only reason for the similar patterns of microplastic distribution among studies worldwide. The most important factor that influences the accumulation of microplastic is the local sources, such as fisheries and tourism activities, as stated by Lo *et al.* (2018). In this study, the beaches in the north part are closer to human activities compared to those in the south part, and this accounts for the higher number of microplastic particles found. The accumulation of microplastic in the marine environment is a complex interaction between human activities and oceanographic parameters, hence, detailed studies are needed to explore the interactions.

## 4. Conclusion

This is the first study that analyzes microplastic abundance on the beaches of the north and south part of East Java Island. Bahak and Pesona Beach that are connected to Java Sea (north part) accumulated more microplastics compared to Tambak Rejo and Balekambang Beach that are connected to Indian Ocean (south part). Oceanographic parameters and microplastic input from human activities influenced the result of this study. The total abundance of microplastic ranged from 20-140 particles $kg^{-1}$ and it is comparable with the results from other studies worldwide. The dominance of fiber and blue color observed is also similar to several studies on microplastic in the beach sediments. Although the result of this study is comparable with the results from other similar studies, further studies are needed since Indonesia has many beaches with different characteristics.

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during sampling and laboratory analysis.

## Authors' Contributions

The contribution of each author is as follows, DY; designed the sampling process and drafted the manuscript. FOS; conducted the sampling and analyzed beach morphology data. SENP and MAK; conducted the sampling and laboratory analysis. FI and AI; drafted the manuscript. All authors discussed the results and contributed to the final manuscript.

## Conflict of Interest

The authors declare that they have no competing interests.

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