JURNAL REKAYASA PROSES
VOLUME 17, NUMBER 1, 2023, 22–29

RESEARCH ARTICLE

Microplastics pollution in sediment of Serang River Kulon Yogyakarta Province

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Received 23 February 2022; revised 20 Agustus 2022; accepted 06 September 2022

OBJECTIVES Microplastics that can harm living things have been found in large rivers in Yogyakarta Province to the digestive tract of fish. However, rivers in the suburban areas of the province, such as the Serang River, have not yet been identified, although many local communities still use them. This study aimed to analyze the abundance, type of polymer, and characteristics of microplastics found in Serang River sediments. Sampling was carried out in December 2019 in the upstream, midstream, and downstream areas of the river. METHODS Six sediment samples were taken from each area and randomly divided into two stations. Each sediment sample was then dried, weighed dry, separated the microplastics, observed visually, calculated the abundance of microplastics, grouped shape, size, and color (characteristics), identified the type of polymer by Fourier-transform infrared spectroscopy (FTIR) test, and analyzed quantitatively descriptively and inferentially. RESULTS The results showed that microplastics were present in all samples with an abundance range of 148.88 to 384.58 particles kg^{-1}. The abundance of microplastics in Serang River sediments was highest in the downstream area, with an average of 321.99 ± 46.76 particles kg^{-1}. The microplastic was identified as a polyethylene polymer as the main ingredient for making single-use plastics. CONCLUSIONS The characteristics of microplastics in Serang River sediments are dominated by a size range of 1-100 µm, in the form of fragments and films, and transparent colors.

KEYWORDS downstream; film; fragment; polyethylene; transparent

1. INTRODUCTION

Plastic is an item that is easily found in packaging for food, beverages, and household goods. Plastic is popular because of its lightweight, durability, and low price (Joesidawati 2018), with various strong polymers such as polyethylene, high-density polyethylene (HDPE), polyester, polyvinyl chloride (PVC), and other polymers (Plastics Europe 2016). However, poor waste management systems and low public awareness make plastic waste, in particular, is wasted into rivers (Hiwari et al. 2019). Plastics that are on the banks and streams of river water will be fragmented by heat, physical shocks of river water flow, and also overhauled by microorganisms into plastic fragments measuring less than 5 mm or commonly known as microplastics (secondary microplastics) (Moore 2008; Cole et al. 2011; Cordova 2020). Microplastics can also be produced intentionally for the cosmetic industry and cleaning products in the form of scrubbers or microbeads, or pellets (primary microplastics) (Tanaka and Takada 2016; Miraj et al. 2021). The high abundance of microplastics in the waters and their color, similar to natural foods such as plankton, can be ingested by marine organisms and enter the food chain (Setälä et al. 2014; Manalu et al. 2017). According to Talsness et al. (2009), microplastics that accumulate in the body of organisms can cause damage such as blockage of the digestive tract, which is carcinogenic and endocrine disorders.

The distribution of microplastics worldwide is found in the water column of rivers and seas, river sediments, to deep-sea sediments (Joesidawati 2018). In Indonesia, especially in

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Yogyakarta Province, microplastics have been found in river sediments in urban areas such as the Winongo River, Gadjahwong River, Code River, and Progo River (Utami et al. 2021b,a). Another river that has seen piles of plastic waste as a source of microplastics in the Yogyakarta Province is the Serang River in Kulon Progo Regency. There has been no data collection on the abundance and characteristics of microplastics in the river. According to Kirmanto (2010), this river flow is used for raw drinking materials, fisheries, and agriculture. Garbage in the Serang River comes from community activities in tourist sites, settlements, and industries. This study aimed to analyze the abundance, type of polymer, and characteristics of microplastics found in sediments of the Serang River. The results of this study can provide information about microplastic pollution in the Serang River, that has not been added as parameter in water quality standard (*Baku Mutu Air*) in Indonesia, to the surrounding community, government, and researchers.

2. RESEARCH METHODOLOGY

2.1 Tools and materials

The tools used in this study include a pipe with a diameter of 4 inches and a height of 10 cm, a glass bottle, a 50x50 cm square plot, an oven, a sewing meter 1 m, a glass funnel, a petri dish, a 1000 mL and 500 mL beaker glass, a ping pong ball, refrigerator, spatula, thermometer, pipette, pH meter, lux meter, binocular microscope, microscope camera, 5 mm mesh sieve, GPS, COD kit, DO kit and a digital scale. The materials used in this study included Serang River sediment, distilled water, NaCl, 0.45 μm filter paper, tissue, and label paper.

2.2 Research procedures

This study consisted of several stages: the sampling station's determination, sediment sampling, abiotic measurements and recording of suspected pollutant sources, sample processing, identification of microplastics, and data analysis. Sampling locations were determined in the upstream, middle, and downstream areas of the Serang River. In each area, there were two stations placed purposively based on the presence of pollutant sources (Figure 1). Station 1 and Station 2 are located between the tourist sites of the Kedung Pedut waterfall, Kulon Progo. Stations 3 and 4 are located before and after Wates city and the PT. HM Sampoerna Tbk (cigarette factory) and PT. Sung Chang Indonesia (wig factory). Stations 5 and 6 are located before and after the fishing port and fish auction place (Tempat Pelelangan Ikan / TPI) Karangwuni, which is also the anchoring location for fishing boats carrying synthetic nets.

Three sediment samples at each station were taken randomly in a 50x50 cm square plot between one and three meters from the riverbank (Dewi et al. 2015). Sediment sampling was carried out with a pipe diameter of 4 inches or 10.16 cm

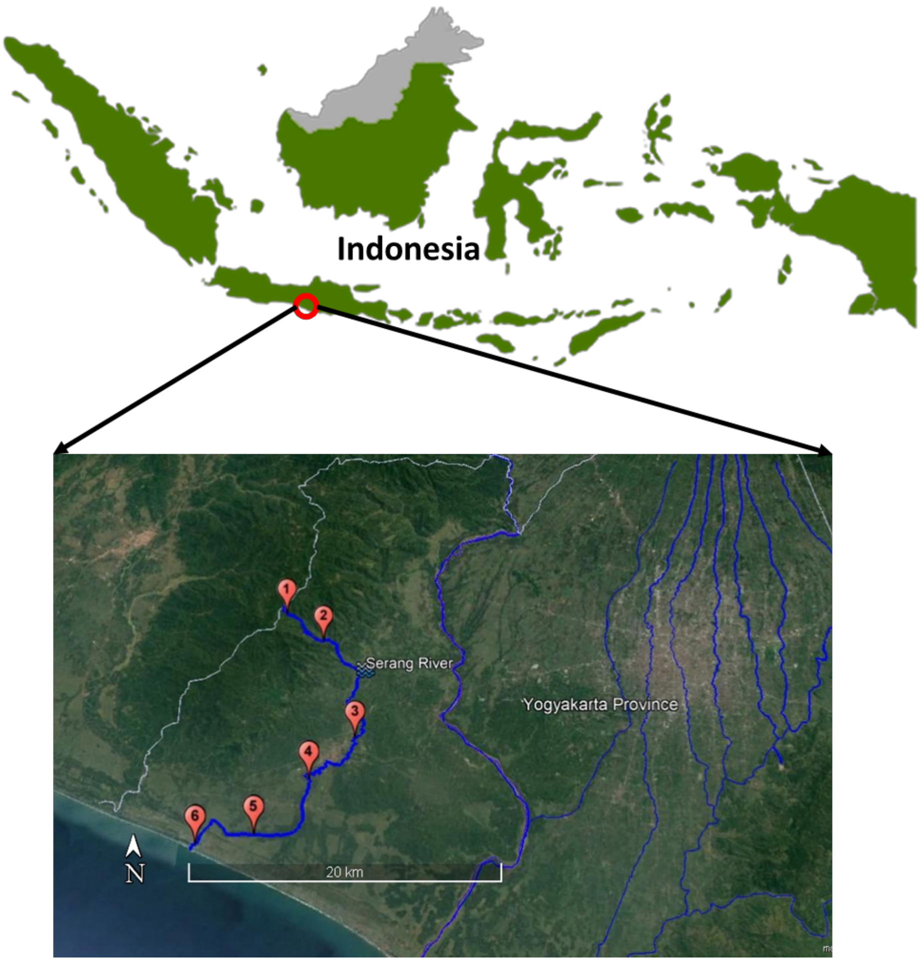

FIGURE 1. The locations of the six sampling stations. Notes: Station 1: 7°46′1.23″ S 110°7′9.92 ″E, elevation 587 masl; Station 2: 7°47′12.01″ S 110°8′40.87″ E, elevation 171 masl; Station 3: 7°51′5.35″ S 110°10′10.52″ E, elevation 17 masl; Station 4: 7°52′37.23″ S 110°8′37.04″ E, elevation 15 masl; Station 5: 7°54′37.27″S 110° 6′50.95″E, elevation 14 masl; Station 6: 7°54′57.96″ S 110°4′51.18″ E, elevation 9 masl.

and a depth of 10 cm, then put into a glass bottle and tightly closed. After that, the glass bottle is put into a container containing ice gel so that the temperature is maintained at 4°C and the sample is ensured not to be damaged. Abiotic factors such as river water temperature, water flow velocity, water pH, light intensity, dissolved O_2 and CO_2, coordinate points, and elevation were measured in the plot with three repetitions. Microplastic pollutant sources were also recorded by walking 500 m in all cardinal directions from the sampling station. All things that have the potential as a source of plastic pollution in settlements, factories, temporary waste disposal sites, tourist attractions, and fish auction sites are recorded as sources of pollution. Sample processing in the laboratory begins with separating microplastic particles from the sediment by first being sieved using a 5 mm mesh sieve. The sediment that passed through the mesh sieve was collected in a beaker and oven at 105°C for 48 hours (Manalu et al. 2017). The dried sediment samples were then weighed using a digital scale. The next step is the separation of microplastics which is done by mixing dry sediment with a saturated NaCl solution (1:3), then the mixture is stirred for 2 minutes and allowed to stand for 2 hours (Claessens et al. 2011). The supernatant suspected to be microplastic will float on the solution's surface, then the supernatant is filtered through 0.45 µm filter paper. The filtered microplastic was then accommodated in a petri dish and identified visually with a binocular microscope, and the images were recorded with the aid of a microscope camera. The total number of microplastic particles per sediment sample will be calculated for their abundance in particles kg^{-1} dry sediment (Dewi et al. 2015). The type of polymer in each area will be validated using the Fourier-transform infrared spectroscopy (FTIR) test by identifying wave crests with their constituent monomers (Utami et al. 2021a). The identified microplastics are then grouped based on shape, color, and size characteristics. Microplastics are grouped into four forms, namely films, fibers, fragments, and pellets (Dewi et al. 2015; Septian et al. 2018; Hiwari et al. 2019). Microplastics are also grouped into transparent, red, blue, brown, gray, and black colors (Manalu et al. 2017). The size of microplastics ranges from 1 µm to 5 mm (Hidalgo-Ruz et al. 2012). This study made modifications to the size by dividing it into several ranges, namely 1-100 µm, 101-500 µm, 501-1000 µm, and 1001- 5000 µm. Each characteristic later, the data will be presented by displaying the percentage of each group.

2.2.1 Instrument and data analysis

The average abundance of microplastics in each area and the percentage of microplastics in each characteristic will be analyzed quantitatively and descriptively. The data will be presented with a pie chart to compare the results in each upstream, midstream, and downstream of the Serang River. The abundance of microplastics between stations and sections will also be analyzed quantitatively inferentially to test for significant differences between data groups. Furthermore, correlation analysis was also carried out between abiotic parameters and the abundance of microplastics to determine the correlation between the two.

3. RESULT AND DISCUSSION

3.1 Abundance of microplastics in Serang River sediment

The results showed that sediment samples in the upstream to downstream areas of the Serang River were found microplastic with an abundance range of 148.88 to 384.58 particles kg^{-1}. The highest average abundance of microplastics in Serang River sediments was found in the downstream area of 321.99 ± 43.63 particles kg^{-1}, followed by the midstream of 239.88 ± 9.20 particles kg^{-1}, and the upstream area of 179. 09 ± 32.08 particles kg^{-1} (Table 1). The abundance of microplastics from six sediment sampling stations in the Serang River varies in number. Station 1, which is in the upstream area, has the least abundance of microplastics, and station 6, which is in the downstream area, has the highest abundance of microplastics. According to Barnes et al. (2009), the abundance of microplastics is influenced by conditions of river water flow and input from land. Determination of sampling locations at six stations on the Serang River considers pollutant sources around the location. The increase in the abundance of microplastics from station 1 to station 6 indicates a source of pollution when determining whether the sampling location is effective. The statistical tests using the Kruskal-Wallis nonparametric test showed significant differences in the abundance of microplastics in Serang River sediments in the upstream, midstream, and downstream areas. Significant differences in the abundance of microplastics between upstream, midstream, and downstream areas indicate an increase in the abundance of microplastics from upstream to downstream. Statistical testing between stations also showed significant differences in the abundance of microplastics between stations 1 and 2 upstream, 3 and 4 in the midstream, 5 and 6 downstream, where there was a source of microplastic pollutants between each station.

According to Nugroho et al. (2018), plastic waste downstream comes from residential areas passed by river flows and settlements close to the downstream area. Microplastics are also abundant in the central area of the Serang River. The central area of Serang River in Wates City is also the center of the Kulon Progo Regency, with many densely populated settlements and several factories. The total population in Wates city in 2019 was 49.090 people, or 11% of total residents in Kulon Progo Regency, 425,758 people (Priyono 2019). This prediction follows Jambeck et al. (2015) theory that the primary input of plastic waste is known to come from densely populated or industrial areas. The sampling location factor close to the mainland also dramatically affects the abundance of microplastics due to considerable waste input (Hiwari et al. 2019). Sedimentation can also affect the abundance of microplastics by accumulating microplastics in a stream (Septian et al. 2018). The texture of the sediment samples taken from the Serang River in this study was sandy loam from station 1 to station 6. According to Watters et al. (2010), soft sed-

TABLE 1. Range and mean of microplastics abundance in Serang River sediments.

Areas	Microplastic abundance Range (particle kg^{-1})	Microplastic abundance Mean (particle kg^{-1})
Upstream	148.88 – 214.13	179.09 ± 32.08
Midstream	229.49 – 252.88	239.88 ± 9.20
Downstream	283.30 – 384.58	321.99 ± 43.63

TABLE 2. Correlation between the abiotic and microplastic abundance.

		Water temperature	Light Intensity	Dissolved O_2	Elevation	Water pH	Dissolved CO_2
Microplastic Abundance	Correlation coefficient	.931**	.990**	.537*	-.990**	-.648**	-.516*
	Sig (2-tailed)	0.000	0.000	0.022	0.000	0.004	0.028

iments can trap more debris than rocky and gravel habitats. Rivers are one of the distribution routes for microplastics and the main route for microplastics from terrestrial sources to the sea (Fischer et al. 2016), originating from community activities around the river. The Serang River passes through many settlements that make this river a place for people to throw garbage carelessly. The average abundance of microplastics in Serang River sediments was 246.99 particles kg^{-1} which was higher than the published average abundance of microplastics in the sediments of the Winongo River (116.81 particles kg^{-1}), Gadjahwong River (170.53 particles kg^{-1}), and the Code River (189.52 particles kg^{-1}), but lower than the average abundance in the Progo River (467.47 particles kg^{-1}) which are all located in the Yogyakarta Province (Utami et al. 2021b,a).

Based on the Spearman test results in Table 2, the abundance of microplastics correlated with abiotic factors such as water temperature, light intensity, water pH, elevation, dissolved O_2, and dissolved CO_2. The correlation coefficient value shows that water temperature, light intensity, and dissolved oxygen show a positive correlation with the abundance of microplastics. In other words, as the abiotic factors increase, the abundance of microplastics also increases. Water temperature and light intensity have a stronger correlation than dissolved oxygen with a two asterisk (**) on the correlation coefficient value. According to GESAMP (2015), the light intensity relates to the abundance of microplastics because microplastics can be formed due to several processes, such as plastic size reduction due to UV light. This condition is also related to the relationship between water temperature and the abundance of microplastics because the higher the light intensity, the water temperature will also increase. Photodegradation triggers the oxidative degradation process of polyethylene by using UV radiation. UV radiation causes the formation of radicals followed by the addition of oxygen to produce a carboxyl group as the final product. This process makes it easier for microorganisms to degrade polyethylene polymers (Arutchelvi et al. 2008).

On the other hand, water pH, elevation, and dissolved CO_2 showed a negative correlation with the abundance of microplastics. The water elevation and pH have a stronger correlation than the dissolved carbon dioxide content with a two asterisk (**) in the correlation coefficient value. According to Das and Kumar (2015), the pH value is a critical factor for the survival and activity of microorganisms. Changes in pH indicate the metabolic activity of microorganisms running to degrade polyethylene. The pH level of the water in this study showed the lower the results, the more the abundance of microplastics increased. This situation was due to the activity of microorganisms in the water. The biodegradation process produces carboxylic acids, the formation of these organic acids can reduce the pH of the environment (Paramita et al. 2012). According to Ayuningtyas (2019), the abundance of microplastics in rivers and seas is influenced by the speed of water flow. Still, in this study, the correlation test results for current velocity did not correlate with the abundance of microplastics because sampling was still at the end of the dry season. The velocity of river water flow was not so heavy. In addition, the sample taken in this study was in the form of sediment, so the speed of the current that was not heavy would help the deposition of microplastics.

3.2 Types of microplastic polymers in Serang River sediments

Based on the results of the FTIR test (Figure 2) on one of the microplastic samples from the midstream, it is known that there are six wave peaks (3029 cm^{-1}, 2987 cm^{-1}, 1678 cm^{-1}, 1295 cm^{-1}, 1125 cm^{-1}, 991 cm^{-1}) where each indicates a specific group of compounds. The peaks of these waves show an alkane group (-CH) with a wave of 3300-3000 cm^{-1}, an ethylene group (C_2H_4) at a wave of 3000-2700 cm^{-1} (Samah 2017), an alkene group (C=C) in wave 1680–1600 cm^{-1} and 1000-650 cm^{-1}, as well as groups of alcohol, ether, ester, carbonic acid (C=O) in waves 1300 – 1000 cm^{-1} (Sastrohamidjajo 1991). Based on the series of wave crests identified in Figure 2, it is estimated that the closest polymer is polyethylene. According to Shah et al. (2008), polyethylene is composed of long chains of ethylene monomers commonly used in synthetic packaging materials.

Polyethylene is one of the polymers with the simplest molecular structure, a thermoplastic made from the polymerization of ethylene (Yuniari and Kasmudjiastuti 2012). Thermoplastic polymers can melt and flow at high temperatures (Charles and Ramkumaar 2009). Polyethylene is generally used to make single-use plastic bags, which are often found in the Serang river. Generally, goods made from polyethylene are transparent (to cloudy). The molecular mass of polyethylene creates variations of this polymer, such as low-density polyethylene (LDPE) to high-density polyethylene (HDPE). The results of the FTIR test on the upstream and downstream also show the same FTIR test results.

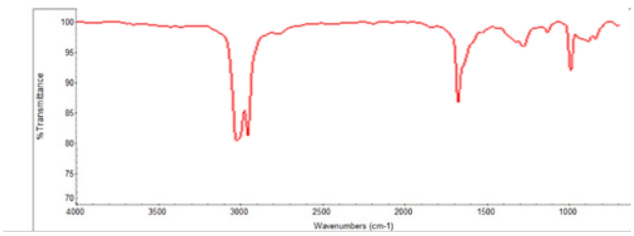

FIGURE 2. FTIR results of microplastics found in representative sediment samples.

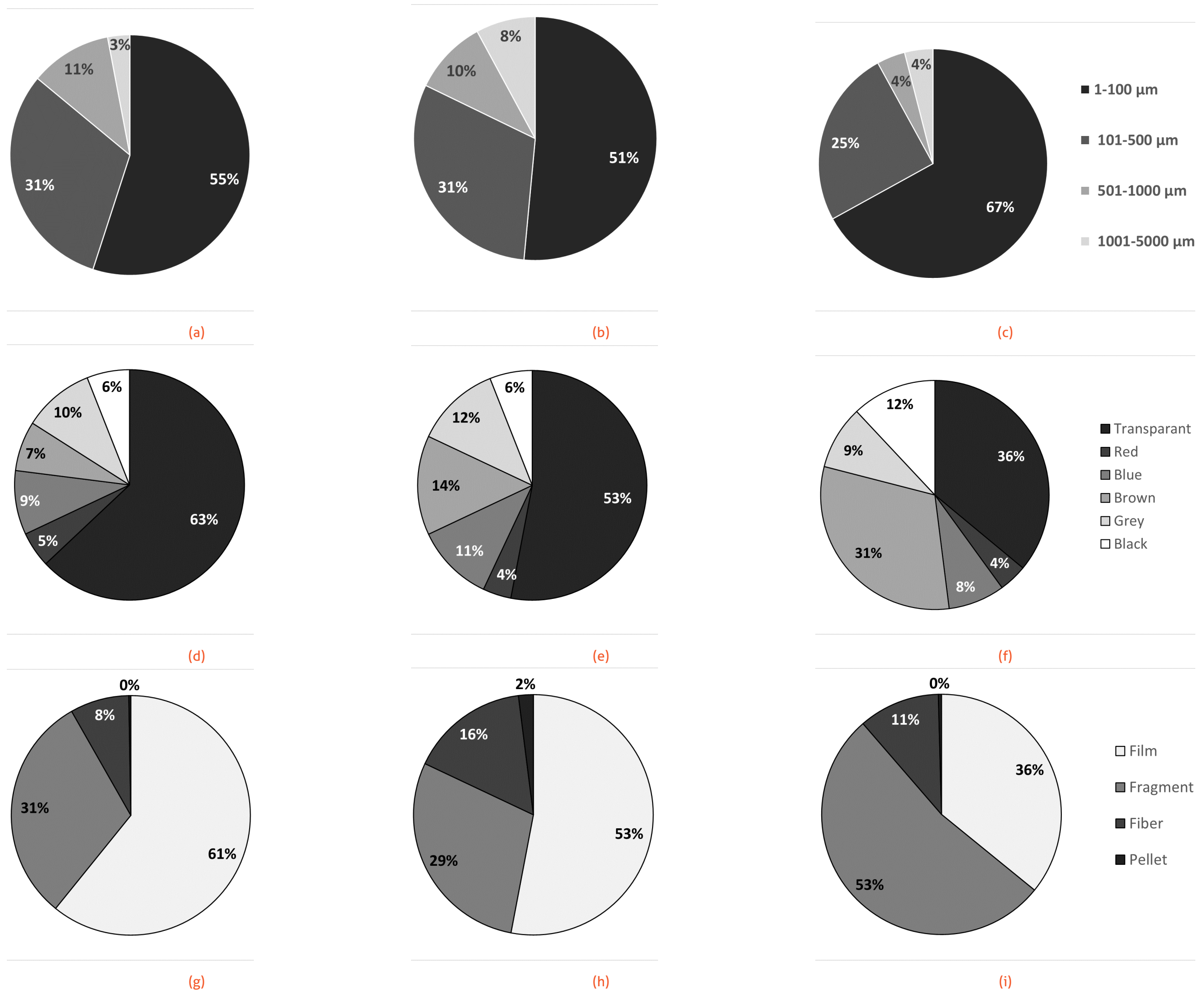

FIGURE 3. Percentage of microplastic characteristics in Serang River sediment. Keterangan: (a, b, c) size; (d, e, f) color; (g, h, i) shape.

3.3 Characteristics of microplastics in Serang River sediment

Microplastics in the upstream, midstream and downstream parts of the Serang River have size, shape, and color characteristics that are not much different. The size of the identified microplastics in all parts was dominated in the range of 1-100 µm with a percentage of 55%, 51%, 67% from upstream to downstream (Fig. 3a, 3b, 3c). The following most commonly found size range is 101-500 μm.. The microplastics found are thought to have undergone a fragmentation process on their way to follow the river flow. The tiny size of this microplastic makes it easier to transport and distribute it downstream of the river (Cooper and Corcoran 2010; Leite et al. 2014). According to Claessens et al. (2011) and Cordova (2020), the cause of macro-to-micro-sized plastic fragmentation is due to ultraviolet radiation, mechanical forces from river water, and decomposing bacteria. Microplastic fragmentation can continue to make microplastics smaller in size and increase the abundance of microplastics over time (Manalu et al. 2017).

Microplastics with transparent color were primarily found upstream to downstream of the Serang River (Figures 3d, 3e, 3f). The colors of microplastics can be in the form of the original color of the microplastic or the color of the degradation that occurs due to the release of the original color due to photochemical processes or other processes (Manalu et al. 2017). The transparent color also indicates the length of time the microplastic is photodegraded by UV light (Hiwari et al. 2019). This study indicates that the transparent colors are clear, light blue, and light gray because the colors have faded. According to Hiwari et al. (2019), the black color can indicate the number of contaminants absorbed in the microplastic. In general, the colors found in the microplastics were still concentrated (red, dark blue, and brown), which meant that the microplastics had not undergone a significant color change (Hiwari et al. 2019). Black microplastics can also absorb high pollutants and affect the texture of microplastics. Microplastics found with full colors can be used to identify polyethylene polymers (Hiwari et al. 2019). Polyethylene is the primary material for making plastic bags and containers (GESAMP 2015). Differences in the color of microplastics are influenced by the source of origin of the microplastics, for example, red and blue are artificial colors resulting from anthropogenic activities (Dekiff et al. 2014). Various colors with high abundance or number values can increase the potential for microplastics to be eaten by fish (Nadal et al. 2016). In addition, the color of microplastics can increase the possibility of microplastics being consumed by organisms due to the similarity of microplastics to the natural food of these organisms (Manalu

 DOI 10.22146/jrekpros.73233

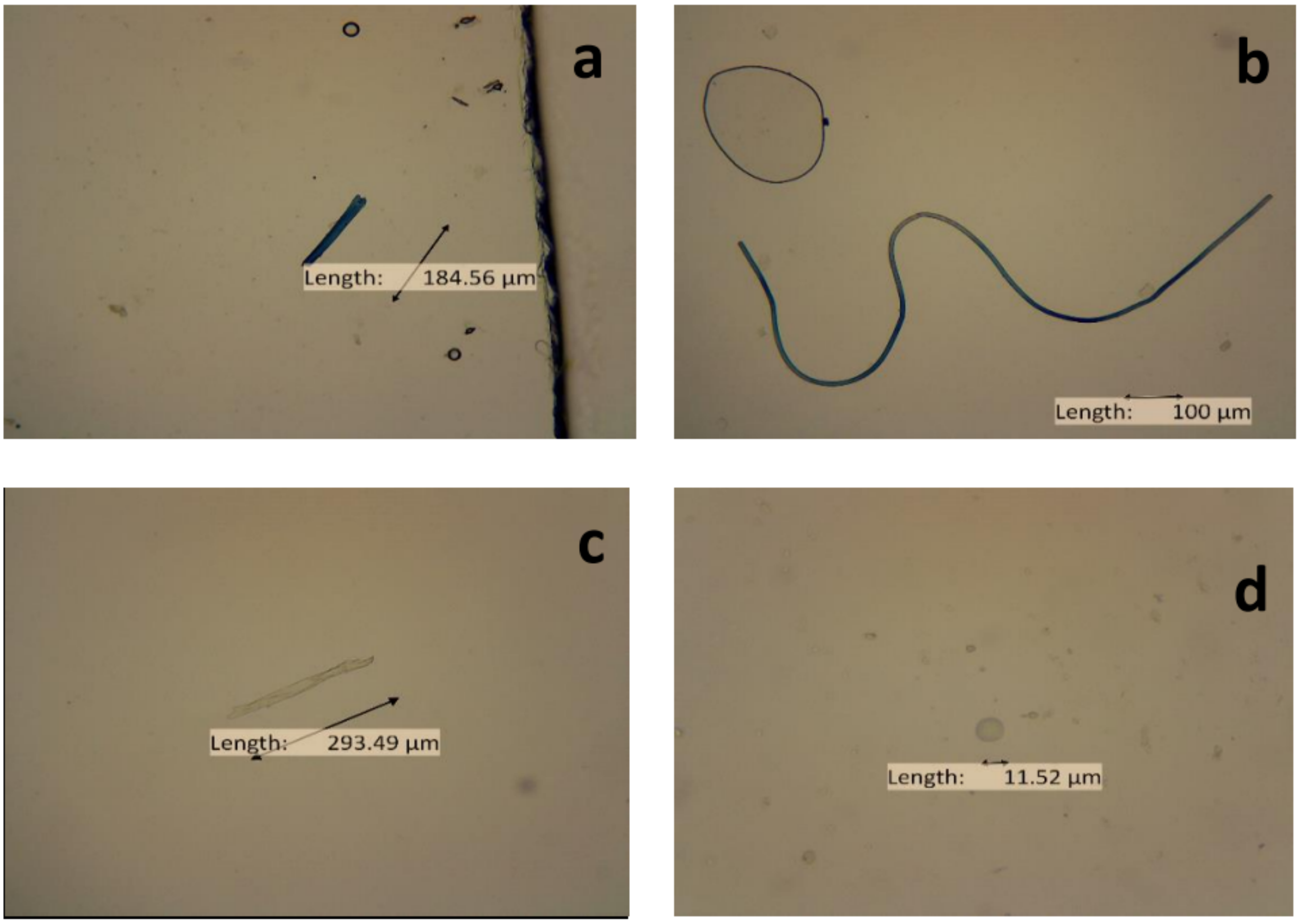

FIGURE 4. Microplastics found in Serang River sediment: fragment (a), fiber (b), film (c), pellets (d).

et al. 2017).

The most common forms of microplastic films are found in the upstream and midstream areas, while in the downstream part, microplastics are dominated by fragments (Figures 3g, 3h, 3i). Microplastics in films can come from single-use transparent plastics that have undergone fragmentation (Hiwari et al. 2019). Fragments result from pieces of plastic products with solid synthetic polymers, such as beverage bottles and other plastic food packaging (Kingfisher 2011; Dewi et al. 2015). According to Hidalgo-Ruz et al. (2012), microplastic in fragments and films has a low density to spread more quickly. Unlike fragments, microplastics in the form of films are pieces of plastic that have a skinny layer in the form of a sheet with a low density (Di and Wang 2018). According to Utami and Asta Putri (2019), in the upper area of the rivers in Yogyakarta, plastic-based waste is found, one of which is diapers that can become fragments and films. Microplastic fragments are more commonly found downstream of the Serang River due to accumulation from the midstream area and community activities around the river. This process follows the opinion of Zobkov and Esiukova (2017) that the dominance of fragments is caused by high human activities in the research area. Microplastics in the form of fibers and pellets were most commonly found in the middle area of the Serang River (Figure 3h). The existence of PT. HM Sampoerna Tbk and PT. Sung Chang Indonesia around the research site can be indicated as a source of microplastic in fiber and pellets due to the use of plastic in the production of cigarette packs and the manufacture of wigs.

River water pollution standards in Indonesia so far have been based on the water quality standard (*Baku Mutu Air*) of the Minister of Environment Decree number 115 of 2003 (MenLHK 2003). There are many parameters in the two quality standards, but the abundance of microplastics has not been used as a parameter as a threshold for river pollution. According to Megumi (2019), from the results of a study by the Oceanographic Research Center of the Indonesian Institute of Sciences microplastics were found in 13 coastal study locations in Indonesia, namely Aceh, Bintan, South Sumatra (Muara Sungai Musi), Jakarta Bay, Semarang, Lombok, Banjarmasin, Manado, Makassar, Bitung, North Minahasa, Biak and Wakatobi. Most of the microplastics were found on the surface waters of South Sulawesi and Jakarta Bay (7.5-10 particles m^{-3}). Microplastics in sediments were more than 100 particles kg^{-1}, namely in Aceh, South Sulawesi, and Biak. Microplastics were also found between 58-89% in anchovy (Stolephorus sp.) 0.25-1.5 particles $gram^{-1}$. The many findings of microplastics in Indonesia and their dangers to living things can be input for the central government to add microplastic parameters to water quality and wastewater quality standards.

4. CONCLUSIONS

Based on the research results, microplastics have been found in all sediment samples of the Serang River with an abundance range of 148.88 particles kg^{-1} to 384.58 particles kg^{-1}.

The highest average abundance of microplastics was found in the downstream area of 321.99 ± 46.76 particles kg^{-1}, then the midstream area of 239.88 ± 9.20 particles kg^{-1}, and the upstream area 179.09 ± 32.08 particles $^{-1}$. The microplastic was identified as a polyethylene polymer as the main ingredient for making single-use plastics. The characteristics of microplastics in Serang River sediments are dominated by a size range of 1-100 µm, in the form of fragments and films, and are dominated by transparent colors.

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