Potential plastic waste input from Citarum River, Indonesia

Bayu Pamungkas, Taryono, Rahmat Kurnia, Etty Riani

Department of Aquatic Resources Management , Faculty of Fisheries and Marine Science, IPB University, Jalan Kamper, Kampus IPB, Dramaga, Bogor, Indonesia. Corresponding author: B. Pamungkas, pamungkas3150@apps.ipb.ac.id

Abstract. One of the main sources of plastic waste originates from human activities alongside river bodies, entering rivers from upstream to estuaries/deltas, undoubtly affecting marine and coastal environments. The purpose of this study was to identify the potential of waste input at the Citarum River estuary. Plastic waste sampling was conducted using a net that stretched across a river body for some time. The samples were identified and quantified. The results show that the potential input of plastic waste from Citarum River reached up to 10.2 g m^{-3} or 24813.7 items m^{-3}. The predominant type of waste was thin plastic wrap and styrofoam products. It is urgent to direct serious attention to considerable plastic waste pollution in Citarum River.

Key Words: coastal environment, Pantai Bahagia Village, plastic waste.

Introduction. The Citarum watershed is one of the largest watersheds in West Java, occupying 6614 km^2 (Cahyaningsih & Harsoyo 2010). The river originates in the mountain range near the southern coast of Java that includes many high volcanic peaks, including Mount Wayang (elevation 2200 m), and travels in a generally north-westerly direction for 270 km, until it empties into the Java sea, east of Jakarta. According to Cahyaningsih (2010), the Citarum River watersheds contain 11.255 million inhabitants with more than 1000 industries, being the most dominant source of pollution, including plastic waste.

The use of plastics and plastic-based products is increasing along with the development of technology, industry, and human population. This can be evident from the use of plastic in everyday life as a medium for packaging foodstuffs and non-foodstuffs (Morritt et al 2014). World plastic production in the last few years has increased along with the increasing demand for plastic. World plastic production in 2002 amounted to 200 million tons and increased to 335 million tons in 2016 and is expected to continue to increase every year (Thompson 2015; Plastics Europe 2017). Barnes et al (2009), Eubeler (2010), and Thompson (2015) stated that plastic production continues to escalate by 9% per year. Plastic waste grows decisively in a short time, but it needs a very long time to degrade, and it will contribute to environmental problems, especially in natural habitats such as aquatic environments.

In 2018, the Coordinating Ministry for Maritime Affairs issued regulations regarding the handling of marine debris. The regulation is contained in Presidential Regulation No. 83 of 2018. It was released with the consideration that there has been an increase in the amount of plastic waste in the sea, which causes environmental pollution and damage, especially to marine and coastal ecosystems, as well as endangering human health. The purpose of issuing the regulation is to establish government commitment in handling marine trash by 70% in 2025 (Coordinating Ministry for Maritime Affairs 2018). The prediction of marine debris growth is receiving enormous attention globally. Jambeck et al (2015) predict that there will be an increase in the amount of marine debris until 2025. However, not much is known about the potential of plastic waste input entering the coastal area from all rivers, including Citarum River.

From the explanation above, it is evident that the potential input of plastic waste at the estuary of the Citarum river is high and not yet clearly known. Densely populated settlements, large cities, and centers of economic activity along the Citarum River body allow the potential of plastic waste input into the river. The purpose of this study is to present the input of plastic waste in the estuary of the Citarum River, West Java, Indonesia.

Material and Method

Description of the study sites. The study was conducted by observing and sampling plastic waste at the Citarum River outlet that partially flows into the Jakarta Bay, in March 2020. Sampling was carried out during the peak periods of the rainy season. It was assumed that the maximum input of plastic waste generally occurs in the rainy season (Cordova & Nurhati 2019). Plastic waste was collected using a 5 cm mesh net placed in the river. Sampling was conducted at 3 different stations with 3 sampling points each (Figure 1): in the middle and both near-sides of the river. The observation time was 30 minutes at each sampling point and was repeated twice. At each repetition, samples were collected in separate plastic bags labeled to distinguish the location and repetition of sampling.

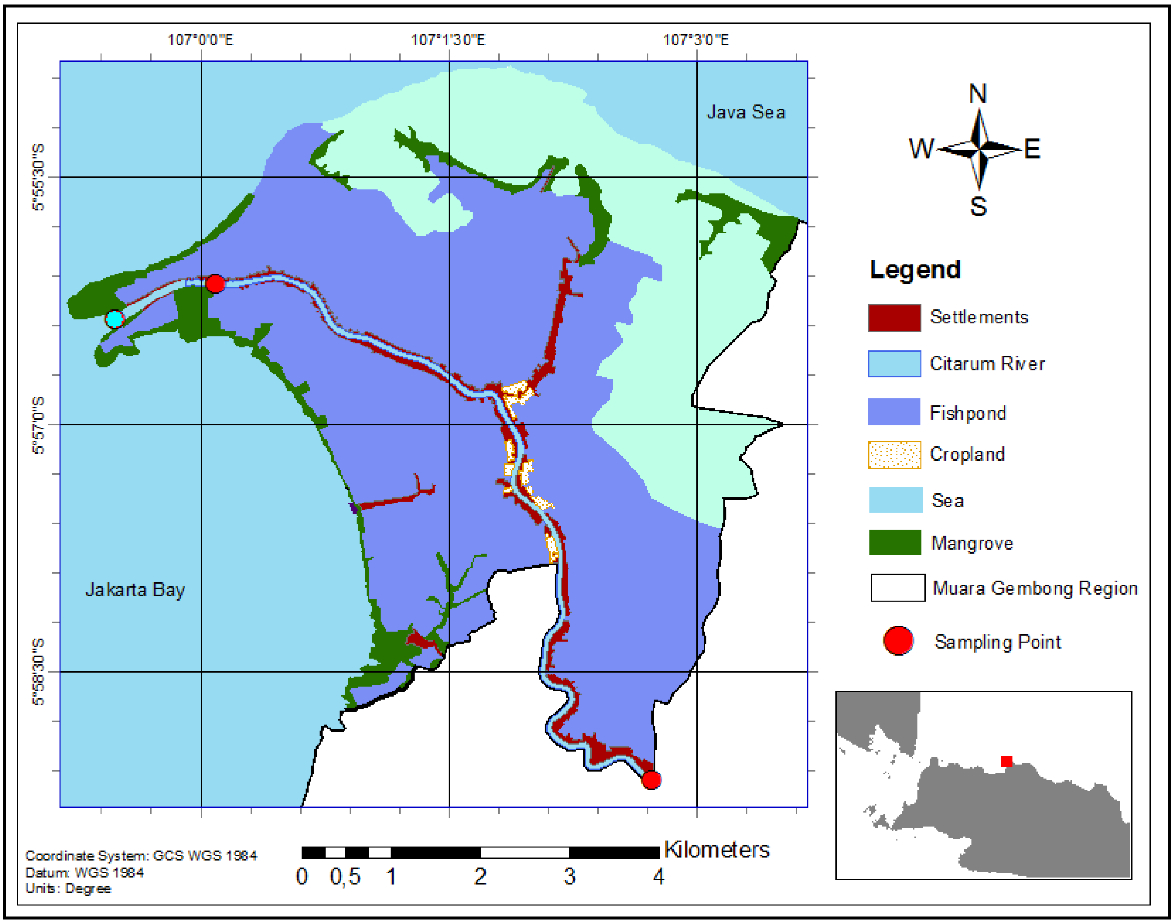

Figure 1. Sampling site.

Sample collection and analysis. Plastic waste collected was sorted according to the category issued by NOAA, modified by Cordova & Nurhati (2019). In this study, the waste samples collected were only plastic waste, which has been widely known to cause alarming ecological detriment (Lusher et al 2013; Neves et al 2015; Rummel et al 2016). Plastic waste from food wrappings or other rubbish that was too small and difficult to identify was grouped in other categories and separately identified. Plastic waste was divided in 19 groups: balls/tires/balloons, plastic bottles, plastic bottle caps, plastic caps, lighters/cigarette/cigarette foam, thin plastic wrap, thick plastic wrap, rubber bands, tape, medical wrapping, straws, food boxes and plastic utensils, footwear (shoes or sandals), styrofoam, ropes/fishing nets, plastic ropes, pipes, other plastic waste, and cosmetic wrap (Cordova & Nurhati 2019).

Plastic waste collected from the field was washed to remove dirt, mud, sand, or other impurities, dried (under the sun) and cleaned using dry tissue (if needed), for further weighing. The samples were categorized by their type and weighed using a digital scale (Walalangi 2012). The abundance of macroplastic was calculated in units of volume of filtered water, which is based on the surface area of the waste trap and water disposal. The density is the ratio of weight in grams to volume units in m^3. The abundance is the ratio of the number of items to the volume units in m^3. Both of these quantities prevail in waste analysis in waters. Water discharge is the result of multiplication between the velocity of river flow and the length of time the waste trap is installed (NOAA 2013), obtaining the unit items m^{-3} and g m^{-3}. River flow was calculated by measuring the surface velocity and vertical dimension of the river. The river dimensions were derived from its width and depth. Both values are then tested statistically using the Kruskal-Wallis and Mann-Whitney tests, used to determine differences in abundance and density in each observation station.

Results and Discussion. The abundance values are similar in regard to density. The largest abundance and density values were found in station 1. The highest abundance value at station 1 was 2.91±1.116 items m^{-3}, with a density value of 18.56±7.614 g m^{-3}. Moreover, the lowest abundance and density values were found in station 2. The highest abundance value at station 2 was 2.48±1.384 items m^{-3}, with a density of 1.78±0.762 g m^{-3}. When compared to the highest level of abundance in Parungkuda, 3.17 items m^{-3} sec^{-1}, the values are relatively similar (Taryono et al 2019). The results showing the comparison of density and abundance values are presented in Table 1, while Figure 2 illustrates the graph of those values.

Table 1

Waste potential in the estuary of Citarum River

	Density (g m^{-3})	*Abundance (item m^{-3})*
Station 1	18.56±7.614	2.91±1.116
Station 2	1.78±0.762	0.23±0.077
Station 3	10.2±7.413	2.48±1.384

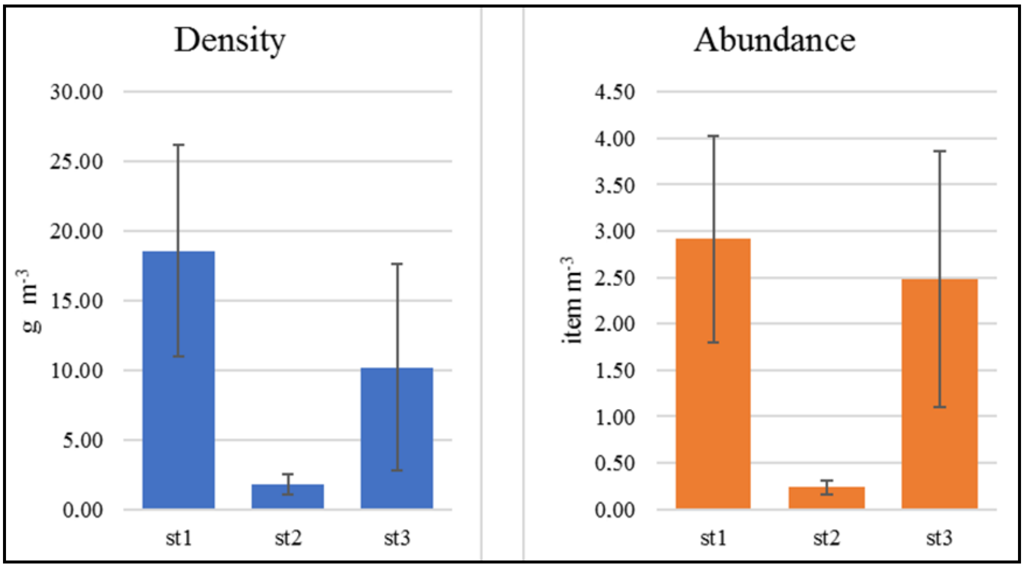

Figure 2. Plastic waste in the Citarum estuary.

The density and abundance values in each station have different patterns. There are differences among the stations. From the results above, it appears that the density and abundance values at station 1 are higher, while the lowest numbers are found at station 2. Statistically, the density values found in station 1 are different from those of station 2 ($p<0.05$) and station 3 ($p<0.05$). Abundance values at station 1 are different from those at station 2 ($p<0.05$), but statistically similar to those at station 3 ($p>0.05$). The t-test results of the abundance and solid waste in each river section can be seen in Table 2.

Table 2

The t-test results of plastic waste in the estuary of Citarum River

			Density			
	K-independent (Kruskal-Wallis)	*2-related (Mann-Whitney)*			*Mean weight (g m^{-3}) (x10^{-2})*	*notes*
		Station 1	*Station 2*	*Station 3*		
Station 1	0.052*	-	0.016*	0.2	1855.750	a
Station 2		-	-	0.262	177.565	b
Station 3		-	-	-	1018.800	b
			Abundance			
	K-independent (Kruskal-Wallis)	*2-related (Mann-Whitney)*			*Mean number*	*notes*
		Station 1	*Station 2*	*Station 3*		
Station 1	0.005*	-	0.004*	0.521	2.912	a
Station 2		-	-	0.01*	0.235	b
Station 3		-	-	-	2.481	a

Note: * - shows significant differences; a and b represent similarities among the stations; stations that have the same notes present no statistical differences.

The results of the analysis showed that footwear waste dominates the collected plastic waste, with 62.69% and 33.14% at stations 1 and 2, respectively. In contrast to density, the most abundant type of plastic waste at these two stations is styrofoam products. At station 3, the largest percentage, both for abundance and density, had the thin plastic waste, with 61.62% and 74.98%, respectively. The lowest percentage of abundance and density were found to vary at each sampling station. The type of wastes with the lowest abundance at station 1 are plastic matches/tips/cigarettes, plastic cups, and plastic utensils, with a value of 0.5% each. At station 2, plastic rope/small net pieces and cosmetic or medicine wrappings had values of 0.58%, and at station 3, there were plastic covers, plastic utensils, and pipes/hoses with a value of 0.35%. In contrast to abundance, the type of waste with the lowest density at station 1 was plastic bottle cups with a value of 0.32%, while at station 2 it was cosmetic or medicine wrappings with a value of 0.05%. At station 3, rope/fishing net had a value of 0.05%.

The results showed that styrofoam-type waste dominated the abundance of findings. The predominant forms of styrofoam obtained are disposable food packaging products and electronic wrappings, both in pieces or in the whole form, with varying sizes. It is known that styrofoam waste is composed of polystyrene polymer or PS (GESAMP 2019). Although the polystyrene or PS polymer waste has the highest abundance value, which reaches more than 50% at two stations, the percentage of the density is found to be relatively low compared to other polymer types, reaching only 5%. This is similar to the results of Moore et al (2011), where the amount of polystyrene polymer abundance showed the greatest abundance (71%), with the lowest weight percentage (11%). Styrofoam waste dominated the findings at all stations. This corresponds with the study of Lee et al (2013), where styrofoam-type waste is known to have the highest abundance in the Nakgong River, South Korea. The level of styrofoam waste abundance has a higher percentage than its density.

Since this study only identifies plastic waste, but there were other findings in the collected samples. Among the samples, there were a small number or glass bottles or pieces and leaf debris. It is known that vegetal debris is also carried in the river stream (Martin et al 2016; Chuan et al 2019). This type of debris is quite often found in sampling sited and have a considerable percentage (Cordova & Nurhati 2019).

Table 3

Percentage of waste categories in the estuary of the Citarum River, Indonesia

Categories	*Station 1*		*Station 2*		*Station 3*	
	Abundance (%)	*Density (%)*	*Abundance (%)*	*Density (%)*	*Abundance (%)*	*Density (%)*
Ball, tires, balloons, and pieces of them	0	0	0	0	0	0
Plastic bottles	2	2.68	4.07	1.91	2.11	4.78
Plastic cups	0.5	0.32	3.49	4.15	0.7	0.64
Plastic covers	1	1.24	3.49	6.67	0.35	0.91
Plastic matches, tips, cigarettes	0.5	0.96	1.16	1.39	0.7	0.06
Thin plastic wraps	18.5	11.55	31.98	15.34	61.62*	74.98*
Tick plastic wraps, sacks	0.5	1.89	1.16	0.48	4.23	6.49
Rubber bands, rubber pieces	0	0	0	0	0	0
Masking tape, duct tape, pieces of them	0	0	0	0	0	0
Medicine wrap	0	0	1.16	0.39	0	0
Straw, straw pieces	16	6.47	9.3	1.35	2.46	0.67
Food boxes, plastic utensil	0.5	2.12	1.16	25.49	0.35	0
Shoes, sandals, gloves, pieces of them	2.5	62.69*	1.74	33.14*	1.06	3.08
Styrofoam	53.5*	5.37	34.3*	3.81	22.89	5.56
Ropes, fishing lines, fishing rods	0	0	0	0	0	0
Plastic ropes/small nets pieces	0	0	0.58	0.12	1.06	0.05
Pipe, hoses	0	0	0	0	0.35	0.27
Other plastics	2	1.99	5.81	5.69	1.41	1.34
Cosmetic wraps, toiletries	2.5	2.72	0.58	0.05*	0.7	1.18

Note: * - the highest percentage.

Waste that enters the river usually originates from human activities around the river body, such as domestic, economic, or industrial activities (Li et al 2016), being classified as a land-based waste source. Economic activity along the river body is assumed to be a source of extreme waste input that accumulates in Jakarta Bay (Manalu et al 2017). Jakarta has large economic and social activities with a large number of people who live and work in the area. A high volume of waste, predominated by solid domestic waste, entering Jakarta Bay from 13 rivers and fluctuating throughout the year was identified (Cordova & Nurhati 2019).

Nevertheless, waste entering the river is found to be less severe in environments or locations that have been well equipped with waste management facilities such as temporary landfills (Taryono et al 2019). In spite of that, if environmental pressure is greater than the existing waste management facilities, waste entering the water system will be more likely to occur. Moreover, when basic waste management is scarce, it becomes a great deal to environment and human health.

The dynamics of rivers and plastic waste characteristics are likely to contribute to the types and sizes of plastic waste that flow from the river to the sea. Several studies have attempted to explain the details, yet there are many variables unmarked due to the very different types of plastic waste (Sul et al 2014). The results in Table 3 indirectly show the dominance of plastic waste through the river stream. Waste with heavy density, such as footwear, is predominantly found at two stations. This type of waste, however, experiences a significant decrease in the estuary. The contrast result prevails for lighter waste, such as thin plastic packaging, which possesses the second-highest percentage after footwear. This type of waste dominates the findings in the river mouth. A similar result occurs for styrofoam waste, its abundance dominating at stations 1 and 2. Its percentage is still high in the river mouth. Footwear waste that tends to be heavier may get stuck on river banks, in mangroves, when the current velocity changes. Sandals and footwear waste can be found in the mangroves around station 2, likely to occur due to high mangrove density (Martin et al 2019). However, more data is needed to prove the dynamic mechanism of plastic waste in rivers.

There is a need to address with more attention the measure or potential of waste input from rivers (Blettler et al 2017), but there are models already developed (Jang et al 2014). In addition to fisheries and other activities on the coast (Li et al 2016), rivers are considered to be one of the main sources of waste entry into the sea through river flow (Claessens et al 2011), which increases during storms or rain (Yu et al 2013).

Research on the accumulation of plastic waste in coastal ecosystems has been conducted considerably. Coastal habitats such as estuaries and sea embankment areas are several habitats that are contaminated with plastic waste from fishing activities (Smith & Edgar 2014). It is also predicted that by 2025, plastic waste accumulated in coral reef ecosystems will increase by 40% (Lamb et al 2018). Juliana et al (2014) explained that the accumulation of plastic waste in the mangrove ecosystem in Brazil is dominated by plastic bags. The publication also emphasized the tendency of the mangrove ecosystem to accumulate plastic waste over a long period. Based on this information, it is essential to pay more attention to preventing the accumulation of waste from its sources, including rivers. The diversity in the coastal area and its complexity results in intricate identification of waste accumulation.

Sampling was also conducted by other authors in different seasons, such as the rain season, to see the fluctuation of waste discharge in the river, this being an important factor (Cordova & Nurhati 2019). Morritt et al (2014) suggested the establishment of a sampling strategy to cover all river depths. In some cases, the river stream may permit a simpler sampling. However, sampling in large rivers will make it difficult to identify the distribution of waste from the surface to the riverbed due to the swift flow. Therefore, simplification of waste monitoring in such conditions should still meet the scientific methodology.

Management of waste input in rivers is urgently needed. It is necessary to monitor the waste input brought from the river to contrive useful information in mitigating disasters caused by marine debris (Ryan et al 2009). Plastic waste input can be mitigated by technical approaches applied in the upstream and river bodies, so that its volume at the river outlet or in the coastal area can be diminished (Tyler 2011). Plastic waste that accumulates in coastal environments such as rivers and seas is evidence of failure to control and manage solid waste from land (Raubenheimer & McIlgorm 2017), which makes it urgent to take serious steps to prevent catastrophic accumulation of marine waste.

Conclusions. The most dominant finding from the sampling of plastic waste is thin plastic wrap and styrofoam. The thin plastic waste consists mainly of snack wrappings, sanitary product wrappings, and cooking spices. On the other hand, the styrofoam waste has a high abundance, while footwear/shoe/sandal waste dominates in density. Styrofoam waste is mostly found in the form of electronic device wrappings and disposable food packaging in various sizes. It is advisable to direct more attention to the management of plastic product usage to significantly reduce the plastic waste volume in the waters.

Acknowledgements. The Head of Pantai Bahagia Village, Pokdarwis Alipbata, and local community leaders who have allowed the research in Pantai Bahagia Village.

References

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 B: Biological Sciences 364(1526):1985-1998.

Blettler M. C., Ulla M. A., Rabuffetti A. P., Garello N., 2017 Plastic pollution in freshwater ecosystems: macro-, meso-, and microplastic debris in a floodplain lake. Environmental Monitoring and Assessment 189:581, 13 p.

Cahyaningsih A., Harsoyo B., 2010 [Spatial distribution of water pollution levels in the Citarum]. Jurnal Sains & Teknologi Modifikasi Cuaca 11(2):1-9. [In Indonesian].

Chuan W., Kuroiwa J. M., Inga L. F. C., Vasquez L., 2019 Transport and trapping of woody debris in a river meander protected with Elj Groynes. E-proceedings of the 38th IAHR World Congress, pp. 5999-5609.

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(10):2199-2204.

Cordova M. R., Nurhati I. S., 2019 Major sources and monthly variations in the release of land-derived marine debris from the Greater Jakarta area, Indonesia. Scientific Reports 9:18730, 8 p.

Eubeler J. P., 2010 Biodegradation of synthetic polymers in the aquatic environment. Dissertation, Bremen University, 209 p.

Jambeck J. R., Geyer R., Wilcox C., Siegler T. R., Perryman M., Andrady A., Narayan R., Law K. L., 2015 Plastic waste inputs from land into the ocean. Science 347(6223):768-771.

Jang Y. C., Lee J., Hong S., Mok J. Y., Kim K. S., Lee Y. J., Choi H. W., Kang H., Lee S., 2014 Estimation of the annual flow and stock of marine debris in South Korea for management purposes. Marine Pollution Bulletin 86(1-2):505-511.

Juliana A., Sul J. A. I., Costa M. F., Silva-Cavalcanti J. S., Araújo M., 2014 Plastic debris retention and exportation by a mangrove forest patch. Marine Pollution Bulletin 78(1):252-257.

Lamb J. B., Willis B. L., Fiorenza E. A., Couch C. S., Howard R., Rader D. N., Harvell C. D., 2018 Plastic waste associated with disease on coral reefs. Science 359(6374):460-462.

Lee J., Hong S., Song Y. K., Hong S. H., Jang Y. C., Jang M., Heo N. W., Han G. M., Lee M. J., Kang D., Shim W. J., 2013 Relationships among the abundances of plastic debris in different size classes on beaches in South Korea. Marine Pollution Bulletin 77(1-2):349-354.

Li W. C., Tse H. F., Fok L., 2016 Plastic waste in the marine environment: A review of sources, occurrence and effects. Science of the Total Environment 566-567:333-349.

Lusher A. L., McHugh M., Thompson R. C., 2013 Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. Marine Pollution Bulletin 67(1-2):94-99.

Manalu A. A., Hariyadi S., Wardiatno Y., 2017 Microplastics abundance in coastal sediments of Jakarta Bay, Indonesia. AACL Bioflux 10(5):1164-1173.

Martin C., Almahasheer H., Duarte C. M., 2019 Mangrove forests as traps for marine litter. Environmental Pollution 247:499-508.

Martin D. J., Pavlowsky R. T., Harden C. P., 2016 Reach-scale characterization of large woody debris in a low-gradient, Midwestern USA river system. Geomorphology 262:91-100.

Moore C. J., Lattin G. L., Zellers A. F., 2011 Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of Southern California. Revista de Gestão Costeira Integrada 11(1):65-73.

Morritt D., Stefanoudis P. V., Pearce D., Crimmen O. A., Clark P. F., 2014. Plastic in the Thames: A river runs through it. Marine Pollution Bulletin 78(1-2):196-200.

Neves D., Sobral P., Ferreira J. L., Pereira T., 2015 Ingestion of microplastics by commercial fish off the Portuguese coast. Marine Pollution Bulletin 101(1):119-126.

Raubenheimer K., McIlgorm A., 2017 Is the Montreal Protocol a model that can help solve the global marine plastic debris problem? Marine Policy 81:322-329.

Rummel C. D., Löder M. G. J., Fricke N. F., Lang T., Griebeler E. M., Janke M., Gerdts G., 2016 Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea. Marine Pollution Bulletin 102(1):134-141.

Ryan P. G., Moore C. J., van Franeker J. A., Moloney C. L., 2009 Monitoring the abundance of plastic debris in the marine environment. Philosophical Transactions of the Royal Society B: Biological Sciences 364(1526):1999-2012.

Smith S. D. A., Edgar R. J., 2014 Documenting the density of subtidal marine debris across multiple marine and coastal habitats. PLoS ONE 9(4):e94593, 7 p.

Sul J. A. I., Costa M. F., Silva-Cavalcanti J. S., Araújo M. C. B., 2014 Plastic debris retention and exportation by a mangrove forest patch. Marine Pollution Bulletin 78(1-2):252-257.

Taryono E. O. L. P., Wardiatno Y., Mashar A., 2020 Macroplastic distribution, abundance, and composition which flows to Cimandiri estuary, West Java. IOP Conference Series: Earth and Environmental Science 420:012031, 9 p.

Thompson R. C., 2015 Microplastics in the marine environment: Sources, consequences and solutions. In: Marine anthropogenic litter. Springer, Cham, pp. 185-200.

Trivedi, A., Singh, A. and Chauhan, A., 2015. Analysis of key factors for waste management in humanitarian response: An interpretive structural modelling approach. International Journal of Disaster Risk Reduction 14:527-535.

Tyler R. N., 2011 River debris: Causes, impacts, and mitigation techniques. Alaska Center for Energy and Power, Alaska, 33 p.

Walalangi J. Y., 2012 [Analysis of the composition of organic and inorganic waste and its impact on the coastal environment of Palu City, Central Sulawesi]. Magister thesis, Bogor Agricultural University, Bogor, Indonesia, 128 p. [In Bahasa].

Yu B., Li L., Wu Y., Chu S., 2013 A formation model for debris flows in the Chenyulan River Watershed, Taiwan. Natural Hazards 68(2):745-762.

***Coordinating Ministry of Maritime Affairs of Indonesia, 2018 [Presidential Decree Number 83 in 2018 about Marine Debris Management]. [In Indonesian].

***GESAMP, 2019 Guidelines for the monitoring and assessment of plastic litter in the ocean. 123 p.

***Plastics Europe, 2017 Plastics – The facts 2017: An analysis of European latest plastics production, demand and waste data. Available at: https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf

Received: 21 September 2020. Accepted: 29 October 2020. Published online: 28 January 2021.

Authors:
Bayu Pamungkas, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, Kampus IPB, 16680 Dramaga, Bogor, Indonesia, e-mail: pamungkas3150@apps.ipb.ac.id
Taryono, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, Kampus IPB, 16680 Dramaga, Bogor, Indonesia, e-mail: tkodiran@yahoo.com
Rahmat Kurnia, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, Kampus IPB, 16680 Dramaga, Bogor, Indonesia, e-mail: rahmatku@apps.ipb.ac.id
Etty Riani, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, Kampus IPB, 16680 Dramaga, Bogor, Indonesia, e-mail: etty_riani_harsono@yahoo.com

How to cite this article:
Pamungkas B., Taryono, Kurnia R., Riani E., 2021 Potential plastic waste input from Citarum River, Indonesia. AACL Bioflux 14(1):103-110.