Sustinere
Journal of Environment and Sustainability
Volume 5 Number 3 (2021) 155-165

Print ISSN: 2549-1245 Online ISSN: 2549-1253
Website: https://sustinerejes.com E-mail: sustinere.jes@iain-surakarta.ac.id

RESEARCH PAPER

Initial investigation of microplastic pollution in river sediments at Yogyakarta City Indonesia

Inggita Utami[1,2*], Pidianto[2], Fahmi Hermawan Tricahya[2], Suci Rahmawati[2]
[1]*Laboratory of Ecology and Systematics, Universitas Ahmad Dahlan, Jl. Ahmad Yani, Bantul, DIY, Indonesia*
[2]*Biology Department, Faculty of Applied Science and Technology, Universitas Ahmad Dahlan, Jl. Ahmad Yani, Bantul, DIY, Indonesia*

Article history:
Received 10 March 2021 | Accepted 13 October 2021 | Available online 31 December 2021

Abstract. Microplastics of less than 5 mm have been widely found in the river sediments that cross the city. Sources of microplastic pollutants can be seen in rivers crossing Yogyakarta City studies on microplastic have never been carried out. This study analyzed the abundance and characteristics of microplastics in river sediments of Yogyakarta City. Data collection was carried out in December 2019 in Winongo River, Code River, and Gadjahwong River. Each sample of the three sediments was taken at each point of the three inlets and outlets in Yogyakarta City. The sediment sample was separated to obtain supernatant-containing microplastics. The abundance of microplastics was quantified and grouped based on the shape, size, and color. Data were analyzed using descriptive and inferential statistics to compare the concentration of microplastic in the three rivers. The results showed that the abundance of microplastics ranged from 279.31 to 1,026.93 particles kg^{-1}, with a higher abundance in the inlet than the outlet. The Code River sediment has the highest microplastic abundance, followed by the Gadjahwong River, and Winongo River. The sediment samples in the rivers crossing Yogyakarta City have been contaminated mainly by the fragment-shaped, transparent, and 1-100 µm microplastics.

Keywords: microplastics; code; gadjahwong; winongo; sedimen; Yogyakarta

1. Introduction

As the capital of the Special Region of Yogyakarta, Indonesia, Yogyakarta City has the highest population density in the province of 13,007 inhabitants per square km (BPS Sleman, 2019). The densely populated settlements at the riparian zone make the Winongo River, Code River, Gadjahwong River, as three main rivers of Yogyakarta City, polluted from domestic sewage and industrial waste (Sarengat et al., 2015; Putro, 2016; Muryanto et al., 2019). Around 359.1 tons of waste per day are generated by the residents of Yogyakarta City residents with 39.3% plastic polymers (Cadman et al., 2018). According to Mehlhart and Blepp (2012), around 90% of plastic waste in rivers was generated from residential land use. Garbages consisting of plastic bottles, single-use plastics, diapers, and used clothes sinking at the bottom of the three rivers (Tribun Jogja, 2018; Utami & Putri, 2019).

*Corresponding author. E-mail: inggitautami@bio.uad.ac.id
DOI: https://doi.org/10.22515/sustinere.jes.v5i3.178

Plastic waste floating in the river will be degraded by sunlight (photodegradation), oxidation, and mechanical abrasion to be microplastics with a size of ≤ 5 mm (Thompson et al., 2009). Ingested microplastics can cause physiological disorders to be carcinogenic (Wright et al., 2013; Vendel et al., 2017). The primary sources of microplastic are microbeads or pellets that are manufactured in microscopic sizes in the cosmetic industry (Boucher & Friot, 2017) and secondary sources such as fragments, films, and fragmented fibers from macro plastics (Cole et al., 2014; GESAMP, 2016). The microplastics in sediment generally range from 1μm-5,000μm (Hidalgo-Ruz et al., 2012). The microplastic polymer has varied densities from the lightest, such as expanded polystyrene (styrofoam) to polytetrafluoroethylene (PTFE) (Duis & Coors, 2016).

Microplastics in water bodies have been recorded to increase in the last decade and they come in a variety of shapes, sizes, colors, and polymers (Waller et al., 2017; Lebreton et al., 2017; Alimba & Faggio, 2019). As the most populous island in Indonesia, microplastic has been found in many rivers and seas in Java Island, such as in Indah Kapuk Beach, Jakarta (Hastuti et al., 2014), Jagir Estuary Surabaya (Firdaus et al., 2020), Pangandaran Beach, West Java (Septian et al., 2018), and West Coast of Karimun Besar Island (Amin et al., 2020). In Yogyakarta City, fish in the Code river has been contaminated by microplastics (Sulistyo et al., 2020). Microplastic pollution poses a threat to the aquatic ecosystem in Yogyakarta. Still, there is no information on how many microplastics are in the rivers across Yogyakarta City. This study analyzed the abundance and characteristics of microplastics in the river sediments of Yogyakarta City. The data collection of microplastic that has never been done by previous research is the novelty of this research. The research on river water pollution in Yogyakarta generally only detects the physical, chemical, and biological parameters contained in *Baku Mutu Air* (Water quality standards). Results of this study can provide necessary information on the level of microplastic pollution as an initial investigation of rivers at Yogyakarta City.

2. Methodology

2.1. Research design

The research began with determining the location, sampling the sediment, separating microplastics from the sediment, and quantifying the abundance of microplastics. The sediment sampling location was at the inlet (I) and outlet (O) points of the Winongo River (W), Code River (C), Gadjahwong River (G) in Yogyakarta City (Figure 1 and Table 1). Samples were taken in December 2019 at the end of the long dry season in 2019 (Prasetyaningtyas, 2020).

2.2. Data collection

Three sediment samples were collected randomly in a 50x50 cm plot of each sampling point (Barasarathi et al., 2014). Sediment samples were taken using a 4-inch iron pipe with a height of 10 cm and were stored in a glass bottle and put into a cooler with a temperature of 4 °C. (Dewi et al., 2015). The measurement of abiotic factors, such as water velocity, water temperature, water pH, dissolved CO_2, dissolved O_2, and light intensity were carried out in each sampling plot (Syranidou et al., 2017). To document all visible pollutants around the sampling spot, environmental conditions were documented over a radius of 500 meters. The sediment samples were filtered with a 5 mm Mesh sieve (Hidalgo-Ruz et al., 2012) and then oven drying at 10˚C for 48 hours. The microplastic separation stage was carried out by mixing the dry sediment sample (1 kg) and saturated NaCl solution (3L). The mixture was stirred for 2 minutes (Dewi et al., 2015). The supernatant-containing microplastics were filtered and identified for abundance in each shape, size, and color (Table 2). Identification of microplastics from supernatants and grouping by shape, size, and color character were carried out by visual separation using a binocular microscope, OptiLab, and Raster Image applications. Microplastic abundance is presented by particles per kilogram of dry sediment (particles kg^{-1}) (Claessens et al., 2011).

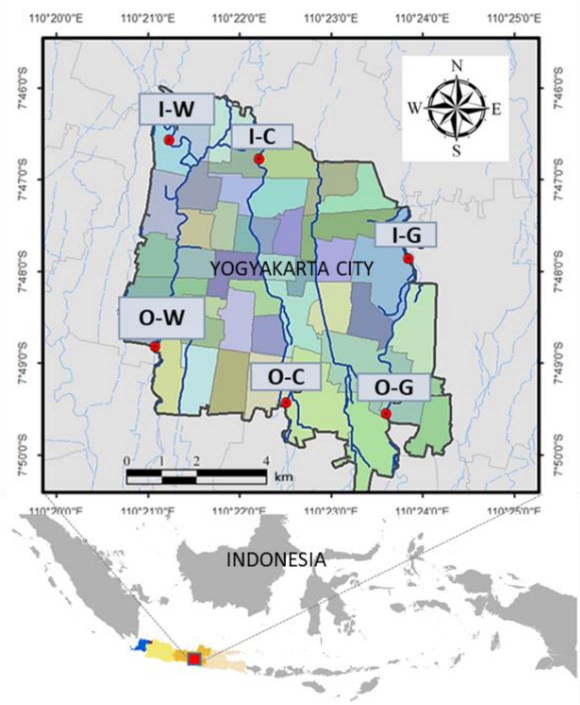

Figure 1. Location of sediment sampling

Table 1. The coordinates of the sampling point

Locations	Coordinates
Inlet of Winongo River (I-W)	7°46'34.58"S 110°21'13.88"E
Outlet of Winongo River (O-W)	7°48'49.78"S 110°21'5.61"E
Inlet of Code River (I-C)	7°46'48.33"S 110°22'13.44"E
Outlet of Code River (O-C)	7°49'28.55"S 110°22'30.00"E
Inlet of Gadjahwong River (I-G)	7°47'53.99"S 110°23'51.43"E
Outlet of Gadjahwong River (O-G)	7°49'33.55"S 110°23'35.39"E

Table 2. Microplastic character classification

Categories	Description
Size	Large: 1,001-5,000 µm Small: 1-100 µm 501-1,000 µm (Vianello et al., 2013; Avio et al., 2015)
Shape	Fragments: irregular, thick sheet Films : irregular shaped, thin sheet Fiber : filament, strands, threads Pellet : spherical microbeads, grains (Hidalgo-Ruz et al., 2012; Lusher et al., 2017)
Color	Transparent, black, gray, red, brown, blue, green (Firdaus et al., 2020)

2.3. Data analysis

Microplastic abundance was descriptively and statistically analyzed in this study using quantitative data analysis. Statistical analyses were performed using SPSS 22.0 software to test for normality and homogeneity to determine a parametric or non-parametric test (Utami & Putra, 2020). Furthermore, *t*-paired or Wilcoxon tests with a significant level of 0.05 were used to test two groups of data on microplastic abundance at the combined inlet and outlet of the three rivers and each river. A correlation test was carried out to correlate abiotic factors and microplastic abundance.

3. Result and Discussion

3.1. Microplastics Abundance

All sediment samples taken from the Winongo River, Code River, and Gadjahwong River at Yogyakarta City showed microplastics in the range of 279.31–1,026.93 particles kg^{-1}. The average abundance of microplastics from the three rivers in the inlet and outlet positions was 635.82 ± 161.72 particles kg^{-1}. The average abundance of microplastics from the three rivers in Yogyakarta City is higher than found in Jagir Estuary Surabaya with 345.20 particles kg^{-1} (Firdaus et al., 2020) and in Pantai Pangandaran with an abundance of about 47.30 particles kg^{-1} (Septian et al., 2018). The study show lower result than that on the West Coast of Karimun Besar Island and Pantai Indah Kapuk Jakarta (Hastuti et al., 2014; Amin et al., 2020).

The Code River has the highest average abundance of 758.07 ± 246.80 particles kg^{-1}, followed by the Gadjahwong River of 682.13 ± 174.96 particles kg^{-1}, and Winongo River of 467.24 ± 156.19 particles kg^{-1} (Figure 2a). Statistically, there was no significant difference in microplastic abundance among the three rivers ($P > 0.05$). The average abundance in the inlet of the three rivers was higher than in the outlet of 688.25 ± 77.50 particles kg^{-1} and 583.39 ± 226.12 particles kg^{-1}. The paired t-test results showed no significant difference in the abundance of microplastics at the combined inlet and outlet ($p > 0.05$) of the three rivers. Sources of microplastics consisting of plastic bottles, plastic bag, used clothes, diapers, and sanitary napkins have been found in many upstream of the river in Sleman District (Tribun Jogja, 2018). This source was one of the causes of the high abundance of microplastics in the three rivers' inlets. Sleman District, located in the north of Yogyakarta City, was ranked the second-highest population density in Yogyakarta Province (BPS Sleman, 2019). According to Barnes et al. (2009), the abundance of plastic waste strongly correlates with the number of people in an area.

The abundance of microplastics at the inlet and outlet of each river varies (Figure 2b). Winongo River and Gadjahwong River tend to flow the microplastics from the inlet to the outlet. The paired t-test results on the microplastics abundance of the Winongo River showed a significant difference between inlet and outlet ($p < 0.05$). In contrast, the Wilcoxon test results on the Gadjahwong River showed no significant difference ($p > 0.05$). The prolonged drought in 2019 became one reason for the decline in microplastic abundance (Prasetyaningtyas, 2020). The decrease in water discharge at the outlet made the narrowing of the river flow. The Winongo river and Gadjahwong river are sinuous that the river flow slows down in the dry season. As a result, microplastics would be quickly sunk before reaching the outlet. On the other hand, code River has more microplastics from the inlet to the outlet. The Wilcoxon test results showed no significant difference between the abundance of microplastics at the inlet and outlet of Code river ($p > 0.05$). The Code River, which crosses Yogyakarta's main tourist attractions such as Tugu, Malioboro, and the Kraton (Widodo et al., 2010), is a waste disposal site. The disposal was from hospitals, hotels, printing companies, the textile industry, tannery factory, and domestic waste as sources of microplastics (Imronatushshoolikhah et al., 2014). Besides, the Code River has a straight channel so that microplastic particles can easily be carried to the outlet. However, because the river's water discharge is still slow due to the prolonged dry season in 2019, the sampling plot varies in its sediment base between sand and rock. This causes the abundance of microplastics in each sample at each station to vary and makes the standard deviation relatively high. According to van Cauwenberghe et al. (2015), soft sediments could trap plastic more than rocky and gravel habitats that supports this study that sediment in the three rivers has a muddy texture.

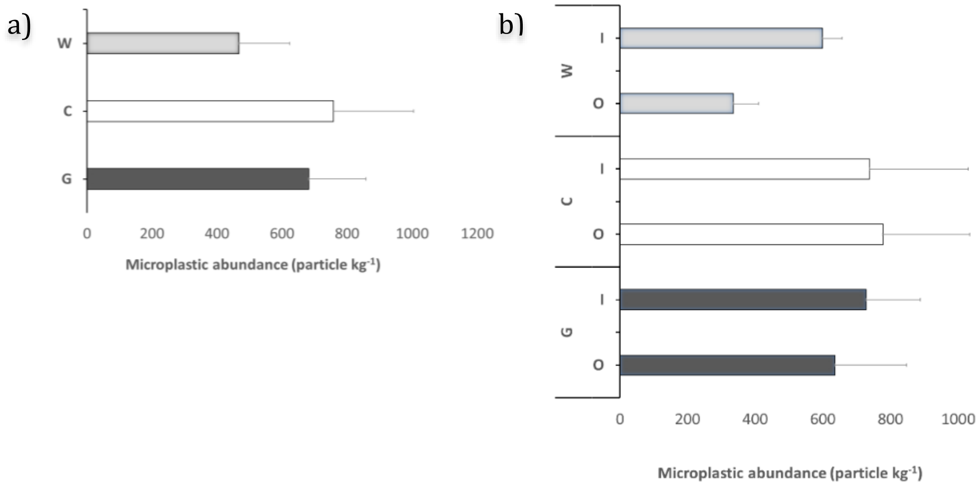

Figure 2. The abundance of microplastics: in each river (a), and in inlet-outlet in each river (b) at Yogyakarta City

Physical activity (cracking and flaking) and chemical activity that harms long polymer chains were causing microplastics formation (Chamas et al., 2020). Each type of synthetic polymer has various degradation pathways depending on its physical and chemical activities (Yousif & Haddad, 2013; Yu et al., 2016; Chamas et al., 2020). Spearman correlation test result showed that the abundance of microplastics in the three rivers in Yogyakarta City was correlated with light intensity, water temperature, dissolved CO_2, dissolved O_2, water velocity, and elevation ($P< 0.05$). The water temperature at the inlet was 28 °C and the outlet was 30 °C. According to Barnes et al. (2009), the damage to plastics' mechanical action is further exacerbated by degradation due to temperatures that have remained warm for several years. Plastic polymers were degraded in the environment due to hydrolysis and oxidation processes accelerated by heat, light, or the combination (Andrady, 2011; Chamas et al., 2020). Synthetic polymers absorb photons, especially the wavelengths emitted by sunlight, such as infrared radiation, visible light, and ultraviolet radiation (UV). This absorption causes thermo-oxidation, photo-oxidation, and photolysis that cause polymer degradation (Scott, 2000; Syranidou et al., 2019). Microscopic microplastic particles are carried downstream to become a source of pollution in the sea (Vianello et al., 2013). Besides, rivers and their flows that act as channels and accumulators have resulted in a higher abundance of plastic in the sediments than in the water column (Castaneda et al., 2014; McCormick & Hoellein, 2016). According to Hoellein et al. (2019), the sedimentation rate was influenced by each particle's characteristics such as shape, type, buoyancy, and biofilms.

3.2. Microplastic Characteristics

Microplastic characteristics were depicted from the size, shape, and color. They vary in each river. The size of microplastics found in the three rivers in Yogyakarta City ranges from 1 to 5,000 μm. The most common size range seen in the three rivers was 1-100 μm with an average abundance of 274.02 ± 142.26 particles kg^{-1} (43%), followed by 101-500 µm of 216.12 ± 95.72 particles kg^{-1} (34%) (Figure 3a). The Winongo River supplies microplastics with a size range of 101-500 µm because of their abundance of 1-100 µm (Figure 3b). Winongo River and Code River have a pattern of shrinkage in the most common size range from the inlet (101-500 µm) to the outlet (1-100 µm). While the Gadjahwong River was dominated by a range of 1-100 µm from the inlet (Figure 3c). Microplastic of fiber, film, fragments, and pellets were found in all sediment samples with varying abundances. In general, the most abundant were fragments by 276.27 ± 89.16 particles kg^{-1} (43%), followed by fiber by (34%), films (23%), and pellets with the smallest abundance by 1.12 ± 0.60 particles kg^{-1} (0%) (Figure 4a). The Winongo River was dominated by a balanced form of fiber and fragments (Figure 4b). Winongo River and Code River both show a pattern where the dominating shape changes at the inlet and then switches to the fragment shape at the outlet. Since the inlet, the Gadjahwong River has been dominated by fragment form. (Figure 4c). The color of microplastics in the three rivers was dominated by transparent colors with an abundance of 272.31 ± 119.86 particles kg^{-1} (43%) (Figure 5a, 5b). Gray microplastics were particularly prevalent at the Gadjahwong River outlet. (Figure 5c). A summary of the size, shape, and color of microplastics in each river can be seen in Table 2.

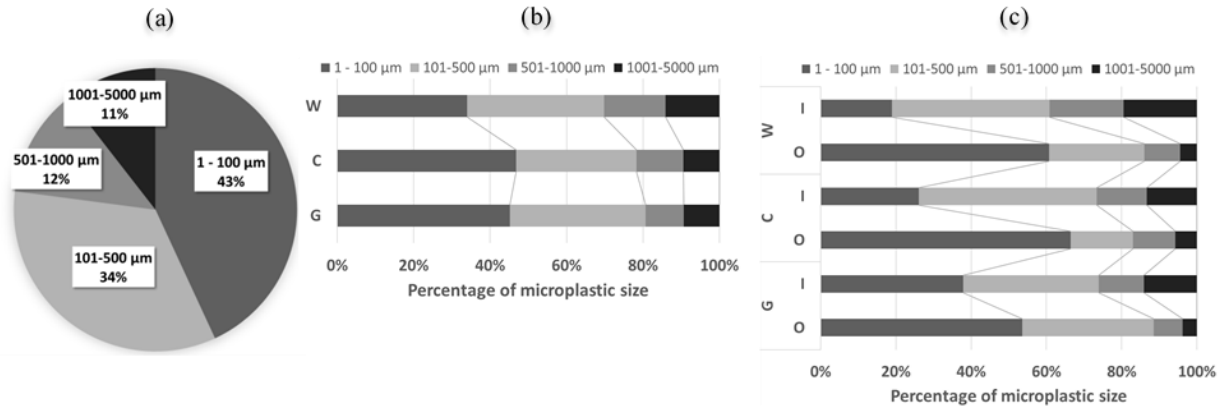

Figure 3. Microplastic sizes in river sediment at Yogyakarta City: (a) the percentage for the three rivers combined, (b) the percentage for each river, (c) the percentage for the inlet and outlet of each river

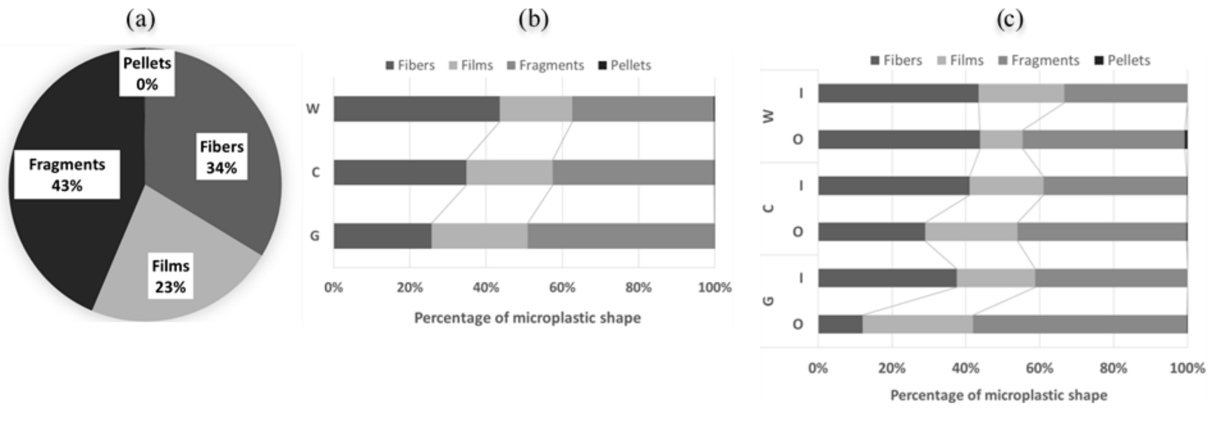

Figure 4. Microplastic shapes in river sediment at Yogyakarta City: (a) the percentage for the three rivers combined, (b) the percentage for each river, (c) the percentage for the inlet and outlet of each river

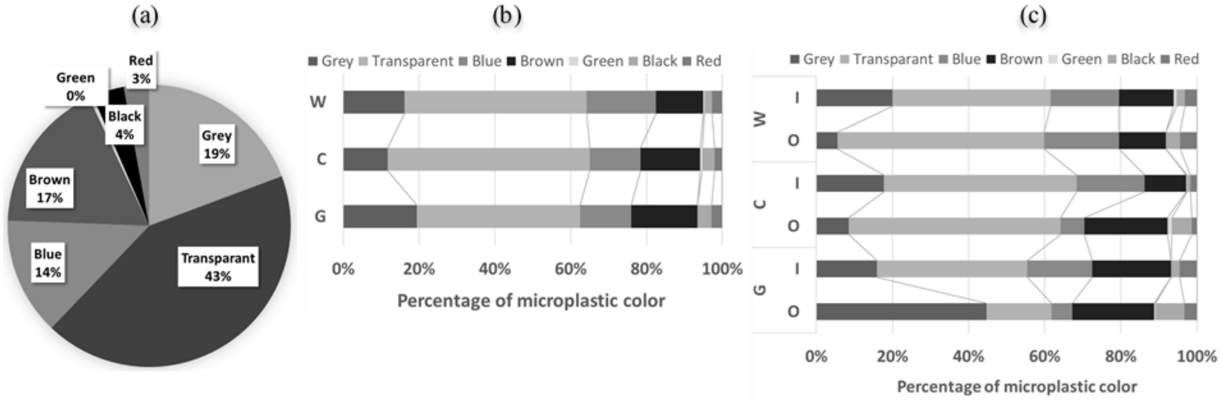

Figure 5. Microplastic colors in river sediment at Yogyakarta City: (a) the percentage for the three rivers combined, (b) the percentage for each river, (c) the percentage for the inlet and outlet of each river

Table 2. The dominant characters in each river

River's name	Size (μm)	Shape	Color
Winongo (W)	101-500	Fiber	transparent
Code (C)	1-100	Fragments	transparent
Gadjahwong (G)	1-100	Fragments	transparent

The type of polymer in this study was not identified using Fourier Transform Infrared Spectroscopy (FTIR). Still, the data on the size, shape, and color of microplastics were linked to published literature studies. Synthetic polymers used to make everyday items are commonly be used by the public. Microplastics in the form of fibers found in the Winongo River and Code River inlet were generated from laundry wastewater that the majority of synthetic fibers come from polyester and polyamide (Napper & Thompson, 2016; Sun et al., 2019). Pipes from household waste could be seen along the banks of the three rivers. According to Browne et al. (2011), one garment can remove more than 1,900 synthetic fibers. The increased density of polyester and polyamide compared to water gives the potential for fiber sedimentation in the riverbed (Hidalgo-Ruz et al., 2012). Besides, many used sacks filled with sand made for river dams upstream of the Code River are fiber microplastics sources. Microplastics in fibers occur from fishing poles or nets, in addition to synthetic garment fibers (UNEP, 2016).

The microplastic fragments can come from several high-density polymers. High-density polyethylene (HDPE) is commonly used for plastic bottles, and polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET) for food packaging, and household goods (Magalhaes et al., 2020; Hwang et al., 2020). According to Hoellein et al. (2019), fragments derived from polystyrene polymer have a short transport, much of which was deposited in the sediments because their density was more significant than river water. The Gadjahwong River inlet is located in the south of Prambanan tourism destination and the center of the resident in Cangkringan, Sleman District, and Klaten District. The upstream of the river made wastewater such as plastic bottles and plastic bags polluted the river. The size of the particles (length and diameter) also affects the sedimentation rate. The river's slope also hastens deposition at the bottom, after which the fragmentation process in the sediment continues (Hoellein et al., 2019). Microplastics with small sizes (< 50 μm) were generally driven by the binding of the biofilm and pushed into the sediments instead of sinking by themselves (Williams et al., 2008). The abundance of color microplastics at the sampling location could be influenced by the length of time the microplastic in nature as well as the sunlight exposure (Marti et al., 2020). Some examples of microplastics found in this study can be seen in Figure 6.

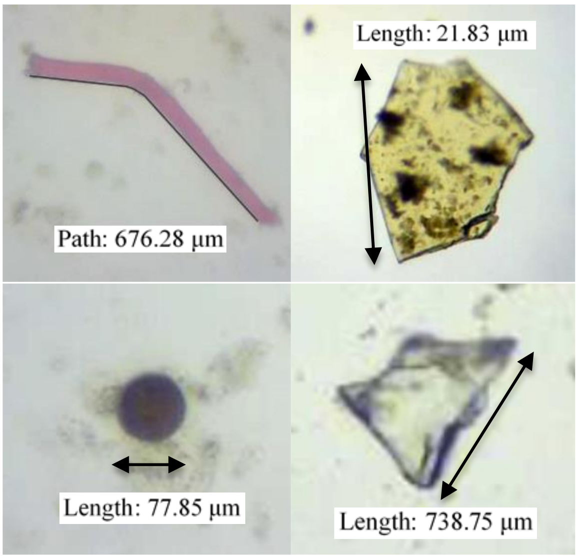

Figure 6. Microplastic shapes in sampling location: (a) fiber, (b)fragment, (c) pellets, (d) film

Microplastics in the rivers across Yogyakarta City was the initial pollution in the urban area of Yogyakarta province. The dangers posed by the ingested microplastics require policies from the government of Yogyakarta Province. There is no microplastic parameter to be a pollution standard in the Governor of Special Region of Yogyakarta Regulation number 7 of 2016 and the Governor of Special Region of Yogyakarta Regulation number 20 of 2008 concerning Water Quality Standards in the Yogyakarta City. The discovery of microplastics in Indonesian rivers highlights the importance of establishing a minimum environmental standards for microplastic pollution. Microplastic pollution sources must be identified, documented, and measures must be taken to decrease microplastic release into the environment.

4. Conclusion

Microplastics polluted the sediments of Winongo River, Code River, and Gadjahwong River in Yogyakarta City. The Microplastic abundance range from 279.31 to 1,026.93 particles kg^{-1} in inlet higher than the outlet. The Code River sediment has the highest microplastic abundance of 758.07 ± 246.80 particles kg^{-1}, followed by the Gadjahwong River of 682.13 ± 174.96 particles kg^{-1} and Winongo River on 467.24 ± 156.19 particles kg^{-1}. The sediment samples in the river crossing Yogyakarta City have been contaminated mainly by the fragment-shapes, transparent, and 1-100 µm microplastic. Waste from residents in the surrounding river, such as plastic bottles, used packaging, and food packaging, was thought to be the source of microplastic.

Acknowledgment

The authors express their gratitude to *Lembaga Penelitian dan Pengabdian kepada Masyarakat* (LPPM) Universitas Ahmad Dahlan for funding this research.

References

Alimba, C. G., & Faggio, C. (2019). Microplastics in the marine environment: Current trends in environmental pollution and mechanisms of toxicological profile. *Environmental Toxicology and Pharmacology, 68*, 61-74. https://doi:10.1016/j.etap.2019.03.001

Amin, B., Galib, M., & Setiawan, F. (2020). Preliminary Investigation on the Type and Distribution of Microplastics in the West Coast of Karimun Besar Island. The 8th International and National Seminar on Fisheries and Marine Science. 430, page. 1-9. *Pekanbaru: IOP Conf. Series: Earth and Environmental Science*. https://doi:10.1088/1755-1315/430/1/012011

Andrady, A. L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin*, *62*(8), 1596-1605. https://doi:10.1016/j.marpolbul.2011.05.030

Avio, C. G., Gorbi, S., & Regoli, F. (2015). Experimental development of a new protocol for extraction and characterization of microplastics in fish tissues: First observations in commercial species from Adriatic Sea. *Marine Environmental Research*. https://doi:10.1016/j.marenvres.2015.06.014

Barasarathi, J., Agamuthu, P., Emenike, C., & Fauziah, S. (2014). Microplastic Abundance in Selected Mangrove Forest in Malaysia. *The ASEAN Conference on Science and Technology* (page. 1-4). Bogor: the ASEAN Committee on Science and Technology.

Barnes, D. K., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of The Royal Society*, *364*(1526), 1985-1998. https://doi:10.1098/rstb.2008.0205

Boucher, J., & Friot, D. (2017). *Primary Microplastics in the Oceans: a Global Evaluation of Sources*. Gland, Switzerland: IUCN. doi:dx.doi.org/10.2305/IUCN.CH.2017.01.en

BPS Sleman. (2019). *Jumlah Penduduk dan Kepadatan Penduduk menurut Kabupaten/Kota di D.I Yogyakarta, 2017*. Retrieved from Badan Pusat Statistik (BPS) Kabupaten Sleman website: https://slemankab.bps.go.id/statictable/2019/06/26/446/jumlah-penduduk-dan-kepadatan-penduduk-menurut-kabupaten-kota-di-d-i-yogyakarta-2017.html

Browne, M. A., Crump, P., Niven, S. J., Teuten, E., Tonkin, A., Galloway, T. S., & Thompson, R. (2011). Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. *Environmental Science & Technology, 45*(21), 9175-9179. https://doi:10.1021/es201811s

Cadman, C. A., Butler, K., Mitchell, L., Latuheru, J., Asquf, H., Pratomo, I. S., Utomo, K. P. (2018). *Hotspot Sampah Laut Indonesia*. Jakarta: World Bank Group.

Castaneda, R. A., Avlijas, S., Simard, A., & Ricciardi, A. (2014). Microplastic pollution in St. Lawrence River sediments. *Canadian Journal of Fisheries and Aquatic Sciences, 71*, 1-5. doi:10.1139/cjfas-2014-0281

Chamas, A., Moon, H., Zheng, J., Qiu, Y., Tabassum, T., Jang, J., Suh, S. (2020). Degradation Rates of Plastics in the Environment. *ACS Sustainable Chemistry Engineering, 8*(9), 3494-3511. https://doi:10.1021/acssuschemeng.9b06635

Claessens, M., de Meester, S., van Landuyt, L., de Clerck, K., & Janssen, C. R. (2011). Occurrence and distribution of microplastics in marine sediments along the Belgian coast. *Marine Pollution Bulletin, 62,* 2199-2204. https://doi:10.1016/j.marpolbul.2011.06.030

Cole, M., Webb, H., Lindeque, P. K., Fileman, E. S., Halsband, C., & Galloway, T. S. (2014). solation of microplastics in biota-rich seawater samples and marine organisms. *Scientific Reports, 4*(4528), 1-8. https://doi:10.1038/srep04528

Dewi, I. S., Budiarsa, A. A., & Ritonga, I. R. (2015). Distribusi mikroplastik pada sedimen di Muara Badak, Kabupaten Kutai Kartanegara. *Depik, 4*(3), 121-131. https://doi:10.13170/depik.4.3.2888

Duis, K., & Coors, A. (2016). Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. *Environmental Sciences Europe, 28*(2), 1-25. https://doi:10.1186/s12302-015-0069-y

Firdaus, M., Trihadiningrum, Y., & Lestari, P. (2020). Microplastic pollution in the sediment of Jagir Estuary, Surabaya City, Indonesia. *Marine Pollution Bulletin, 150*, 1-9. doi:10.1016/j.marpolbul.2019.110790

GESAMP. (2016). *Sources, Fate and Effects of Microplastics in the Marine Environment: Part 2 of a Global Assessment*. London: International Maritime Organization.

Hastuti, A. R., Yulianda, F., & Wardiatno, Y. (2014). Distribusi spasial sampah laut di ekosistem mangrove Pantai Indah Kapuk, Jakarta. *Bonoworo Wetlands, 4*(2), 94-107. https://doi:10.13057/bonorowo/w040203

Hidalgo-Ruz, V., Gutow, L., Thompson, R. C., & Thiel, M. (2012). Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. *Environmental Science and Technology, 46,* 3060-3075. https://doi:10.1021/es2031505

Hoellein, T. J., Shogren, A. J., Tank, J. L., Risteca, P., & Kelly, J. J. (2019). Microplastic deposition velocity in streams follows patterns for naturally occurring allochthonous particles. *Scientific Reports, 9*(3740). https://doi:10.1038/s41598-019-40126-3

Hwang, J., Choi, D., Han, S., Jung, S. Y., Choi, J., & Hong, J. (2020). Potential toxicity of polystyrene microplastic particles. *Scientific Reports Nature Research, 10*(7391), 1-12. https://doi:10.1038/s41598-020-64464-9

Imronatushshoolikhah, Purnama, S. I., & Suprayogi, S. (2014). Kajian Kualitas Air Sungai Code Propinsi Daerah Istimewa Yogyakarta. *Majalah Geografi Indonesia, 28*(1), 23-32.

Lebreton, L. C., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world's oceans. *Nature Communications, 8*(15611), 1-10. https://doi:10.1038/ncomms15611

Lusher, A., N.A. Welden, Sobral, P., & Cole, M. (2017). Sampling, isolating and identifying microplastics ingested by fish and invertebrates. *The Royal Society of Chemistry, 9*, 1346-1360. https://doi:10.1039/c6ay02415g

Magalhaes, S., Alves, L., Medronho, B., Romano, A., & Rasteiro, M. d. (2020). Microplastics in Ecosystems: From Current Trends to Bio-Based Removal Strategies. *MDPI, 25*(17), 1-19. https://doi.org/10.3390/molecules25173954

Marti, E., Martin, C., Galli, M., Echevarria, F., Duerte, C. M., & Cozar, A. 2020. The Colors of the Ocean Plastics. *Environmental Science and Technology*, 54(11), 6594-6601. https://doi:10.1021/acs.est.9b06400

McCormick, A. R., & Hoellein, T. J. (2016). Anthropogenic litter is abundant, diverse, and mobile in urban rivers: Insights from cross-ecosystem analyses using ecosystem and community ecology tools. *Limnology and Oceanography, 61*(5), 1718-1734. https://doi:10.1002/lno.10328

Mehlhart, G., & Blepp, M. (2012). *Study on land-sourced litter (LSL) in the marine environment. Review of sources and literature*. Darmstadt Freiburg: the Context of the Initiative of the Declaration of the Global Plastics Associations for Solutions on Marine Litter.

Muryanto, Suntoro, Gunawan, T., Setyono, P., Nurkholis, A., & Wijayanti, N. F. (2019). Distribution of Nitrate Household Waste and Groundwater Flow Direction around Code River, Yogyakarta, Indonesia. *Indonesian Journal of Geography, 51*(1), 54-61. https://doi:10.22146/ijg.43420

Napper, I. E., & Thompson, R. C. (2016). Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. *Marine Pollution Bulletin*, 1-7. https://doi:10.1016/j.marpolbul.2016.09.025

Prasetyaningtyas, K. (2020). *Analisis Curah Hujan dan Sifat Hujan Bulan Desember 2019*. Retrieved from Badan Meteorologi Klimatologi dan Geofisika (BKG) website: https://www.bmkg.go.id/iklim/informasi-hujan-bulanan.bmkg?p=analisis-curah-hujan-dan-sifat-hujan-bulan-desember-2019&lang=ID

Putro, S. S. (2016). The Study of Water Quantity and Quality (Case Study: Gajahwong Watershed). *Journal of the Civil Engineering Forum, 2*(3), 151-156. https://doi:10.22146/jcef.26588

Sarengat, N., Yuniari, A., Setyorini, I., & Suyatini. (2015). Kajian Potensi Pencemaran Industri Pada Lingkungan Perairan di Daerah Istimewa Yogyakarta. *Seminar Nasional Kulit, Karet, dan Plastik ke-4* (hal. 125-156). Yogyakarta: Balai Besar kulit, karet, dan plastik, Badan Penelitian dan Pengembangan Industri.

Scott, G. (2000). Green Polymers. *Polymer Degradation and Stability, 68*, 1-7. https://doi:10.1016/S0141-3910(99)00182-2

Septian, F. M., Purba, N. P., Agung, M. U., Yuliadi, L. P., Akuan, L. F., & Mulyani, P. G. (2018). Sebaran Spasial Mikroplastik di Sedimen Pantai Pangandaran, Jawa Barat. *Jurnal Geomaritim Indonesia, 1*(1), 1-8.

Sulistyo, E. N., Rahmawati, S., Putri, R. A., Arya, N., & Eryan, Y. A. (2020). Identification of the Existence and Type of Microplastic in Code River Fish, Special Region of Yogyakarta. *Eksakta, 1*(1), 85-91 https://.doi:10.20885/EKSAKTA.vol1.iss1.art13

Sun, J., Dai, X., Wang, Q., van-Loosdrecht, M. C., & Ni, B.-J. (2019). Microplastics in wastewater treatment plants: Detection, occurrence and removal. *Water Research, 152*, 21-37. https://doi:10.1016/j.watres.2018.12.050

Syranidou, E., Kalogerakis, G. C., Karkanorachaki, K., Gotsis, A., Partsinevelos, P., & Kalogerakis, N. (2017). Fragmentation and biodegradation rates of weathered plastics in the marine environment - The new challenges. *40th AMOP Technical Seminar on Environmental Contamination and Response*. Calgary, Canada: Environment and Climate Change Canada.

Syranidou, E., Karkanorachaki, K., Amorotti, F., Avgeropoulos, A., Kolvenbach, B., Zhou, N.-Y., Kalogerakis, N. (2019). Biodegradation of mixture of plastic films by tailored marine consortia. *Journal of Hazardous Materials, 375*, 33-42. https://doi:10.1016/j.jhazmat.2019.04.078

Thompson, R. C., Swan, S. H., Moore, C. J., & vom Saal, F. S. (2009). Introduction Our Plastic Age. *Philosophical Transactions: Biological Sciences, 364*(1526), 1973-1976. https://doi:10.1098/rstb.2009.0054

Tribun Jogja. (2018). *Sungai di DIY Darurat Popok. Yogyakarta, DIY, Indonesia*. Retrieved from Tribun Jogja online: http://issuu.com/tribunjogja/docs/tribunjogja-23-08-2018

UNEP. (2016). *UNEP Frontiers 2016 Report: Emerging Issues of Environmental Concern*. Nairobi: United Nations Environment Programme.

Utami, I., & Putra, I. L. (2020). *Ekologi Kuantitatif, Metode Sampling dan Analisis Data Lingkungan*. Bantul: K-Media.

Utami, I., & Putri, D. A. (2019). Pemberdayaan Anggota 'Aisyiyah se-Daerah Istimewa Yogyakarta dalam Pengolahan Diaper Bekas Sebagai Campuran Media Tanam. *Logista Jurnal Ilmiah Pengabdian Kepada Masyarakat,* 3(2), 76-81. https://doi:10.25077/logista.3.2.76-81.2019

van Cauwenberghe, L., Devriese, L., Galgani, F., Robbens, J., & Janssen, C. R. (2015). Microplastics in sediments: A review of techniques, occurrence and effects. *Marine Environmental Research, 111*, 5-17. https://doi:10.1016/j.marenvres.2015.06.007

Vendel, A. L., Bessa, F., Alves, V., de Amorim, A. L., Patricio, J., & Palma, A. (2017). Widespread microplastic ingestion by fish assemblages in tropical estuaries subjected to anthropogenic pressures. *Marine Pollution Bulletin, 117*(1-2), 1-8. https://doi:10.1016/j.marpolbul.2017.01.081s

Vianello, A., Boldrin, A., Guerriero, P., Moschino, V., Rella , R., Sturaro, A., & Ros, D. L. (2013). Microplastic particles in sediments of Lagoon of Venice, Italy: First observations on occurrence, spatial patterns and identification. *Estuarine, Coastal and Shelf Science, 130*, 54-61. https://doi:10.1016/j.ecss.2013.03.022

Waller, C. L., Griffiths, H. J., Waluda, C. M., Thorpe, S. E., Loaiza, I., Moreno, B., Hughes, K. A. (2017). Microplastics in the Antarctic marine system: An emerging area on Research. *Science of the Total Environment, 598*, 220-227. https://doi:10.1016/j.scitotenv.2017.03.283

Widodo, B., Lupiyanto, R., & Wijaya, D. (2010). Pengelolaan Kawasan Sungai Code Berbasis Masyarakat. *Jurnal Sains dan Teknologi Lingkungan, 2*(1), 7-20. https://doi.org/10.20885/jstl.vol2.iss1.art2

WIlliams, N., Walling, D., & Leeks, G. (2008). An analysis of the factors contributing to the settling potential of fne fuvial sediment. *Hydrological Processes: An International Journal, 22,* 4153-4162. https://doi.org/10.1002/hyp.7015

Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: A review. *Environmental Pollution, 178*, 483-492. https://doi:10.1016/j.envpol.2013.02.031

Yousif, E., & Haddad, R. (2013). Photodegradation and photostabilization of polymers, especially polystyrene: review. *SpringerPlus, 2*(398), 1-32. https://doi:10.1186/2193-1801-2-398

Yu, J., Sun, L., Ma, C., Qiao, Y., & Yao, H. (2016). Thermal degradation of PVC: A review. *Waste Management, 48*, 300-314. https://doi:10.1016/j.wasman.2015.11.041