Journal of Sustainability Science and Management
Volume 16 Number 8, December 2021: 289-306
eISSN: 2672-7226

THE ABUNDANCE AND CHARACTERISTICS OF MICROPLASTICS IN THE SEDIMENTS OF THE PROGO RIVER OF YOGYAKARTA, INDONESIA

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Submitted final draft: 17 March 2021 *Accepted: 28 March 2021* http://doi.org/10.46754/jssm.2021.12.021

Abstract: Microplastics may pollute water bodies and endanger living things. The Progo River, one of the longest rivers crossing Yogyakarta Province, has been used as a source for drinking water for residents. However, plastic waste as a source of microplastics is tremendously high in this river. The objective of this study is to analyze the abundance and characteristics of microplastics in the sediments of the Progo River. Sediment sampling was administered in December 2019 at six stations in the upstream, midstream, and downstream rivers. The results showed that all sediment samples from upstream to downstream of the Progo River were found to contain microplastics with an abundance range of 209.37 to 1173.25 particles kg^{-1}. The highest microplastic abundance was found in the downstream area of 645.34 ± 405.94 particles kg^{-1}, followed by the midstream of 480.23 ± 174.09 particles kg^{-1}, and the upstream part of 276.85 ± 73.70 particles kg^{-1}. Microplastics in the Progo River sediments both in the upstream, midstream, and downstream areas are dominant in size of 100 - 500 µm, fibers, and transparent in color. The type of polymer identified in each sample is polyester which is widely used for textile fibers due to the discharge of the residents' laundry washing water into the river. The Progo River, which is one of the top 20 dirtiest rivers globally, has a high abundance of microplastics after Jakarta and Karimun Jawa's rivers. Seeing the high number of microplastic abundance, the Indonesian government must immediately include microplastic parameters to regulate environmental quality standards.

Keywords: Fibers, microplastics, sediments, sustainability, Progo river.

Introduction

Microplastics have been widely reported in aquatic ecosystems such as rivers (Emmerik & Schwarz, 2019), lakes (Turner *et al*., 2019), estuaries (Willis *et al*., 2017), sea (Chatterjee & Sharma, 2019), even in sea products commonly consumed by humans such as seafood (Rochman *et al*., 2015) and salt (Peixoto *et al*., 2019). Microplastics are plastic debris formed from synthetic solid particles or polymers with a diameter of 1 µm to 5,000 µm (Frias & Nash, 2019), including nano-plastics (GESAMP, 2015). Based on the source of origin, microplastics are divided into primary microplastics deliberately produced for a mixture of cosmetic products as pellets or microbeads (Gouin *et al.,* 2015; Tanaka & Takada, 2016; Miraj *et al*., 2019) and secondary microplastics as a result of more considerable plastic fragmentation into fragments, fibers, and films (Murphy *et al*., 2016; Vermaire *et al*., 2017; Tibbetts *et al.,* 2018; Kataoka *et al*., 2019). The small size and food-like shape make microplastics easy to swallow, enter the food chain, and are found in marine life's digestive tracts (van-Cauwenberghe & Janssen, 2014; Alimba & Faggio, 2019) to human feces (Schwabl *et al.,* 2019). Toxic additives contained in a series of plastic-forming polymers increase the effects of inflammation and toxicity on the human body in line with the concentration, particle size, shape, and additive content of ingested microplastics (Smith *et al*., 2018; Campanale *et al.,* 2020).

Degradation and fragmentation of plastic particles are caused by biological processes, chemical weathering, the physical strength of waves, wind, sand friction (Andrady, 2011; Hernandez *et al.,* 2017), UV radiation, heat, and oxidation processes (Campanale *et al.,* 2020). GESAMP (2016) explained that most microplastics end up in the sea through river flow or directly dumped on the coastline and into the sea. Microplastics are widespread with varied sizes, shapes, polymers, and concentrations in aquatic ecosystems (Smith *et al.,* 2018; Campanale *et al*., 2020). Various polymers such as polypropylene, polyethylene, polystyrene, polyamide, polyester, polymerizing vinyl chloride (PVC), and acrylic have low to high density, so that they are found on the surface to the bottom of the water (Hidalgo-Ruz *et al*., 2012; Plastics Europe, 2017). The type of polymer and the deposition process with water currents make microplastics detectable in water and sediments (Enders *et al.,* 2019). Hidalgo-Ruz *et al.* (2012) stated that the size of the microplastics is found in the sediments ranges from 1 µm to 5,000 µm. The microplastic forms found varied from the long shape (fibers), round or ovoid with smooth edges (pellets), irregular fractions with angular edges (fragments and films) (Hidalgo-Ruz *et al*., 2012). Microplastic colors are generally transparent, although many were found in color (Firdaus *et al*., 2020). Color on microplastics is used for identifying the initial chemical composition (Abu-Hilal & Al-Najjar, 2009).

Indonesia is the second country that contributes plastic waste to the oceans after China, in line with the country's high population (Jambeck *et al*., 2015). The population density without an awareness of managing waste (Syakti *et al*., 2017; Rinasti *et al*., 2020) is the cause of the high waste case in mainland Indonesia. One source of plastic waste in the ocean comes from land and river flows in the Special Region of Yogyakarta (Yogyakarta Province) (Cadman *et al.,* 2018; Sakti *et al*., 2020). Yogyakarta Province which comprises Kulon Progo Regency, Sleman Regency, Yogyakarta City, Bantul Regency and Gunung Kidul Regency produces a total waste of 359.1 tons per day, of which 39.3% is plastic waste (Cadman *et al.,* 2018). Referring to Andrady (2011), 80% of waste in the water result from the land. It is not surprising that rivers in Yogyakarta, one of which is the Progo River, are full of garbage. Progo River is a large river with a length of 138 km crossing Central Java Province, and 75% of its flow length enters the Yogyakarta Province (KPUPR, 2010). Tribun Jogja, the local newspaper, stated that several bridges in Progo River were stuck with 200 to 500 diapers (Tribun Jogja, 2018; Utami & Putri, 2019) and other debris that is difficult to decompose, such as clothes, sanitary napkins, gauze, and other plastic waste. Research findings have investigated the abundance of microplastics in river sediments in Indonesia in several locations, such as the Muara Badak Estuary of 107.39 particles kg^{-1} (Dewi *et al.,* 2015), Jagir Estuary Surabaya of 345.20 particles kg^{-1} (Firdaus *et al.,* 2020), West Coast of Karimun Jawa amounting to 2,062.22 particles kg^{-1} (Amin *et al.,* 2020), Jakarta Bay amounting 38,790 particles kg^{-1} (Manalu *et al.,* 2017), Badung Bali around 90.7 particles kg^{-1} (Mauludy *et al.,* 2019) and Pangandaran Beach about 47.30 particles kg^{-1} (Septian *et al.,* 2018). Although water from the Progo River is used as raw material for *Sistem Penyediaan Air Minum* (Drinking Water Supply System) (Yanuar, 2019), the findings of microplastics in the river have not been published. The objective of this study is to analyze the abundance and characteristics of microplastics in the sediments of the Progo River crossing Yogyakarta Province. Hopefully, these research results can be used as input for the government and institutions to utilize the water from the Progo River.

Materials and Methods

Study Area

The research was conducted on the upstream, midstream, and downstream areas of the Progo River flowing into Yogyakarta Province. Sampling and sediment sample processing were conducted from December 2019 until January 2020. There are six data collection stations:

Station 1 (7°39'45.86"S 110°16'0.82"E and elevation of 170 meter above sea level – m asl) and Station 2 (7°40'56.40"S 110°15'46.21"E and 146 m asl) in the upstream area, Station 3 (7°52'0.42"S 110°15'26.33"E and 58 m asl) and Station 4 (7°53'3.87"S 110°16'8.19"E and 25 m asl) in the midstream, Station 5 (7°57'59.16"S 110°13'29.86"E and 9 m asl), and station 6 (7°58'48.09"S 110°12'32.69"E and 11 m asl) are in the downstream area (Figure 1). Figure 1 shows that the Progo River is the widest and one of the longest rivers crossing Yogyakarta Province (Yamazaki *et al*., 2019) and empties into the Indian Ocean.

Collection and Processing of Sediment Samples

The sampling stations in each area were determined purposively before and after the microplastic pollutant sources. The majority of microplastic pollutants in rivers come from land activities, including laundry and household waste disposals (Haap *et al*., 2019), waste from the cosmetic and plastic raw materials industries (Nizzetto *et al*., 2016a), leachate from landfill (He *et al*., 2019; Puthcharoen & Leungprasert, 2019), waste from agricultural fertilizers, agricultural mulching film (Weithmann *et al*., 2018; Guo *et al*., 2020), tourism activities, and fishing villages (Dewi *et al*., 2015). Stations 1

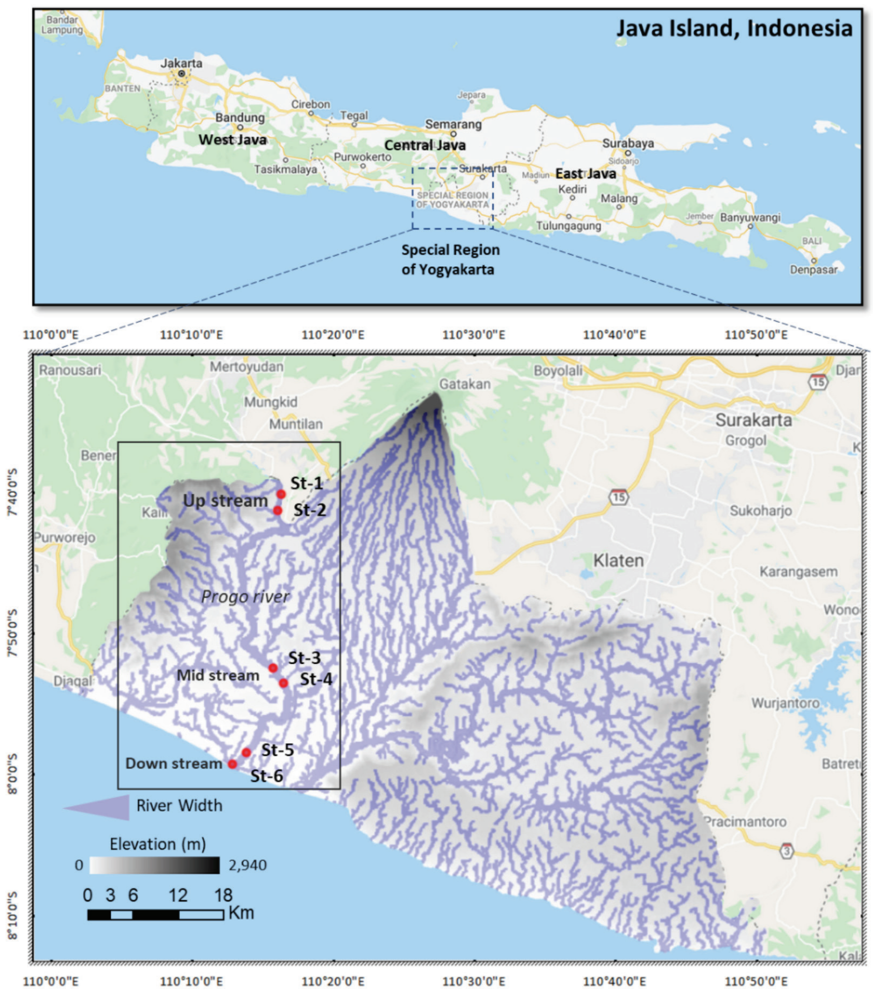

Figure 1: Sampling locations at station (St) 1 until station 6 at the Progo River, Yogyakarta

and 2 in the upstream part are located between Ancol Dam tourism Kalibawang Kulon Progo Regency and rafting tourist site. Stations 3 and 4 in the midstream are between Kamijoro Dam tour Pajangan as a tourist site, the Banyuroto landfill Nanggulan District, and several cosmetics industries. Stations 5 and 6 in the downstream are between the dense settlements around Serandakan Bantul Regency, fishing villages, and Pandansimo Beach as a tourist site. The rice fields also occupy the entire Progo River bank from upstream to downstream. Three sediment samples were taken randomly at each station using four-inch pipes and 10 cm high inside the 50 x 50 cm plot (Dewi *et al*., 2015). The pipes used are made from iron to prevent microplastic contamination. The sediment sample was placed into a glass bottle and put in a cool box. Environmental parameters such as light intensity, water temperature, water flow velocity, water pH, elevation, dissolved oxygen, and dissolved carbon dioxide were measured at each sampling station. Environmental conditions as far as 500 meters around the sampling location were documented to see plastic contamination sources. Sediments less than 5 mm in size were filtered using a mesh sieve, heated at 105°C for 48 hours (Manalu *et al.,* 2017). Each sample's dry weight is recorded as the dry weight (DW) of the sediment sample x. Sediment separation was performed by mixing dry sediment sample and saturated NaCl with a ratio of 1:3 (Dewi *et al.,* 2015), and then stirring for three minutes using a stirring rod (Claessens *et al*., 2011; Löder & Gerdts, 2015). The supernatant in the top layer which contains microplastics (Hidalgo-Ruz *et al.,* 2012; Dewi *et al.,* 2015; Löder & Gerdts, 2015) was strained in stages and placed on a petri dish. Furthermore, the character of the microplastics was identified using the visual sorting and separation method.

Characterization and Identification of Microplastics

Identification of microplastics was carried out using an Olympus CX 23 microscope and an advance MTN 004 Opti lab. Microplastic grouping is divided into four size ranges which are 1-100 µm, 101 - 500 µm, 501 - 1,000 µm, and 1,001 - 5,000 µm (Avio *et al.,* 2015). Microplastic forms are identified into four groups comprising fragments, films, fibers, and pellets (Hidalgo-Ruz *et al.,* 2012; Vianello *et al.,* 2013; Dewi *et al.,* 2015). Microplastic colors are divided into transparent colors and other colors as red, blue, green, brown, black, gray, and white (Firdaus *et al*., 2020). Visual separation is the first step to avoid misidentification of microplastics (Hidalgo-Ruz *et al.,* 2012). According to Norén (2007) and Löder and Gerdts (2015), microplastic characters can be determined from the absence of cellular or organic structures, the microplastic's color is generally clear and homogeneous, and the fibers found must also be of the same thickness. Transparent or white microplastic particles should be examined up to 100x magnification (Hidalgo-Ruz *et al.,* 2012; Silva & Nanny, 2020). The microplastics found by visual sorting were validated by performing a Fourier transform infrared spectroscopy (FT-IR) to confirm the synthetic polymers found (Sastrohamidjajo, 1991; Löder & Gerdts, 2015). Representatives of each sample at each station were tested with FTIR transmission mode in the range of 4,000–650 cm^{-1}, a resolution of 8 cm^{-1} for 32 scans.

Data Analysis Method

This study used quantitative analysis methods to present the abundance and characteristics of microplastics in the Progo River sediment. Microplastic data is generally presented descriptively with units of particles per kg of dry weight (particles kg^{-1}) ± standard deviation (SD) (Dewi *et al.,*2015; Manalu *et al.,* 2017; Mauludy *et al*., 2019). Comparative analysis was also used for comparing the data between data groups in the upstream, midstream, and downstream areas of the Progo River. The relationship between environmental factors and microplastic abundance data was analyzed using the correlation test. Data testing was conducted in SPSS version 25.0 software by performing a normality test and a homogeneity test first on the data group to be tested (Utami & Putra, 2020). Comparative analysis between two paired groups between stations in each section was conducted using the paired T-test. Another comparative analysis to test three abundance data groups for the upper, midstream, and lower reaches was administered using the Kruskal Wallis test. Meanwhile, the correlation test between the abundance of microplastics in each section with abiotic parameters was performed using the Spearman correlation test.

Result and Discussion

The Abundance of Microplastic in Sediment

The results show that all sediment samples from upstream to downstream of the Progo River found microplastics with an abundance average of 467.47 ± 225.92 particles kg^{-1} and an abundance range of 209.37 to 1,173.25 particles kg^{-1}. The highest microplastic abundance in the Progo River's sediment was found in the downstream area of 645.34 ± 405.94 particles kg^{-1}, followed by the midstream part of 480.23 ± 174.09 particles kg^{-1}, and the upstream part of 276.85 ± 73.70 particles kg^{-1} (Table 1). The results of statistical tests using Kruskal Wallis show that the abundance of microplastics in the upstream, midstream and downstream areas were significantly different with a p-value < 0.05, which is 0.031. The Kruskal Wallis test results indicate that the station's location affects the abundance of microplastics in the Progo River's sediment. Testing the abundance of microplastics between stations in each location using the paired T-test shows that the overall results are not significantly different with a p-value >0.05, which are 0.632 (Station 1 and Station 2), 0.434 (Station 3 and Station 4), and 0.188 (Station 5 and Station 6). These statistical tests conclude that the sampling station's location before and after the pollutant source did not affect the abundance of microplastics in the sediments of the Progo River. The Spearman bivariate correlation test result indicates a significant value (2 - tailed) <0.05 for light intensity parameters of 0.002, an elevation of 0.024, and a dissolved CO_2 of 0.010. The test results show that three parameters have a correlation strengthened by the correlation coefficient values, which are all negative of -0.674** for light intensity, -0.530* for elevation, and -0.593** for dissolved CO_2 (Table 2).

Characteristics of Microplastics in Sediment

Microplastic sizes in the Progo River sediments were found from 1 µm to 5,000 µm. Hidalgo-Ruz *et al*. (2012) asserted that the sediment's microplastics' size would have a broader range than that found in the water. The size of microplastics found in the Progo River is in the range of 101 - 500 µm (40%), followed by

Table 1: Abundance of microplastics in the sediments of the Progo River, Yogyakarta Province

Informations	Sampling Location of Progo River					
	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Abundance Average*	281.21 ± 90.68	272.49 ± 72.78	564.33 ± 216.29	396.14 ± 88.17	874.19 ± 446.38	416.48 ± 235.75
	Upstream		Middle		Downstream	
Abundance range*	209.37 – 383.11		296.16 – 809.68		243.50 – 1173.25	
Abundance Average*	276.85 ± 73.70		480.23 ± 174.09		645.33 ± 405.94	

*Unit particles kg^{-1}

Table 2: Correlation test of the abundance of river sediment microplastics with abiotic

Correlations

			Abundance	Temperature	Light intensity	Water flow velocity	Water pH	Elevation	Dissolved Oxygen	Carbon dioxide Disolved
Spearman's rho	Abundance	Correlation Coefficient	1.000	.342	-.674**	-.361	.409	-.530*	-.331	-.593**
		Sig. (2-tailed)	.	.165	.002	.142	.092	.024	.180	.010
		N	18	18	18	18	18	18	18	18
	Temperature	Correlation Coefficient	.342	1.000	-.278	-.278	.559*	-.926**	-.689**	-.802**
		Sig. (2-tailed)	.165	.	.264	.264	.016	.000	.002	.000
		N	18	18	18	18	18	18	18	18
	Light intensity	Correlation Coefficient	-.674**	-.278	1.000	.771**	-.621**	.486*	.319	.543*
		Sig. (2-tailed)	.002	.264	.	.000	.006	.041	.197	.020
		N	18	18	18	18	18	18	18	18
	Water flow velocity	Correlation Coefficient	-.361	-.278	.771**	1.000	-.621**	.257	.319	.200
		Sig. (2-tailed)	.142	.264	.000	.	.006	.303	.197	.426
		N	18	18	18	18	18	18	18	18
	Water pH	Correlation Coefficient	.409	.559*	-.621**	-.621**	1.000	-.621**	.000	-.414
		Sig. (2-tailed)	.092	.016	.006	.006	.	.006	1.000	.088
		N	18	18	18	18	18	18	18	18
	Elevation	Correlation Coefficient	-.530*	-.926**	.486*	.257	-.621**	1.000	.609**	.943**
		Sig. (2-tailed)	.024	.000	.041	.303	.006	.	.007	.000
		N	18	18	18	18	18	18	18	18
	Dissolved Oxygen	Correlation Coefficient	-.331	-.689**	.319	.319	.000	.609**	1.000	.696**
		Sig. (2-tailed)	.180	.002	.197	.197	1.000	.007	.	.001
		N	18	18	18	18	18	18	18	18
	Carbon dioxide Disolved	Correlation Coefficient	-.593**	-.802**	.543*	.200	-.414	.943**	.696**	1.000
		Sig. (2-tailed)	.010	.000	.020	.426	.088	.000	.001	.
		N	18	18	18	18	18	18	18	18

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

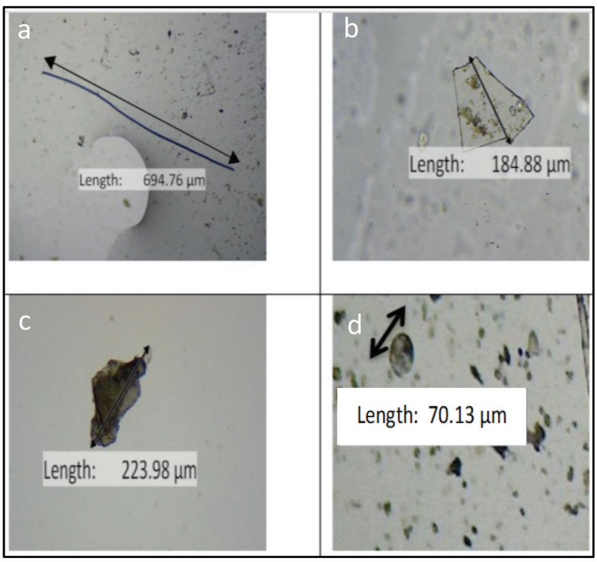

Figure 2: Form of microplastics in the Progo River sediments: (a) fiber, (b) film, (c) fragments, (d) pellets

1 - 100 µm (36%), 501 - 1000 µm (17%), and 1001 - 5000 µm (7%). The size of 101 - 500 µm was dominant in the upstream and downstream of river sediment area with an abundance of 109.58 particles kg^{-1} and 262.90 particles kg^{-1}. Meanwhile, the midstream was dominated by microplastics measuring 1 - 100 µm with an abundance of 187.98 particles kg^{-1}, followed by microplastics measuring 101 - 500 µm with an abundance of 181.55 particles kg^{-1} (Figure 3).

Microplastic forms in the Progo River sediments were found in fibers, films, fragments, and pellets (Figure 2). Microplastic forms discovered mainly in the upstream, midstream, and downstream of the Progo River were fibers with a total abundance of 232.94 ± 112.52 particles kg^{-1} (49.9%), followed by fragments of 134.69 ± 57.37 particles kg^{-1} (28.8%), film 98.25 ± 16.81 particles kg^{-1} (21%) and pellets of 1.60 ± 1.38 particles kg^{-1} (0.3%). The abundance of fiber raised from the upstream area of 116.08 ± 47.13 particles kg^{-1}, the midstream part of 242.17 ± 81.52 particles kg^{-1}, and the downstream area reaching 340.56 ± 148.54 particles kg^{-1} (Figure 3).

The color of microplastics in the Progo River sediments was dominated by transparent colors, even in the upstream, midstream, and downstream areas (Figure 3). The average abundance of microplastics in the Progo River sediments was dominated by the transparent color of 212.38 ± 88.81 particles kg^{-1} (45%), the brown color of 100.40 ± 76.13 particles kg^{-1} (22%), the blue color of 56.60 ± 41.53 particles kg^{-1} (12%), the black color of 46.13 ± 25.36 particles kg^{-1} (10%), the grey color of 44.08 ± 26.73 particles kg^{-1} (9%), the red color of 4.25 ± 3.81 particles kg^{-1} (1%), and the minor abundance is green in the amount of 3.62 ± 4.97 particles kg^{-1} (1%).

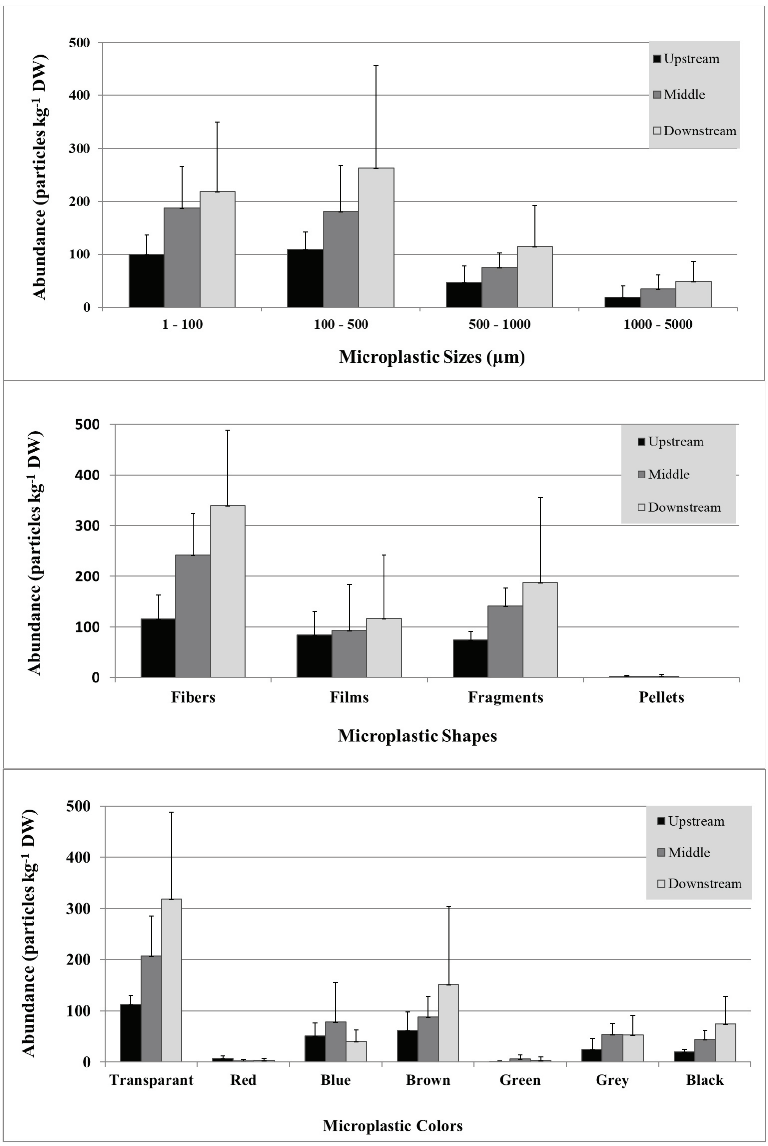

Figure 3: Abundance sizes, shapes, colors of microplastics in the Progo River sediments

Based on the FTIR test results obtained by analyzing the hydrocarbon chain and other chemical chains, a polyester polymer was identified in each sample (Figure 4). The formation of group peaks shows the polyester chain in several wavelength ranges, including the O - H bond in the range of 3550 – 3250 cm^{-1}, the C – H bond function group in the range of 2980 – 2850 cm^{-1}, the C = O (ester) double bond at a wavelength range of 1780-1710 cm^{-1}, and single bond COC (ester) in the wavelength range of 1290 – 1180 cm^{-1} (Parvinzadeh & Ebrahimi, 2011; Reddy *et al.,* 2012; Koto & Soegijono, 2019). Polyester is thought to reflect fiber dominance in the previously identified sediment samples in the Progo River. Polyester has a higher density (1.37 g m^{-3}) than seawater, so that it quickly settles in river sediments (Firdaus *et al.,* 2019).

Discussion

Based on Table 1, microplastics were found in the sediments of the Progo River in the upstream, midstream, to downstream areas of the river crossing the Yogyakarta Province. The abundance of microplastics was primarily due to human activities around the station (Hidalgo-Ruz *et al*., 2012). When collecting samples on the Progo River, a pile of plastic bags, plastic bottles, used clothes, sanitary napkins, diapers, and plastic-based sacks to embank the river showed on the riverbank (Figure 5) and under the bridge on the river. According to Luqman (2019) and Sarengat *et al*. (2015), the Progo River has been a disposal site for household and industrial waste even in the upstream part. Lebreton *et al*. (2017) published that the Progo River is one of the 20 dirtiest rivers globally with waste input of d 12,800 (range 9,800 – 22,900) tonnes of plastics per year. Along the Progo river banks, many rice fields use river water as a source of irrigation. According to Steinmetz *et al*. (2016) and Corradini *et al.* (2019), mulching film and organic fertilizers contaminated with plastic become a source of microplastics in the farmland soil. The microplastics will be carried into the ground flow or runoff to the river (Nizzetto *et al*., 2016b). Weithmann *et al.* (2018) emphasize that the shape of fragments with 1 - 5 mm plastic size generally dominates sewage sludge disposal. Besides, many household exhaust pipes can be seen along the banks of the Progo tributary. There has been no further research regarding findings of microplastics in household sewage pipes along the Progo River, even in Indonesia. However, many theories confirm microplastic fiber comes from the waste of the residents' laundry (Haap *et al.,* 2019; Silva & Nanny, 2020).

The abundance of microplastics reaching 276.85 ± 73.70 kg^{-1} particles in the upstream area of the river in Yogyakarta Province proves

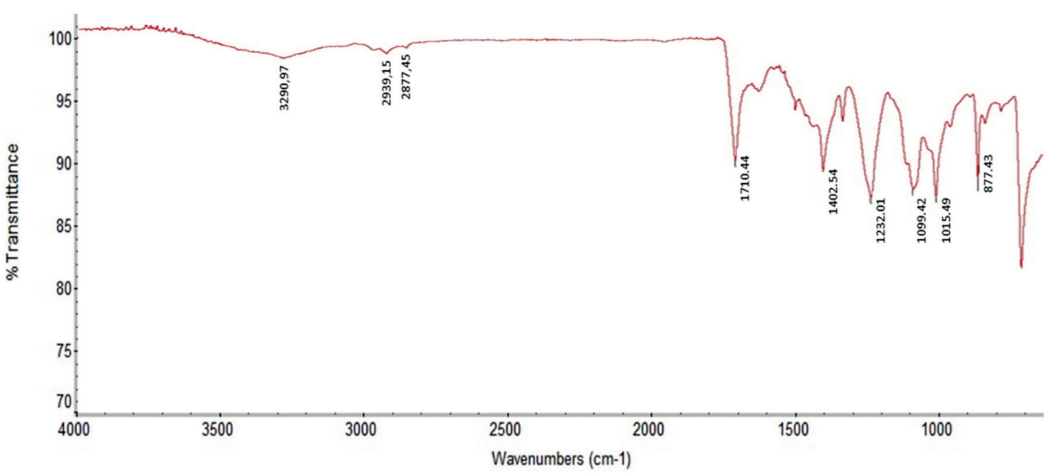

Figure 4: Polymer polyester identified in one of the sediment samples from the Progo River

that sources of microplastics like plastic waste have polluted 34.5 km of the Progo River before crossing Central Java Province. The upstream of the Progo River passes through several cities in Central Java Province (Figure 1 and Figure 6), such as Temanggung City (north of Magelang city) with a population of 772,018 people (BPS, 2021), Magelang City and Regency with a population of 1,412,702 people (BPS, 2021) and also passing through leather and textile factories, and tourist site around Magelang Regency (Luqman, 2019). After entering Yogyakarta Province, the Progo River is traversed by a densely populated area, namely Bantul Regency (population 1,018,402 people) (BPS Bantul, 2020). Figure 5 shows the Progo River flow that passes through several densely populated cities is yellow (Gaughan *et al*., 2013; Yamazaki *et al.,* 2019). Castaneda *et al.* (2014) stated that the sediment's high microplastic comes from municipal and industrial wastes. The Progo river is also used to dispose leachate from the Banyuroto Landfill in the Kulon Progo district (west of the midstream river). According to Puthcharoen and Leungprasert (2019), leachate in landfills carries microplastics in fragments and films in high amounts. The Progo River in the Bantul district is also used to dispose of waste from textile factories and sanitary napkins factories that use raw materials from synthetic fibers (Luqman, 2019). Until now, there has been no specific study that has detected microplastics directly from sewers. The presumed source of microplastics is still linked from the relevant research literature.

The fiber microplastic abundance is influenced by the residents' activities in which laundry wastewater is thrown into the Progo River. Thousands of fiber particles are wasted per cubic meter of clothes wastewater (Cesa *et al*., 2017) or 124 to 308 mg of microfiber released per kg of washed fabric depending on the textile characteristics (de-Falco *et al*., 2019). Browne *et al.* (2011), Dris *et al.* (2015), and Napper and Thompson (2016) stated that fibers derived from polyester, polyester-cotton blend, and acrylic fabrics are the primary sources of microplastic fiber in water and river sediments flowing in the cities today. Furthermore, the source of fiber comes from textiles, tire particles, fishing nets, and large degraded plastics (Browne *et al.,* 2011; Smith *et al.,* 2018). Fiber microplastics have been reported to dominate Indonesia's waters, such as in Surabaya (Firdaus *et al*., 2019), Pangandaran (Seprian *et al*., 2018), Lamongan (Asadi *et al*., 2019), Karimun Jawa Islands (Amin *et al*., 2020), and Bali (Mauludy *et al*., 2019) (Table 3). The fiber commonly found comes from polyester polymer (Firdaus *et al.,* 2019), which is thought to come from the waste of laundry and household laundry and abrasive friction during the clothing production (Cai *et al*., 2020) in textile factories found along the Progo River. Other polymer fibers that commonly sink into

Figure 5: Piles of waste the Progo River

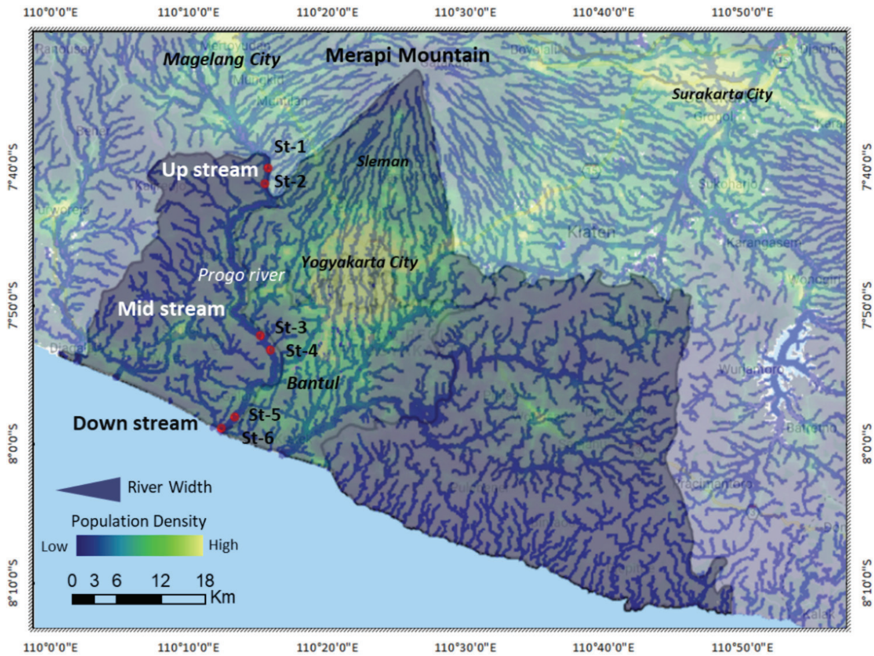

Figure 6: The Progo River passing through Magelang City in Central Java and Bantul City in Yogyakarta

river sediments are polyamide polymers (Jung *et al.,* 2018). In Indonesia, there are findings of polyamide type fibers from fishing nets found in most fish on the southern coast of Bantul Yogyakarta (Suwartiningsih *et al.,* 2020).

Fragment-form microplastics were placed in the second rank after fiber. The fragments are from beverage bottles, food packaging, and containers used daily due to being cut from plastic products with solid synthetic polymers (Kingfisher, 2011; Baldwin *et al.,* 2016; Wang *et al.,* 2016). On the other hand, plastic bags, a packaging material that is thinner and softer than transparent plastic, can be the primary source of microplastics in the form of films (Teuten *et al*., 2009; Lassen *et al*., 2015) dominating the third place which also exists in the Progo River (Figure 4). Foam-form microplastics may come from food packaging materials, while pellets from cosmetic product ingredients (Fendall & Sewell, 2009). Pellets, as industrial products used in hygiene and care such as scrubs (Cole *et al.,* 2011; Duis & Coors, 2016), were found in minor abundance in the Progo River. Moreover, pellet microplastic is always bound to other metal types and only found in water with a high pH value (Turner & Holmes, 2014). The average pH of the Progo River water ranges from 6 - 7. Several cosmetic products circulating in Indonesia have started using biodegradable beads to reduce microplastic pollution in beads in rivers.

Various studies have found that microplastics pollute rivers and other water bodies in Indonesia. The abundance of microplastics in the Progo River sediments is relatively high compared to other locations (Table 3). The abundance of microplastics is mainly located on Java Island, in which Jakarta, as the capital city of Indonesia, has the highest abundance. Jambeck *et al.* (2015) and Cadman *et al.* (2018) stated that the high number of microplastics in water bodies is proportional to the number of human population in that location. *Baku Mutu Lingkungan* regulating the environmental pollution threshold in Indonesia has not included microplastic parameters in it. Meanwhile, the abundance of microplastics became a parameter of environmental pollution (Browne *et al.,* 2011).

Table 3: Comparison of abundance of microplastics in sediments in Indonesia

Location	Province	Microplastic Abundance (Particle kg^{-1})	Microplastic Shapes Dominant	Citations
Pluit Jakarta Bay	Jakarta	38,790.00	Fragment	Manalu *et al*. (2017)
Karimun Besar Island	Central Java	2,062.22	Fiber	Amin *et al.* (2020)
Pantai Indah Kapuk	Jakarta	1,232.90	Film	Hastuti (2014)
Progo River	**DIY**	**467.47**	**Fiber**	**This research**
Jagir Estuary, Surabaya	East Java	345.20	Fiber	Firdaus *et al.* (2019)
Intertidal Lamongan	East Java	206.00	Fiber	Asadi *et al.* (2019)
Muara Badak	East Kalimantan	107.39	Fragment	Dewi *et al.* (2015)
Coastal Beaches in Badung, Bali	Bali	90.70	Fiber	Mauludy *et al.* (2018)
Coral reef Sekotong, Lombok	West Nusa Tenggara	48.30	Foam	Cordova *et al.* (2018)
Pangandaran, West Java	West Java	47.30	Fiber	Septian *et al.* (2018)

Microplastics' size varies greatly depending on the type, physical and chemical factors (Septian *et al*., 2018). Based on the Spearman correlation test, only light intensity, elevation, and dissolved CO_2 were correlated with the abundance of microplastics in the Progo River's sediments. Claessens *et al.* (2011), Septian *et al*. (2018), Cordova (2020) stated that physical factors affecting microplastic fragmentation include water temperature and river water velocity and chemical factors such as dissolved oxygen and dissolved carbon dioxide found to be correlated in this study. A strong negative correlation (Table 2) indicated by light intensity occurred because the sampling time entered the beginning of the rainy season so that the conditions were cloudy. Light intensity has a relationship with the abundance of microplastics because, according to GESAMP (2015), microplastics can be formed due to several processes like shrinking plastic size due to UV rays. The negative correlation with the elevation parameters indicates that sampling location with lower elevation increased the abundance of microplastics. Nugroho *et al.* (2018) and Jambeck *et al.* (2015) stated that plastic waste at the downstream river comes from residential areas traversed by rivers and settlements close to downstream areas. The sampling location factor approaching land also dramatically affects the abundance of microplastics due to a large amount of waste input from the land (Hiwari *et al.,* 2019). Sedimentation may also affect the abundance of microplastics by accumulating microplastics in a river (Septian *et al*., 2018). Microplastics floating on water surfaces have a low density, while the microplastics that settle in the sediments have a greater density (Hidalgo-Ruz *et al*., 2012). Over time, plastic's persistent nature is lower, such as in downstream, resulting in smaller fragmented plastics.

Pellets or beads are micro-sized when coming into the aquatic environment (Moore, 2008), while fragments, films, fibers take a long time to fragment from the large plastic pieces (Arthur *et al*., 2009). Microplastics with a range of 101-500 µm to 1 - 100 µm are found along with the Progo River sediments due to the accumulation of plastic debris leading to the river estuary. It is important to emphasize that the smaller the microplastic size, the greater the toxicological consequences (Browne *et al*., 2011). Given that microplastics in water are potentially hazardous for aquatic biota and humans, if ingested, they can disrupt the digestive tract and damage the ecosystem's balance (Boerger *et al.,* 2010; Browne *et al.,* 2011).

Most microplastic colors found in the Progo River sediments are transparent, coming from the film shape starting from plastic which is evident in color and then degraded (Lassen *et al.,* 2015). Transparent is frequently used by industry in plastic products such as beverage bottles and plastic bags used in everyday life (Hastuti, 2014). Microplastics having dark colors contain many chemical substances to absorb higher pollutants (Hiwari *et al.,* 2019). Thick colors such as brown and black are found in microplastics in fragments such as trash bags and plastic containers (GESAMP, 2015) with the main constituent of polyethylene having a density of 0.917 - 0.965 g cm^{-3} (Hidalgo-Ruz *et al.,* 2012). Other microplastic colors such as red, blue, brown, green, and gray resemble prey potentially consumed by various aquatic organisms, either invertebrates or fish (Setala *et al.,* 2014). The presence of black microplastics may absorb bioaccumulation and toxic compounds from persistent organic pollutants (Mato *et al.,* 2001; Rios *et al.,* 2007; Ogata *et al.*, 2009).

Conclusion

All sediment samples in the Progo River, Yogyakarta Province, had microplastics with an abundance range of 209.37 to 1,173.25 particles $kg^{-1.}$ Microplastics in the Progo River sediment is dominated by 100 - 500 µm, fibers, and transparent in color. The highest microplastic abundance in the Progo River's sediment was found in the downstream area after administering the accumulation of microplastic pollution even before entering Yogyakarta Province. The location of the sampling determined based on the elevation affects the abundance of microplastics in the Progo River. It is interesting to detect microplastics in rivers before and after significant cities passed by the Progo River, such as Temanggung, Magelang, and Bantul, which have varying population densities. The type of polymer identified in each sample is polyester which is widely used for textile fibers due to the discharge of the residents' laundry washing water into the river. The presumption of the primary fiber source from household waste also needs to be further investigated by taking samples from the resident's wastewater pipes found along the tributary of the Progo River. Seeing the high occurrence of abundance, the Indonesian government should immediately include microplastic parameters to regulate environmental quality standards.

Acknowledgments

The authors would like to acknowledge the support from Lembaga Penelitian dan Pengabdian kepada Masyarakat Universitas Ahmad Dahlan (LPPM UAD) and Young Researcher Capacity Program by Institute for Research and Community Services of Institut Teknologi Bandung (LPPM ITB). We also thank the anonymous reviewers whose valuable comments helped us prepare an improved and more precise version of this paper.

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