Temporal Variation of Microplastic Abundances and Characteristics in Surface Water of Banger River of Pekalongan City, Indonesia

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ABSTRACT

The presence of microplastic pollution in coastal areas has garnered attention due to its detrimental impact on aquatic ecosystems and human health. In this study, our objective was to identify and characterize microplastics in the Banger River area of Pekalongan City, which is known for its numerous industrial activities, particularly batik small-medium industries. The extraction process involved filtration, drying, wet peroxide oxidation, density separation using NaI, and identification of microplastic particles. The shape, color, and size of the particles were characterized using a stereo microscope, while Fourier Transform Infra-Red Spectrometer and the hot needle method were employed for chemical structure analysis. Given that rivers serve as primary conduits for waste transport from land to sea, we conducted sampling at different times of the day. Our findings revealed an average of 0.61 ± 0.47 particles/m³ in the morning, 0.59 ± 0.67 particles/m³ in the afternoon, and 0.10 ± 0.02 particles/m³ in the evening. Among the microplastic polymers analyzed, we successfully identified polypropylene as one of the two predominant types. To establish a baseline for mitigating the release of plastic waste and microplastic residues into the environment, long-term monitoring is essential to evaluate the flow of plastic waste and microplastics from Indonesian rivers to the oceans.

Keywords: microplastic, pollution, river, surface water, Batik, Pekalongan, coastal area, Indonesia.

INTRODUCTION

Long-chain monomers with a higher molecular mass and lower density make up plastics, which are also incredibly elastic and structurally sound. Plastics are non-biodegradable due of their chemical resistance, cost-effectiveness, and durability. In addition to these, their low cost, exceptional oxygen and moisture inhibitors, bio rigidity, and light weight make them excellent packaging material (Andrady, 2011). The considerable growth in the use of plastics, which contaminate ground and surface waters as well as seas, along with plastic accumulation in surface waters, causes a chemical imbalance in the aquatic ecosystem (Rajesh and Nagalakshmi, 2020). According to studies conducted by Lebreton et al. (2017) and Schmidt et al. (2017), 1.15 to 2.41 million tons of plastic are estimated to reach the oceans annually. According to Isobe and Iwasaki (2022), approximately 5% of the overall plastic waste, including both land-based and marine sources, ends up accumulating in the world's oceans, encompassing both surface waters and the seabed (Isobe and Iwasaki, 2022). This accumulation corresponds to an estimated 25 million tons of plastic waste. In contrast, Eriksen et al. (2014) found that ocean currents are responsible for approximately 0.27 million tons of plastic waste floating on the ocean's surface. The substantial disparity between the accumulation estimates reported by Isobe and Iwasaki (2022) and

Eriksen et al. (2014) suggests an overestimation of plastic waste flux from rivers and the absence of a significant missing sink (Weiss et al., 2021).

The uneven distribution of sustainable waste management practices in Indonesia, combined with the vulnerability of coastal areas to plastic waste leakage, contribute to the pollution of oceans by plastic materials. Over time, plastic waste undergoes degradation processes such as oxidation, photodegradation, and hydrolysis, leading to the formation of microplastics (Kameda et al., 2021). Microplastics are polymer particles that are 5 mm or smaller in size and are a typical anthropogenic contaminant that has spread into the aquatic, terrestrial, and atmospheric environments (Veerasingam et al., 2016). Microplastic particles can absorb many kinds of coexisting contaminants and act as carriers of these adsorbed pollutants for long-distance migration because they have a high specific surface area and common functional groups (such as hydroxyl and carboxyl). Furthermore, microplastics may continually accumulate in soils, water, sediments, and other media (Wei et al., 2021; Wang et al., 2021; Koelmans et al., 2019). Microplastic pollution has drawn more attention globally due to its detrimental effects on aquatic ecosystems and human health (Vivekanand, Mohapatra and Tyagi, 2021). Microplastic pollution include household goods, industrial spills, transportation, construction work, regular activities, sea activities, waste management, and recycling. These plastic particles are chemically hazardous due to several additives that were added to the polymer during the production process (Veerasingam et al., 2016).

Natural disasters occur frequently in Pekalongan City, a coastal city in Central Java, Indonesia. Various natural disasters, such as floods, landslides/river erosion, storms, and land degradation, have been reported between 2005 and 2007 (Municipal Government of Pekalongan, 2009). The Kupang River bifurcates into the Banger River, which then flows east of the Kupang River towards the sea, and is part of the Pekalongan River, which is intended to control flooding that occurs almost every year, with the Banger River serving as a canal. It is assumed that more than 80% of water used for domestic, industrial and commercial sectors in Pekalongan City turns into wastewater containing organic and inorganic substances in the form of wastewater and solid waste (Municipal Government of Pekalongan, 2009). Conflicting interests between the industry, fishing sectors, and agricultural sector arise regarding the utilization of the Banger River, which serves as a water source for irrigation.

The lack of proper municipal waste management practices in Pekalongan City can contribute to the input of plastic waste into the Banger River (plastic leakages to the environment), potentially leading to microplastic pollution. Currently, there is a scarcity of information regarding the presence of microplastic contamination in the Banger River. Therefore, this study aims to address this knowledge gap by identifying microplastics in the Banger River and analyzing their characteristics. This research serves as a preliminary investigation of microplastic pollution in the surface water of Pekalongan and was conducted in the Banger River area, which is surrounded by small to medium-scale industrial activities.

METHODOLOGY

Study area and sampling methods

The study focused on a specific section of Pekalongan City, Central Java Province, Indonesia, specifically along the Banger River. Figure 1 represents four study sites along Pekalongan's Banger River, namely the Bantaran Bridge, Setono Bridge, Kali Banger Bridge, and Kuripan Bridge, This figures also illustrates the land-use area in 2020. In 2019, the paddy fields covered an approximate area of 969 hectares, but experienced a decline of 4.54% in 2020. Conversely, the size of dry land increased by roughly 1.24%, expanding from 3,556 hectares in 2019 to 2020 (Statistics of Pekalongan Municipality, 2022). These land use changes reflect the dynamic nature of agricultural activities in the region.

A total of 24 surface water samples were collected at four predetermined location points, as indicated in Figure 1. The selection of these sampling locations was based on the assumption of one sub-basin within the Pekalongan River Basin, where the presence of a batik industry and domestic sewage influx from residents along the Banger River in Pekalongan City suggested potential sources of microplastic contamination. Purposive sampling was employed to choose these sampling points, considering the likelihood of microplastic contamination from both residential and industrial sources.

The sampling was conducted in August 2022 in three separate times, e.g., morning (07.00–10:00), afternoon (10:00–14:00), and evening (14:00–18:00). Sampling methods was adopted from the Japanese Riverine Microplastic Survey Guideline (Ministry of Environment of Japan, 2021). Plankton net (pore size of 0.300 mm) was deployed in duplicates. Water current was measured using a current meter (Kenek, Japan) to calculate the microplastic abundances. The trawling was conducted for 10 minutes following the river flow. After trawling, the plankton net was washed until clean, the sample in cod-end was transferred into a cleaned glass jar and stored at 4 ± 2 °C before further analysis.

Sample treatment and microplastics identification

To initiate the process, water samples were carefully passed through nylon filters with a pore size of 0.3 mm. This step effectively eliminated non-plastic particles and any contaminants larger than 5 mm. Once the filtration was completed, the samples were transferred to glass cups and subjected to a drying period of 48 hours at 60 °C.

After the drying phase, the sample mass underwent peroxide oxidation. A volume of 100 mL of 30% H_2O_2 from SmartLab was added to the samples to degrade any organic matter present. The samples were then placed in an oven for an additional 3 days, maintaining a temperature of 55 °C.

Following the peroxide oxidation step, the samples underwent a filtration process utilizing a vacuum pump. Nal, a substance with a density of 1.6 g/cm^3 from SmartLab, was introduced into a pre-prepared glass funnel along with a nylon filter with a pore size of 0.1 mm. The sample was carefully passed through this setup, allowing for the separation of microplastic particles based on density (plastic particles floated while heavier materials sank). Finally, the separated microplastic
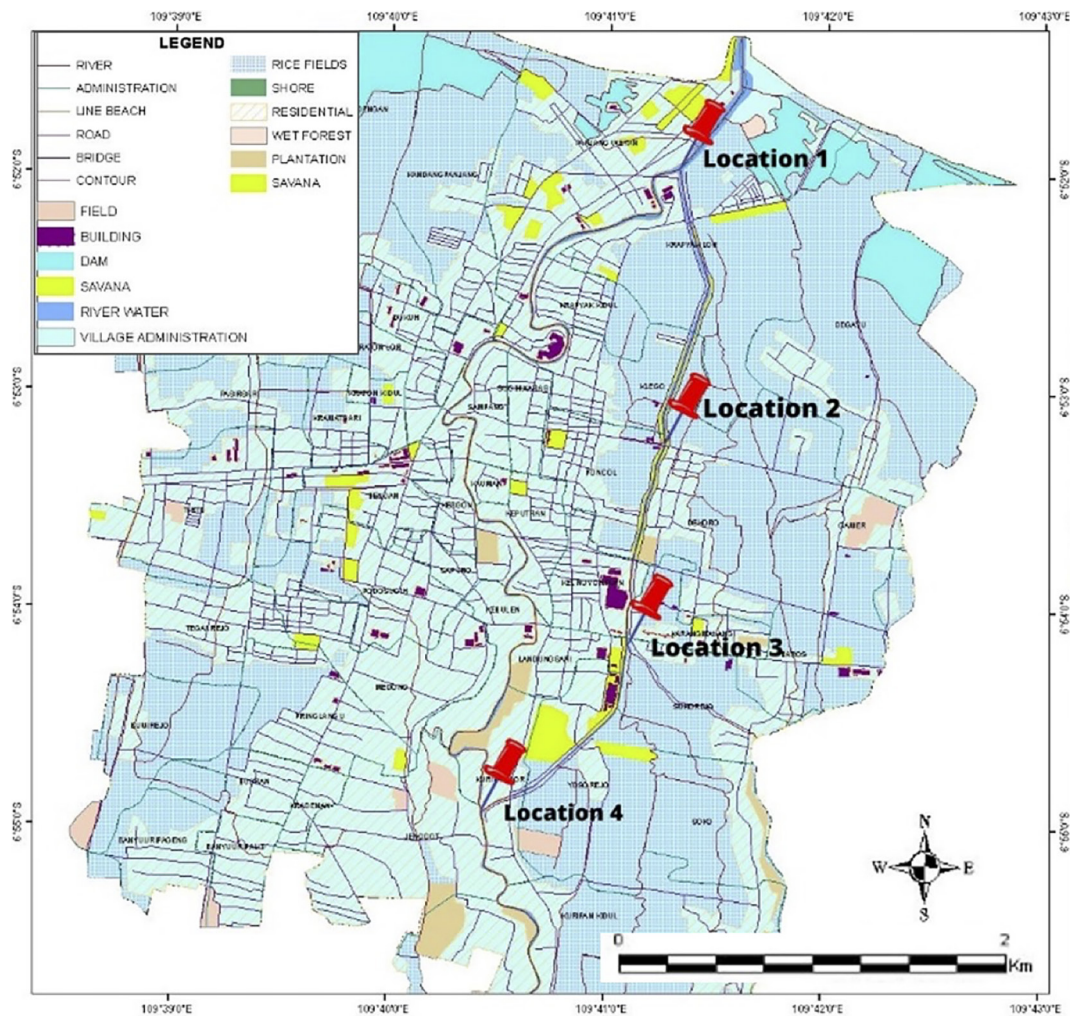

Figure 1. Map of Pekalongan City and the study area

particles were transferred to a petri dish, ready for further analysis and examination.

The next step in the procedure involved the identification of the separated particles. Three categories were used for identification: shape, size, and polymer type. The shape and size of microplastic particles were determined using a Shimadzu Zoom Trinocular Stereo Microscope STZ-161-TLED (114–870). Particles were identified based on specific characteristics such as uniform color, absence of organic or cellular structures, and lack of segmentation. The sizes measured were categorized into three ranges: 0.1–0.5 mm, 0.5–1.0 mm, and 1.0–5.0 mm (Sulistyowati et al., 2022).

Subsequently, the chemical structure of the identified particles was evaluated using Attenuated Total Reflectance (ATR) Fourier Transform Infra-Red (FTIR) analysis (Cary 630 FTIR Spectrometer) with range 4000-650 cm^{-1}, resolution 8 cm^{-1} and background scans 32. Specifically, the ATR-FTIR analysis was employed to verify the size range of 1–5 mm. For sizes of 0.1–0.5 mm and 0.5–1.0 mm, the hot needle method was used as an additional verification technique. The hot needle method involves applying a very hot needle to the particles, which helps distinguish between plastic fragments and organic material. Plastic particles typically melt or warp when exposed to the high temperature of the needle (Beckingham et al., 2023; Chen et al., 2020). In this study, all observed particles were subjected to chemical structure verification.

During the field survey and analysis, the glass container was thoroughly washed with deionized water to ensure cleanliness. To prevent airborne contamination, the samples were promptly sealed with aluminum foil or a watch glass. The wet-peroxide procedure was performed in a controlled environment on a laminar flow cabinet, maintaining optimal conditions. The analyst took precautions by wearing a cotton lab coat and powder-free nitrile gloves to minimize any external microplastic contamination.

Before and after analyzing the samples, the workbench was diligently cleaned to maintain a particle-free workspace. In the FTIR analysis, ethanol was utilized to clean the sensor between each particle sample, ensuring accurate and reliable results.

Data analysis

The microplastic abundances of each sampling time (morning, afternoon, and evening) were averaged and the standard deviations were calculated. Other parameters such as microplastic shapes, colors, and sizes were also summarized and descriptively evaluated based on the sampling time. The abundance of microplastics found was calculated using equation (1):

$$K = \frac{n}{Vol} \qquad (1)$$

where: K – microplastic abundance (particles/m^3);
n – number of microplastics (particles);
Vol – water volume (m^3).
Based on research by Bagas and Trihadiningrum (2019) the formula for obtaining the volume of water in equation 1 was obtained from:

$$V = v \times D \times t \qquad (2)$$

where: v – water current (m/s);
D – area of plankton-net opening (m^2);
t – trawling duration (s).

RESULTS AND DISCUSSION

Microplastic abundances

The study assessed the abundance of microplastics at four specific sites along Pekalongan's Banger River. We observed 252 particles in total. The results showed that the morning abundance ranged from 0.61 ± 0.47 particles/m^3, the afternoon abundance from 0.59 ± 0.67 particles/m^3, and the evening abundance from 0.10 ± 0.02 particles/m^3 (Figure 2). The presence of microplastics in freshwater systems is predominantly attributed to anthropogenic sources, including household usage, industrial activities, wastewater treatment facilities, and agricultural systems (Hitchcock and Mitrovic, 2019). Compared to other studies, the microplastic abundances observed in this research were relatively low. For instance, the Jeneberang River exhibited higher microplastic abundance, ranging from 5.77 ± 1.25 to 3.93 ± 1.32 particles/L (Wicaksono et al., 2021), while Lake Singkarak recorded 9.23 ± 2.14 items/m^3 (Henny et al., 2022).

The lower microplastic abundances found in the Banger River may be attributed to factors such as slower surface water flow, which can be influenced by weather conditions during data collection and the size of the river cross-section. However, it is important to note that variations in research
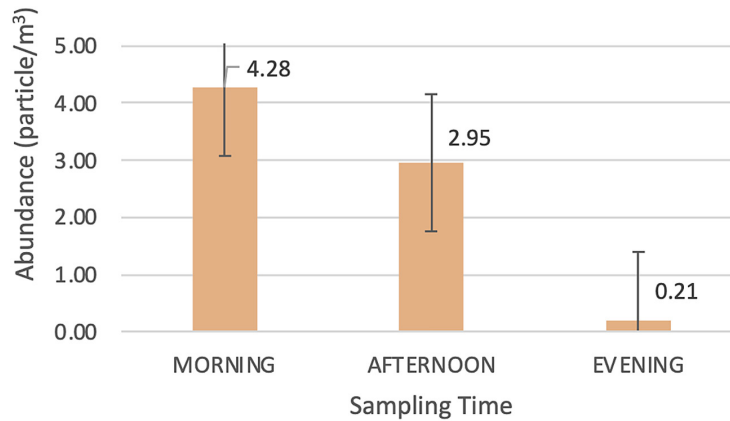
Figure 2. Abundances of microplastic in Banger River

methods can greatly influence microplastic abundance, making direct comparisons challenging. Notably, both the studies (Henny et al., 2022; Wicaksono et al., 2021) did not identify the chemical structure of the particles to confirm whether they were indeed composed of plastic or not.

Microplastics characteristics in Banger River

The study focused on analyzing the characteristics of microplastics, including their shape, size, and color. The shape of microplastics was classified into nine types, namely filaments (7%), fragments (23%), films (36%), granules (5%), fibers (22%), beads (2%), foam (4%), foil (1%), and rubber (1%) (see Figure 3). Figure 4 shows examples of microscope images of microplastics in this study. Throughout the sampling process at various locations, the predominant type of microplastics observed was film-shaped particles, which is consistent with previous findings in Surabaya River, rivers in Greater Semarang, and Singkarak

Lake (Lestari et al., 2020; Andarani et al., 2023; Henny et al., 2022). Similarities between the film particles found in this study and debris from aged plastic packaging further support the notion that these particles originate from the degradation of plastic bags and packaging materials (Mohamed Nor and Obbard, 2014).

The prevalence of film-shaped microplastics can be attributed to the escalating demand for plastic products in daily life (Thompson et al., 2009). Similarly, fragments were identified as the second most abundant shape of microplastics in the samples. Fragmentation of larger plastic items due to weathering, mechanical processes, and landfill incineration contributes to the formation of microplastic fragments (He et al., 2019). The high presence of fragments in aquatic environments indicates that microplastics result from human-generated waste, primarily through river systems (Sarminingsih et al., 2022) and landfill sites (Cordova et al., 2019).
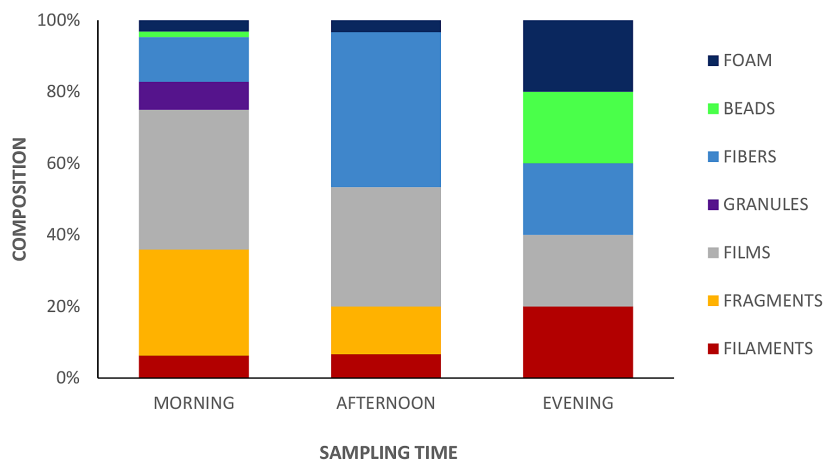

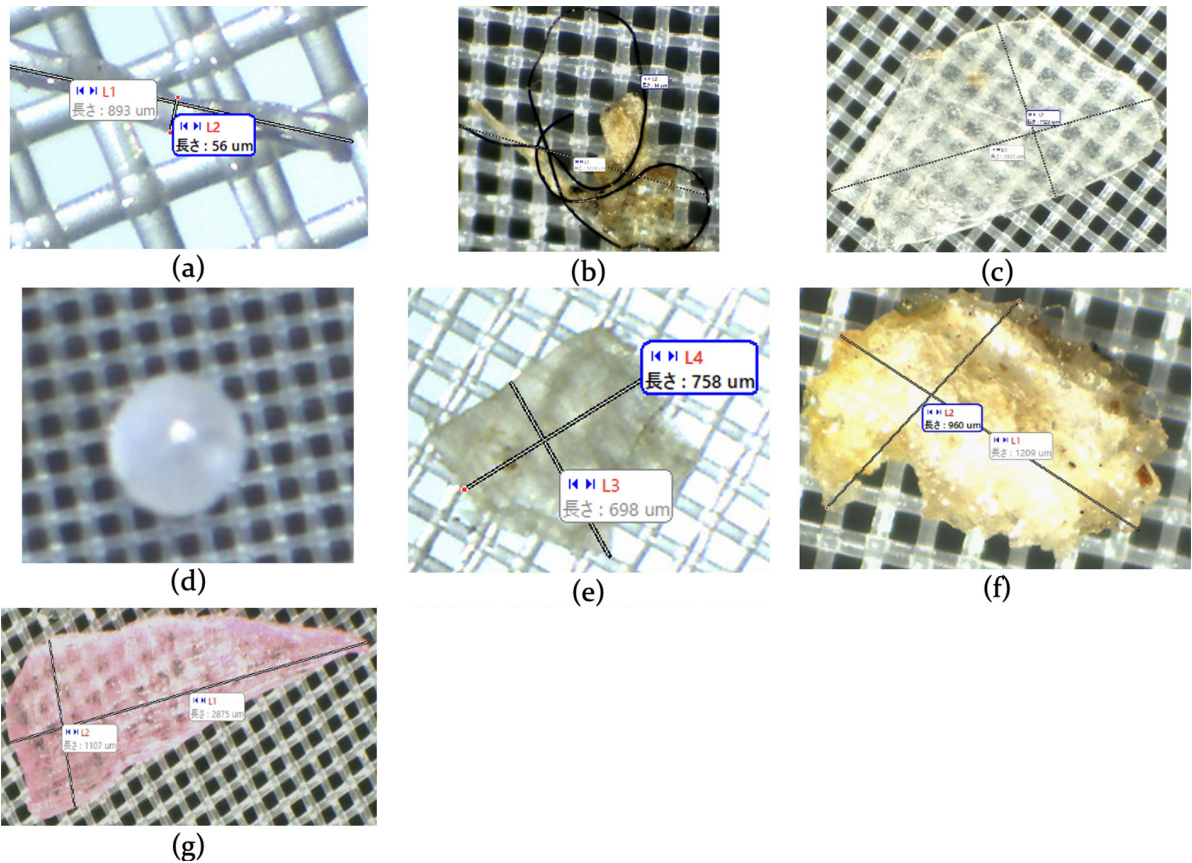**Figure 3.** Percentages of microplastic shapes in Banger River

Figure 4. Representative particle of microscopic image of typical microplastic shapes obtained from Banger River, Pekalongan: (a) filament, (b) fiber, (c) fragment, (d) beads, (e) film, (f) foam, (g) granules. A square grid indicates size of 0.1 mm × 0.1 mm

The study conducted three collection times and examined microplastic samples within the size ranges of 0.1–0.5 mm, 0.5–1.0 mm, and 1.0–5.0 mm, as shown in Figure 5. Interestingly, the highest abundance of microplastics was consistently observed in the morning for each size category. Specifically, the most dominant collection times were associated with the following size ranges: 0.1–0.5 mm with an average of 22%, 0.5–1.0 mm with an average of 10.7%, and 1.0–5.0 mm with an average of 9.3%.

In contrast to the microplastic classification conducted in rivers of Greater Semarang area, where the dominant size category was 1.0–5.0 mm, the current study revealed a higher prevalence of smaller microplastics (Andarani et al.,
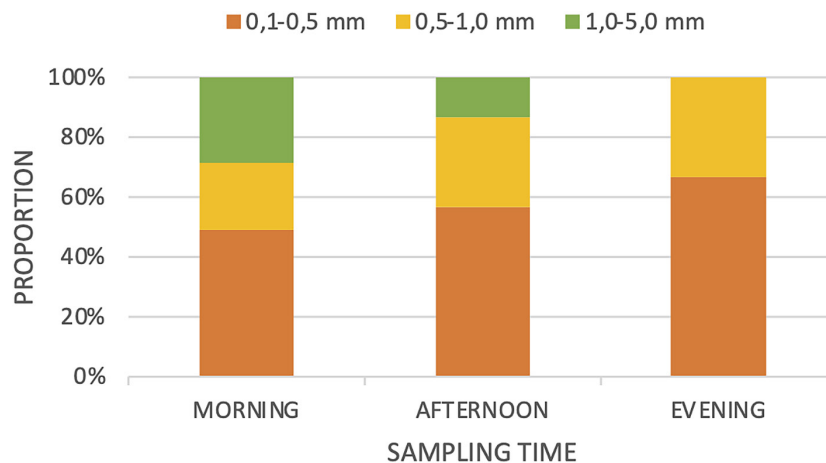

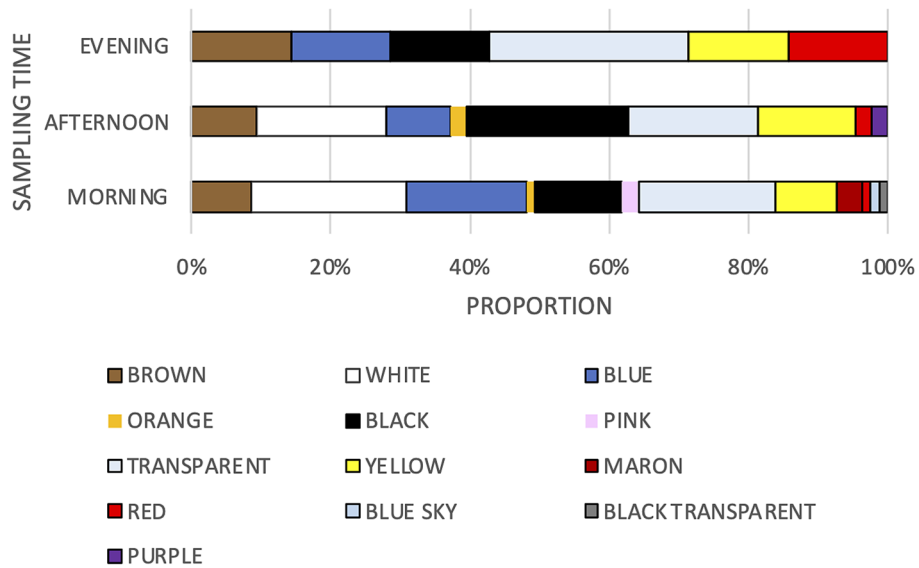**Figure 5.** Percentages of microplastic sizes (mm) in Banger River

Figure 6. Percentages of microplastic colors in Banger River

2023). This suggests that the composition of small microplastics is more prominent compared to larger sizes, potentially due to further degradation caused by physical and chemical stresses from the environment (Wicaksono et al., 2021). Over time, the size of microplastics may gradually decrease due to deterioration mechanisms within the river channel. Additionally, microplastics can shrink to smaller sizes as they migrate closer to the river mouth. Consequently, lower segments of the river are likely to contain a higher concentration of these smaller microplastics (Firdaus et al., 2020).

The study revealed the presence of thirteen different colors of microplastics (MPs) at the study site, as depicted in Figure 6. Among these colors, white (8.7%), transparent (8.7%), and black (7%) were identified as the most dominant colors of microplastics at the Banger River site. In comparison to research conducted in the Jeneberang River, the dominant colors of microplastics were blue, black, white, and red (Wicaksono

et al., 2021). Similarly, in the Tallo Estuary, the dominant color of microplastics was transparent (Wicaksono et al., 2021). The prevalence of colorful and transparent microplastics particles can be attributed to the fragmentation of clear plastic packaging, clothing, and fishing lines (Cole et al., 2014).

Polymer identification in microplastics

Based on the analysis conducted using FTIR measurements on the collected samples, a subset of 10 particles was identified and verified based on their discernible size. These microplastic particles were found to consist of various polymer types, including polypropylene (PP), ethylene propylene (EP), polypropylene with silicate (PP+silicate), polyethylene (PE), polyethylene terephthalate (PET), Chlorinated Polyethylene (PE-C), and High Density Polyethylene (HDPE), as depicted in Figure 7.
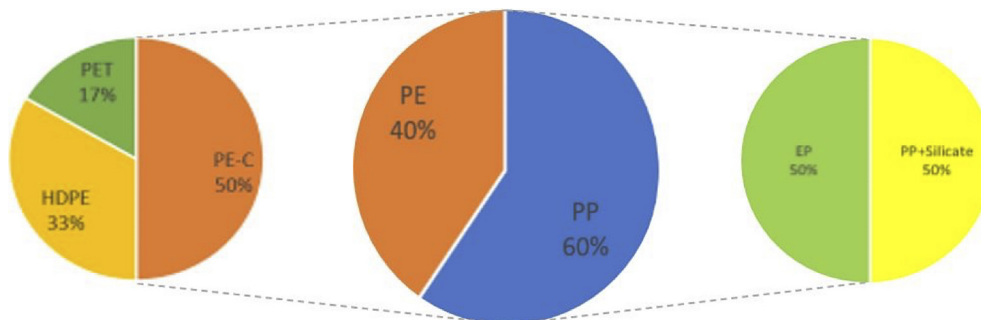

Figure 7. Polymer types of microplastics in Banger River

Among the verified microplastic particles, the most predominant polymer type detected through FTIR analysis in this study was polypropylene, accounting for 60% of the total (Geyer et al., 2017; Kukkola et al., 2021). Polypropylene is widely used as a raw material in the production of various plastic types worldwide, which explains its frequent presence in freshwater environments. This finding contrasts with research conducted in the Cisadane River, where polyethylene was identified as the dominant polymer (Sulistyowati et al., 2022), and in the Tallo River, where polyethylene also prevailed (Wicaksono et al., 2021).

Discussion

Microplastics have been found to be present in surface water across different segments, including upstream, middle, and downstream areas, due to their widespread distribution through fate and transportation processes. However, in the case of the Banger River, the abundance of microplastics was relatively low compared to other studies conducted in the waters of Jakarta Bay (Purwiyanto et al., 2022).

The sources of microplastics identified during the study primarily belong to the secondary category of anthropogenic activities (Eriksen et al., 2013). In the context of the Banger River, these anthropogenic activities extend beyond household-related actions. High levels of microplastics are attributed to various population-driven activities that involve the frequent consumption of plastic items. Some notable direct sources of microplastics in the Banger River area include agriculture, wastewater treatment plants (WWTPs), fishing and fish farming, as well as laundry practices (Purwiyanto et al., 2022).

The findings of this study align with the conclusions of Wang et al. (2017), who established a positive relationship between population and microplastic abundance. Economic activities, such as industrial emissions and land use, have been identified as contributing factors to the high levels of microplastics in the environment and the consequent deterioration of water quality (Zhang et al., 2015).

The study revealed that the level of microplastic pollution in the Banger River is significantly higher in the morning compared to the afternoon and evening, primarily due to increased human activity during that time. However, it should be noted that more data are needed to strengthen the evidence and verify the short-temporal variation. Increased human activity may result in the entry of microplastic particles into the water body, which subsequently transfers from upstream to downstream areas (Ramadan and Sembiring, 2020). The findings indicate that the escalating human activity plays a significant role in the introduction of microplastics into surface water.

Pekalongan, known as a batik city with both household and large-scale textile industries, is characterized by various economic activities. Apart from the batik industry, the city is also home to printing/screen printing, tofu/tempeh, fish processing, and tea leaf processing industries. Most of these industries lack individual wastewater treatment plants (WWTPs), resulting in the discharge of waste directly into surface water channels, including the Banger River (Municipal Government of Pekalongan, 2009). This illustrates how human activities contribute to plastic contamination in freshwater systems, ultimately leading to the entry of microplastics into the ocean.

Landfills serve as significant sources of microplastics, and in the case of the Banger River, there is a landfill (Degayu Landfill) located downstream that potentially releases leachate into the water body, as in the case of Galuga Landfill (Nurhasanah et al., 2021). Degayu Landfill operates open dumping system to dispose of the municipal solid waste. Microplastics are generated during the fragmentation of biodegradable polymers as part of the biodegradation process. However, before complete degradation occurs, microplastics derived from biodegradable plastics pose environmental hazards (Agarwal, 2020). Biodegradable polymers also undergo conventional degradation processes such as oxidation, photodegradation, and weathering aging, which can accelerate the formation of microplastics. As a result, microplastics created from biodegradable polymers can persist for decades in natural environments (Kubowicz and Booth, 2017). The longevity of these microplastics can be further extended when considering their potential migration from favorable biodegradation environments to unfavorable ones influenced by environmental factors such as rain, wind, and tide (Pantani and Sorrentino, 2013).

Research conducted by Wei et al. (2021) compared PBAT (a biodegradable polymer) and LDPE (a conventional polymer) under UV or sunlight exposure. The results indicated that PBAT was

more susceptible to oxidation, leading to cross-linking and chain breaks, which in turn promoted the formation of microplastics compared to biodegradable polymers. This suggests that biodegradable polymers produce a higher quantity of microplastics than conventional polymers such as polyethylene. Similar findings were observed in a study on the Cisadane River, where microplastics in the research location increased threefold (Sulistyowati et al., 2022). To address this issue, it is crucial to transition from an open dumping system to a controlled dumping system, or even to a fully sanitary landfill system, as this can facilitate the reduction of microplastics (Mahon et al., 2017; Murphy et al., 2016).

In addition to releasing leachate that introduces small plastic debris into the aquatic environment, landfill conditions can also contribute to the fragmentation of plastics (Imhof et al., 2013). Small microplastics have a higher likelihood of being ingested by organisms inhabiting the aquatic environment and can easily enter the human body through the food chain, leading to health issues associated with microplastic contamination (Cverenkárová et al., 2021). Moreover, small MPs are more readily absorbed by the soft tissues of organisms, further increasing the risk to these creatures (Triebskorn et al., 2019).

Microplastic shape of films, characterized by irregular shapes and folded structures near the edges, exhibit greater susceptibility to environmental factors, resulting in faster aging compared to other forms of microplastics (Ding et al., 2019). The degree of weathering in the environment can enhance the ability of particles to absorb metal ions and organic pollutants. Fragments, which are derived from the degradation of larger plastic items, transform into smaller sizes (microplastics) with well-defined edge shapes (Guo et al., 2018).

The municipal solid waste entering the Banger River predominantly consists of plastic bags and plastic packaging, which serve as sources of the polymers identified during the study (Manalu et al., 2017).). All the polymers found have a lower density than water, causing microplastics to float on the water surface, thereby facilitating their detection. The current contamination of microplastics in the surface water of the Banger River is expected to provide significant insights into the extent and diversity of microplastic contamination, aiding in the development of remediation strategies to mitigate microplastic pollution in specific geographic areas.

CONCLUSIONS

The morning collection in the Banger River revealed the highest abundance of microplastics, with an average value of 0.61 ± 0.47 particles/m^3. Among the various shapes observed, film-shaped microplastics were the most prevalent, with polypropylene identified as the dominant polymer. These findings underscore the need for a comprehensive understanding of the mechanisms that contribute to the transportation of macro and microplastic waste from rivers to the ocean, posing a significant threat to aquatic ecosystems.

The results of this study provide valuable insights into the distribution of microplastics within the Banger River. By identifying the types and quantities of microplastics present, this research can support initial planning efforts for managing and mitigating microplastic pollution. This information is crucial for devising effective strategies to reduce environmental contamination and mitigate the associated risks to both the ecosystem and human health. A deeper understanding of microplastic dynamics in rivers is essential to safeguard water ecosystems and ensure a sustainable future.

Acknowledgements

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