ACCUMULATION OF MICROPLASTICS (<300 µM) IN MANGROVE SEDIMENTS OF BANDA ACEH CITY, INDONESIA

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Abstract. Mangrove sediments serve as sinks for microplastics originating from land, rivers, and the sea. Several studies have examined microplastic contamination in sediments; however, limited research focuses on microplastics smaller than 300 µm in mangrove sediments in Banda Aceh, Indonesia. The purpose of this research is to investigate the abundance of microplastics in surface mangrove sediment in Banda Aceh. Sediment samples were taken from December 2023 to February 2024. Sediment samples were dry sieved and underwent a process to remove organic matter using H_2O_2, followed by density separation using saturated NaCl. A microscope was used to identify the microplastics while applying the rules of Hidalgo-Ruz and a hot needle test. The results revealed that the microplastic abundance was ranged from 1140–3840 particles/kg where the higher microplastic abundance was found in station 1 (Alue Naga Village) in February 2024. Pellets were the most commonly identified microplastics in this study, followed by fibers smaller than 300 µm, and black was the most frequently observed color. The data obtained from this study can be used to support plastic waste management in the area.
Keywords: *coastal water pollution, plastic waste, pellet form microplastic, black color microplastic, microplastic thread*

Introduction

Plastic waste is a global concern due to increasing production and consumption driven by population growth, changing consumption patterns, and urbanization (Liang and Yang, 2019). It is estimated that between 1950 and 2015, approximately 6,300 million tons of plastic waste entered the sea and ocean, while 4,977 million tons accumulated in natural environments and landfill (Geyer et al., 2017). The amount of plastic waste released into the environment is expected to continue increasing unless there is a significant change in waste management. Plastic waste in the sea degrades over time due to sunlight, water currents, and oxidation, breaking down into small particles known as microplastics (Klein et al., 2018). Microplastics are smaller than 300 µm and categorized by type, shape, color, and size (Willis et al., 2017; Browne et al., 2010). Microplastic pollution has dispersed throughout marine ecosystems via currents, winds, waves, tides, and river discharge (Supit et al., 2022). Microplastics that enter water bodies will partially sink into the water column and accumulate in the sediment (Choy et al., 2019). The small size of microplastic particles makes them more likely to be ingested by marine organisms, such as fish and benthos. This is because the color and shape of microplastics resemble zooplankton, leading to global concerns about microplastic contamination that poses a threat to food safety, health, and the environment (Giani et al., 2019).

Mangrove forests are a group of trees that are often found in coastal areas, where mangroves grow in tidal zones that serve as a link between land and sea, playing an important role in the ecosystem. In addition, mangrove forests serve as habitats, spawning grounds for fish, provide food and medicines, act as carbon reservoirs, and their roots function to prevent sediment erosion (Besset et al., 2019; Veettil et al., 2019; Perera and Amarasinghe, 2019). Mangrove forests are important as a source of food and economic resources for coastal communities. Above that, mangrove forests have been identified as being able to prevent plastic waste from drifting from land to the open sea, by plastic waste accumulating between the roots of mangrove trees (Emmerik et al., 2022; Martin et al., 2020). Many reports on microplastics in mangrove sediments and in maine ecosystem have been conducted around the world, including in Vietnam (Nguyen et al., 2020), India (Shelciya et al., 2023), Bangladesh (Tajwar et al., 2022), Malaysia (Mohamed et al., 2023), Thailand (Pradit et al., 2024), the Philippines (Navarro et al., 2022), Singapore (Nor and Obbard, 2014), and China (Li et al., 2018).

Many studies have been conducted on microplastic contamination of sediments in Indonesia, but there is little research on microplastic size < 300 μm in mangrove sediments, especially in the city of Banda Aceh. Microplastics have the potential to become a serious threat to the environment due to their very small size, which can resemble plankton, a food source for various marine biota in the marine food chain. The smaller the size, the more toxic it is since it can get into the tissues of aquatic animals and finally consume by human. The impact of the presence of microplastics is evident in the widespread contamination of various types of marine biota, including benthic animals and pelagic fish (Azad et al., 2018).

Primary microplastic was make at the factory as a bead or pellet shape with a tiny size (normally < 300 μm) and it is mix in the daily goods such as shampoo, cosmetic products. Once microplastic contaminate in the sea or in the sediment, this is concerning because the consumption of microplastics can affect the health of biota. Physical and chemical damage can occur to the internal organs of the biota, as well as potential issues with the digestive system (Azizah et al., 2020), and finally it may enter to human as a top consumer. Therefore, this research aims to determine the abundance of microplastics sized <300 μm in mangrove sediments, focusing on the mangrove ecosystem area of Banda Aceh City Indonesia, an important coastal region in Banda Aceh City. This research contributes to the understanding of microplastics in mangrove sediments and raises awareness about the threats posed by contamination from microplastics.

Materials and methods

Study area

The sampling stations were determined using the purposive sampling method conducted at three stations in Banda Aceh City, Aceh Province, Indonesia, based on characteristics such as station 1 (GPS coordinate: 5°35’29.0”N; 95°20’59.5”E) located in Alue Naga Village, Syiah Kuala District, with an area of 26 ha, mangrove age of 19 years, near shrimp farming, crab farming, oyster farming, settlements, and next to the river mouth. Station 2 (GPS coordinate: 5°57’83.023” N; 95°30’91.072” E) is located in Pande Village, Kuta Raja District, with an area of 47.9 ha, a tourist area, a bivalve harvesting area, and close to a waste disposal site. Station 3 (GPS coordinate:

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5°34’40.0”N; 95°18’32.1”E) is located in Blang Village, Meuraxa District, on the beach directly connected to the open sea, with a mangrove area of only 3 ha, mangroves aged 3 years, and situated in a restaurant area. The research location and mangrove ecosystem in every location are presented in *Figures 1* and *2*.

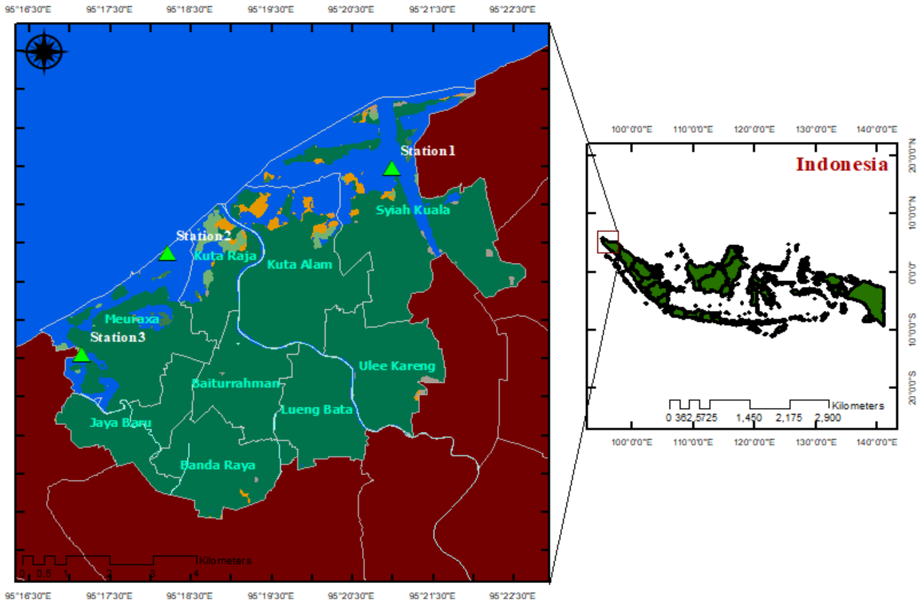

Figure 1. *Study area in Bunda Aceh, Indonesia. The green triangles are showing sampling location*

(a) (b) (c)

Figure 2. *The mangrove plant in the sampling location; (a) Alue Naga Village, (b) Pande Village, (c) Blang Village*

Sediment sampling

Sediment sampling was conducted from December 2023 to February 2024 during the first week of each month. Sampling was conducted at low tide using a corer with a diameter of 8 cm and a length of 30 cm (0–15 cm). At each sampling station, there were transects (*Fig. 3*), with each transect having three plots as repetitions by inserting a corer into the substrate, then rotating it 360 degrees, and slowly pulling it out while covering one end to prevent sediment from escaping. The sediment was then removed and put in the sample bag. Sediment sample analysis was conducted at the Marine

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Chemistry and Biotechnology Laboratory, Faculty of Marine and Fisheries, Syiah Kuala University, Banda Aceh City.

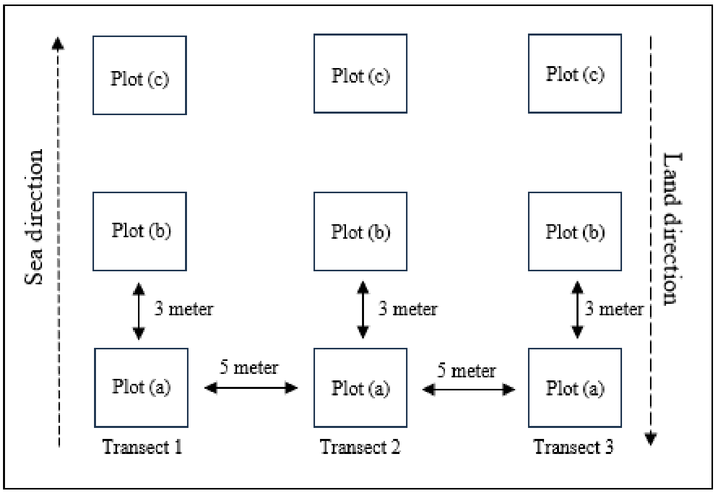

Figure 3. *Sediment sampling at each station*

Microplastic extraction from sediment

After sampling, the sediment was wrapped in aluminum foil and dried in an oven for 48 h at 100°C. Once dry, the sample, which usually clumped together, was broken down into small particles. Next, the sample was sieved using a sieve (mesh size 63 µm). After the sieving process, the sediment sample was placed into a 600 ml beaker glass. Then, 20 ml of 30% H_2O_2 (Hydrogen peroxide) solution was added while heating the sample and homogenizing it at 75°C on a hotplate stirrer for 5 min. After that, density separation was done using saturated NaCl. The beaker was then covered with aluminum foil to prevent contamination from external particles and left for 24 h to allow the sediment to settle while the microplastic particles floated to the surface. The floating microplastic particles were then transferred into centrifuge glass tubes. The centrifugation process was conducted at 7,000 rpm for 20 min to separate the remaining sediment (Fatema and Farenhorst, 2022). After that, the floating microplastic particles were filtered using Whatman filter paper., and then the filter paper was placed on a petri dish glass and dried in an oven at 60°C until dry.

Prevention of microplastics contamination

During the research, precautionary measures were taken during the sediment sample separation process to ensure that the experiment was as free from contamination as possible. All equipment used was avoid plastic, researcher wear cotton lab coats, face masks during experiment to limit contamination during the procedure (Karami, 2017). Aluminum foil was used as a cover for petri dishes and beakers containing samples to prevent contamination, and the tubes used are made from glass.

Microplastic identification

Microplastics are visually identified using a Zeis Primo Star microscope connected to a laptop and equipped with a lighting that can assist in visualizing microplastic

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particles. To determine the microplastic particles found during identification using a microscope, the three rules by Hidalgo-Ruz et al. (2012) were followed: Rule 1 - microplastics do not have cellular structures; Rule 2 - microplastics must have the same fiber thickness; Rule 3 - microplastics must be the same color throughout the particle. Additionally, when using a hot needle, if the particles melts or bends, it can be confirmed to be microplastic because organic material will not change (De Witte et al., 2014). Additionally, identification was based on microplastic characteristics such as shape, color, and particle size.

Statistical analysis

The data of microplastic abundance were subjected to a Duncan's multiple range test to evaluate the difference level among the locations and times of sampling.

Results and discussion

Abundance of microplastics in mangrove sediment

Based on the analysis of microplastic abundance in sediment samples from the mangrove ecosystem over three months of observation was ranged from 1140–3840, where it was found that the highest microplastic abundance occurred at station 1 (Alue Naga Village), with a ranged from 1780–3840 particles/kg. At station 2 (Pande Village) ranged from 1720–2140 particles/kg, while Station 3 (Blang Village) had a lower ranged from 1140–1840 particles/kg (*Fig. 4*).

Station 1 had the highest amount of microplastics among the three stations studied. Several environmental factors that influence this include residential settlements that can increase household waste, small rivers that flow vertically can facilitate the accumulation of microplastics, mangrove trees that allow waste to get caught in their roots increasing contamination, and rainwater can carry microplastics from roads and urban areas to rivers through drainage systems. Additionally, the sediment structure at station 1 consists of muddy and gravel that can trap small particles such as microplastics. Human activities such as fishing, tourism, coral collection, and crab and oyster farming also contribute to the increase in microplastics. Poor waste management exacerbates the pollution problem and the presence of aquatic organisms such as crabs and bivalves accelerates the breaking down process of plastic trapped in sediments into smaller particles. Overall, the combination of location, near the river mouth, drainage channel influence, sediment structure, and human activity play a significant role in the high abundance of microplastics at Station 1.

At Stations 2 and 3, the abundance of microplastics is lower compared to Station 1. Several factors influence this, such as the type of substrate since rocky and sand tends to be coarser, making it more difficult for microplastic particles to become trapped compared to finer substrates. The areas of Stations 2 and 3 are larger, providing more space for plastic waste to be transported by currents to the open sea, thereby reducing the amount of microplastics in the sediment. According to Supit et al. (2022), the abundance and distribution of microplastics on the beach are influenced by oceanographic factors, particularly currents and tides. Stations 2 and 3 are also less affected by human activities since they are further away from residential areas, although there are still tourist spots, fishing activities, crab harvesting, and waste disposal sites nearby.

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Monthly sampling showed that in December 2023, the higher microplastic abundance was found in station 2 (Pande Village), but it was not significantly different from station 1 (Alue Naga Village); however, in January 2024, the higher abundance was recorded at station 1 (Alue Naga Village), but it was not significantly different from station 2 (Pande Village). While in February 2024, the higher microplastic abundance was found at station 1 (Alue Naga Village), it was significantly different from stations 2 (Pande Village) and 3 (Blang Village). Therefore, in general the research results indicate that the highest abundance of microplastics was found at station 1 in February 2024 (*Fig. 4*). The rainy season is predicted to start from September to January, while the dry season runs from February to July. Since station 1 is next to the mouth of the river, and in February is less a start of no rain and the current velocity might less than December and January, therefore more microplastic accumulate at station 1.

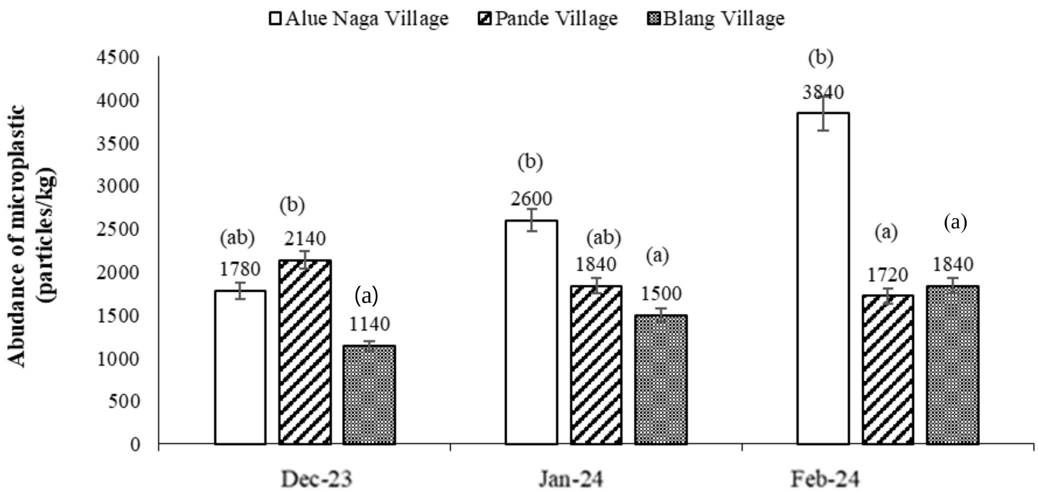

Figure 4. *Abundance of microplastics in sediment mangrove. Bars with the different letters (in parentheses) at the same month are significantly different ($p < 0.05$)*

The research results show that the abundance of microplastics in the sediment of the mangrove area in Banda Aceh is higher compared to mangrove sediment in the Mae Klong River; the upper Gulf of Thailand ranges from 63 to 794 particles/kg (Chaisanguansuk et al., 2023), the Lach Huyen Area, Hai Phong City, Vietnam, is approximately 1,309 particles/kg (Linh et al., 2023), Butuan Bay in the Philippines has an abundance of 40-71 particles/kg (Navarro et al., 2022), the Southeast Coast of Mauritius has an abundance of 107-140 particles/kg (Seeruttun et al.,, 2023), and Muara Angke, Indonesia, has about 28 particles/kg (Cordova et al., 2021). This is probably due to community activities (settlements, fishing ports and tourism), and mangrove density in the Banda Aceh coastal area are being higher compared to the above areas. Field observation showed that Rhizophora is the most dominant species of mangroves growing at the research stations. This species has the breathing roots (Pneumatophores). This root can be a trap for plastic waste drifting from the mainland resulted in increasing of plastic accumulation in this area. Several studies showed that the microplastic abundance in mangrove sediment is higher than in non-mangrove sediment; for example, Manalu et al. (2017) reported 18-38 particles/kg of microplastic in the non-mangrove coastal sediments of Jakarta Bay; Lo et al. (2018) reported the microplastic abundance of 16.8 particles/kg in the mudflat and sandy beach of Hong

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Kong; and Piehl et al. (2019) found the microplastic abundance of 2.92-23.30 particles/kg in the beach sediment of the Po River Delta, Italy. However, the microplastics abundance is not only determined by the presence of mangroves but also by wind, water current, season, and human activities in coastal areas (Alomar et al., 2016; Wilyalodia et al., 2023).

Type of microplastics in mangrove sediment

Fibers, films, fragments, pellets, and foams are five forms of microplastics found in the sediments of the mangrove area in Banda Aceh City, with pellets being the dominant form in the sediments. Laksono et al. (2021) reported pellet-shaped microplastics to be dominant in the waters of Bandiri, Kendal Regency, Indonesia. Similarly, in Sao Paulo, Brazil, pellet forms were found to be more abundant in coastal sediments (Balthazar-Silva et al., 2020). It is known that pellets are a form of primary microplastics made in micro sizes from the outset, produced directly by factories as raw materials for plastic products. However, the abundance of microplastics in pellet form was only highest at station 1, while fiber form was also the most common type at station 1 (*Fig. 5*). The distribution of microplastics in fiber form was the second most dominant, indicating that human activities have a significant impact, such as household waste, especially laundry waste which results in fibers from clothing detaching during the washing process, then spreading through wastewater disposal and enter river waters until being carried by currents to the open sea. This is due to the detergent, the age of the clothing, the spin system, and the presence of water in the process, which increase the release of microplastic fibers during washing process. Types of microplastics in mangrove sediments are presented in *Figure 5*.

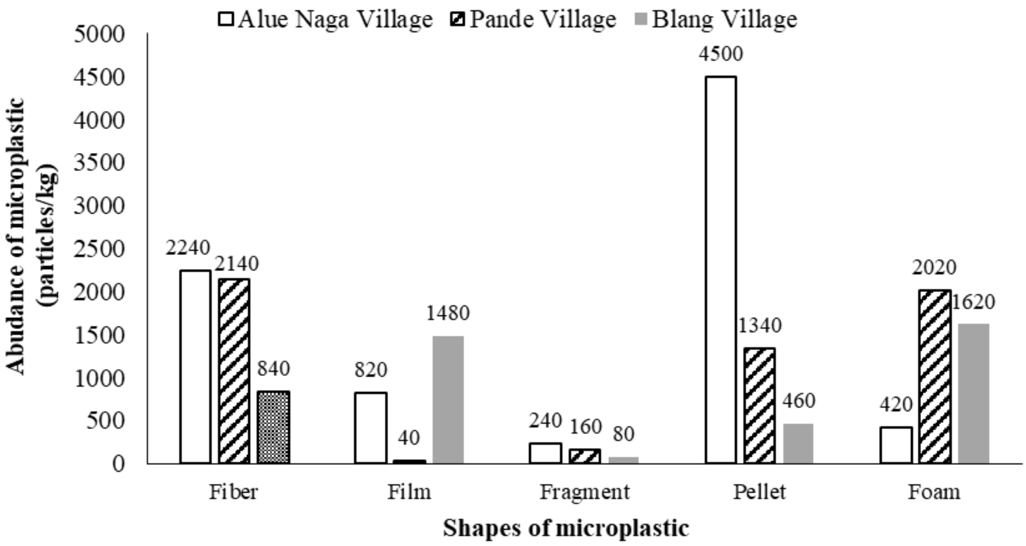

Figure 5. *Shape of microplastics in mangrove sediment*

Fibrous microplastics are long and thin particles resembling threads that originate from fishing nets, ropes, and synthetic fabrics. Fragment-shaped microplastics are irregularly shaped fragments that originate from the breakdown of larger plastic products. Film-form microplastics are thin sheets produced from the fragmentation of plastic bags or packaging into particles. Pellet-form microplastics originate from

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primary microplastics in particle size found in cosmetics and have a round shape. Foam-shaped microplastics originate from styrofoam material, have a round and porous structure, are lightweight, and are usually white in color. The example of forms of microplastics found at the stations are presented in *Figure 6*.

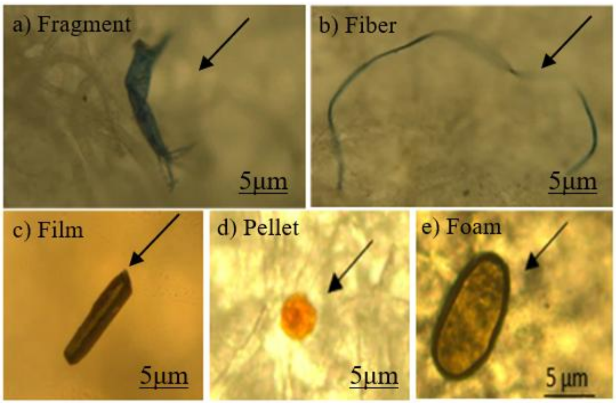

Figure 6. *Microplastic forms found in sediment mangrove: (a) fragment, (b) fiber, (c) film, (d) pellet, (e) foam*

Several studies reported these five forms of microplastics in various bodies of sediments around the world, such as in the beach of Thailand (Jualaong et al., 2021), the coastal waters of Bangladesh (Rakib et al., 2022), the red sea coast at Jeddah in Saudi Arabia (Al-Lihaibi et al., 2019), the Elbe and Mulde rivers in Germany (Laermanns et al., 2021), and in Manila Bay in the Philipphines (Castro et al., 2021). In addition, the diversity of microplastic forms has been reported in Indonesia: sediment from the eastern waters of the Java Sea (Yona et al., 2019), sediment of Muara Angke, Wildlife Reserve (Cordova et al., 2021), sediment from Progo River in Yogyakarta (Utami et al., 2021), sediment of the Surakarta City River basin (Ismanto et al., 2023), and sediment of the Krukut River, Jakarta city (Azizi et al., 2022).

Color of microplastics in mangrove sediment

Seven colors of microplastics were identified in sediment samples, including brown, yellow, blue, white, purple, black, and red. Black was the most dominant color found among the microplastic particles, while white was the second most commonly observed color at the three research stations. Black or dark-colored microplastics may indicate that the microplastics have been degraded in the waters or sediment for a long time and have absorbed more contaminants, whereas light-colored microplastics indicate that the microplastics have not been in the waters for long, so they have not undergone color degradation (Khuyen et al., 2021). In addition, white or gray microplastics come from styrofoam materials. This is probably because of there is a campus and school located in the city and we found many food packaging using styrofoam. The abundance of microplastic colors in mangrove sediments can be seen in *Figure 7*.

The variety of colors found at the research stations is due to the relatively recent degradation process, allowing the microplastics to retain their original colors. The longer it degrades, the more color of the microplastics will fade, however plastic colorants have an impact on the rate of environmental deterioration and the evolution of microplastics (Key, et al., 2024; Azizah et al., 2020).

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Based on the research results, the number of colors found in this study are similar to the number of microplastic colors in the waters of the Northern Adriatic Sea, Italy in which six colors were identified (Digka et al., 2018), in the waters of Songkla Lagoon in Thailand where five microplastic colors were identified (Jitkaew et al., 2024), River Estuary, Borneo Island which had six colors (Liong et al., 2021), Golden Beach, Puri, India which had six colors (Singh et al., 2022).

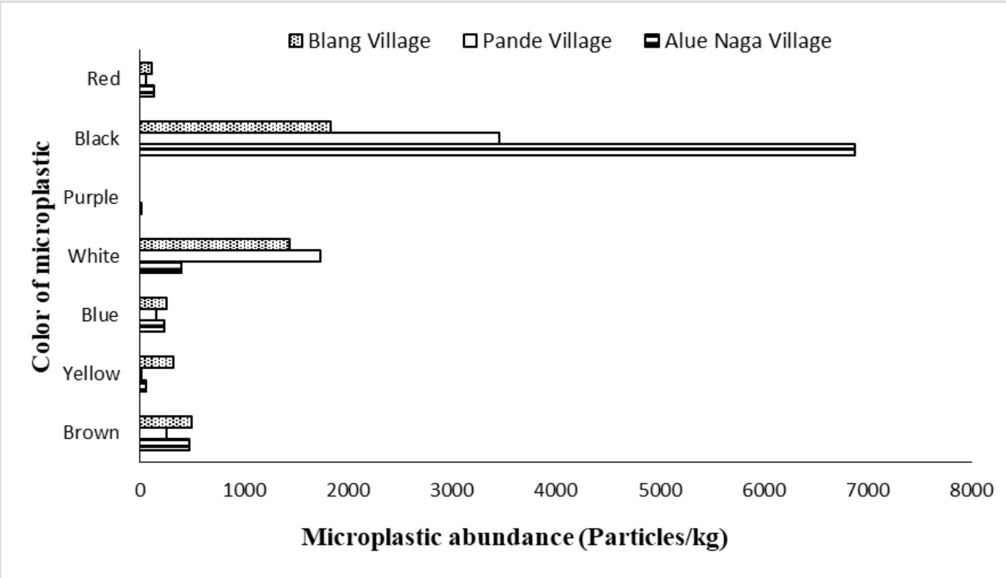

Figure 7. *Colors of microplastic found in mangrove sediment*

Size of microplastics in mangrove sediment

The size of microplastics found in sediments ranged from <20 to 140 µm. Microplastics that are more dominant at all stations were sized <20 µm with a total of 807 particles. Almost the small size, is pellet shape, called primary microplastic, intentionally produced in small sizes, such us those found in health and beauty care products. In addition, the size of microplastic is also influenced by the level of degradation. In this study, the highest abundance of microplastic size <20 µm was found at station 1 followed stations 2 and 3 respectively. Station 1 is an area with many campuses along the riverbank, so it is highly likely that human lifestyles in terms of cosmetic, shampoo, and microbead use is one of the sources of microplastic type pellet and fiber. Therefore, the authors suspect that the microplastics sampled during this study have been in the waters for a long time and have undergone a long decomposition period into smaller sizes below 140 µm. The size composition of microplastics in each seawater region is generally influenced by radiation intensity, microplastic density, air temperature, wind, and oceanography (Classense et al., 2011). In tropical waters such as Indonesia, water temperatures tend to be warm year-round, allowing plastic waste to break down more quickly into smaller sizes. Xiong et al. (2019) stated that climate affects the degradation and formation of microplastic particle sizes in aquatic environments. The classification of microplastics based on size categories follow from this study was shown in *Figure 8*. Microplastics sized <300 µm in sediment also have been found in various countries such as South Korea (Eo et al., 2018), East China (Wang et al., 2018), Indonesia (Manalu et al., 2017), and New York (Faull et al., 2021).

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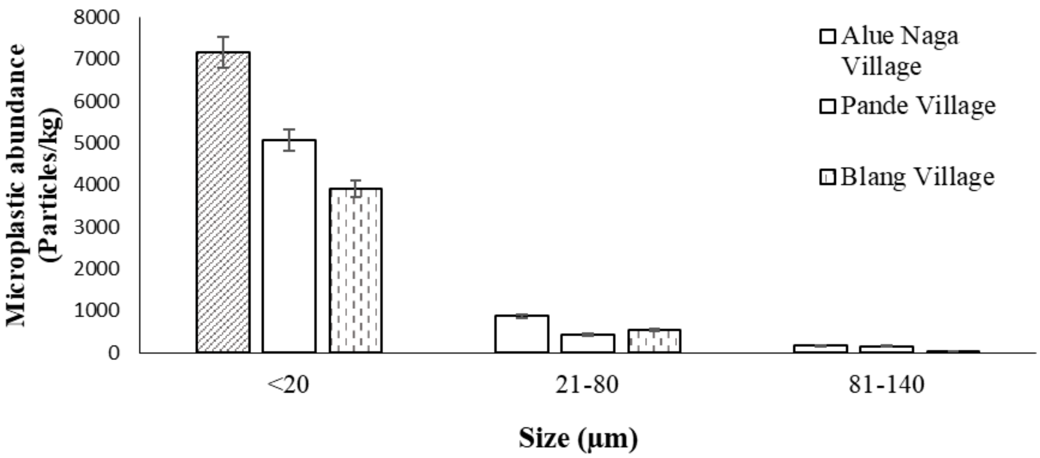

Figure 8. *The size of microplastics in mangrove sediments*

Conclusion

This study investigated microplastics contamination in mangrove sediments of Banda Aceh City, Indonesia. The smaller the size, the more toxic it is since it can get into the tissues of aquatic animals. This research was conducted during December 2023 to February 2024, a rainy season in the region. From the research, microplastic accumulation was found in the sediments from all stations. The microplastic abundance was ranged from 1140–3840 particles/kg where the higher microplastic abundance was found in station 1 (Alue Naga Village) in February 2024. At station 1 located in Alue Naga Village, pellet form was the most abundant followed by fiber shape. The data obtained from this study provides basic information used for plastic waste management in the area. Because this is a preliminary study looking at the accumulation and contamination of microplastics in sediments, the kind of polymer was not explored, so we urge that the future study investigate the type of polymer so that it may be utilized to determine toxicity risk level.

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