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Quantification of Riverbank Macroplastic Contamination in The Lower Citarum River

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Abstract. Plastic waste generation has been increasing over the last decades. Rivers represent complex environments where plastics may be stored and remobilized. Studies on riverine plastic, including riverbank contamination, are still lacking. Riverbank surveys were carried out in the Citarum River, Indonesia, at three river sections in Purwakarta, Karawang, and Muara Gembong in March-April 2021. The aim was to quantify the abundance of plastic waste at different points in the riverbank zone. The sample 'monolith' was taken by digging a quadrat of 30x30x10 cm^3. All material was then weighed. Three replicates along the length of the bank and three replicates across the bank were taken. The non-plastic fraction was weighed and its composition was estimated. Plastic fraction was classified into categories, counted, and weighed. The result show that plastic litter was found in all monolith ranging from 0.7-301 g of plastic litter per monolith. The largest proportion of plastic contaminant was found in Karawang with 2.85% of plastic in a single monolith and the largest average plastic contaminant was about 0.78% of the total monolith weight, showing that plastic contamination is prevalent. Enhancing waste management, reducing single-use plastics, and plastic recycling are recommended to tackle plastic contamination in the study area.

1. Introduction

Plastic waste generation in Indonesia has been increasing over the last few decades and is currently growing to unsustainable levels. Recent studies reveal significant contamination of soil, atmospheric, and freshwater systems [1][2]. This is boosted, among others, by the growing trend of single-use plastics consumption despite its initial purpose that is mainly for long-lasting items [3][4]. Mismanaged plastic waste is leaked to the environment and is transported from far inland to the marine environment via rivers. Riverine plastic storage and remobilization are controlled by the natural characteristics of the river systems and their anthropogenic modifications [5]. The riverbank zone is likely to be an important site for the temporary storage of plastic waste.

The route of macroplastic litter through a river system or river reach can be divided into five phases, namely: input, transport, storage, remobilization, and output [5], which are briefly described as follows. Plastic litter input to river system is mainly controlled by anthropogenic activities that dispose litter in channels, riverbanks/floodplain, or landfills. The transport phase occurs when the litter becomes initially entrained by the stream flow. The storage phase of plastic litter occurs due to natural or artificial deposition, or such as when the litter is deposited on riverbed or bank sediments, in vegetation or accumulated in river sediments below the riverbed or floodplain surface. Remobilization takes place when this stored litter is once again entrained by river flow or erosion processes and starts to be transported downstream. The output phase is controlled by either natural or artificial factors. Therefore, it can be a natural transport of litter out of a river system such as to the ocean or estuary or its artificial removal by infrastructure or cleanup actions [5]. Several additional and complex processes may also occur, such as upstream transport from tidal influence or degradation of litter in the river environment, which can alter the dynamics of transport, deposition, and remobilization.

Studies on riverine plastic, especially on riverbank plastic contamination, are currently lacking in Indonesian literature. Nowadays, 88% of plastic research in Indonesia is conducted in the marine environment [6] despite the fact that plastics are produced, used, and disposed of on land [1] and leaked waste from lands and rivers are suspected to be the biggest source of marine plastic pollution. Efforts to find solutions for this plastic contamination problem require a better understanding of the processes in the terrestrial environment. Therefore, a shift towards the monitoring of plastic pollution in the riverine and terrestrial environments is necessary to be able to tackle the problem and mitigate its impact earlier at the source. This includes sampling plastics in different environments within the river to establish the processes and controls influencing the transport and storage of plastic over different spatial and temporal scales.

As part of the ASEANO project (ASEAN – Norway cooperation project on local capacity building for reducing plastic pollution in the ASEAN region), a field observation campaign has been performed in the lower Citarum River, West Java - Indonesia. This study was performed in an effort to find a practical methodology for riverbank macro debris observation in the lower Citarum River. The aim was to quantify the abundance and the types of plastic waste at different points in the riverbank zone.

2. Methodology

2.1. Study area

The Citarum River, with a watershed area of 6,614 km^2 and a length of 297 km, is the largest river in West Java Province. The river flows from Bandung Regency through the rural and urban areas of Bandung, Cianjur, Purwakarta, Karawang, and Bekasi before discharging into the Java Sea. The river is known to be highly polluted with plastics and other types of waste due to the significant mismanagement of waste [7]. At present, a major national restoration project known as "Citarum Harum" is conducted to assist in cleaning up plastics and other sources of pollution [8].

Three locations were selected as the sampling locations for riverbank monitoring in this study, depicted in figure 1. The first location (St. 1) is a sand-dominated riverbank near the bridge of Ciganea in Purwakarta (6° 33' 40.48" S, 107° 26' 0.87" E), the second location (St. 2) is a clay-dominated riverbank at a river section in an urban area of Karawang City (6° 17' 56.02" S, 107° 17' 17.12" E), and the third location (St. 3) is a silty clay riverbank in Muara Gembong (5° 59' 2.54" S, 107° 2' 26.94" E).

2.2. Sampling

The sample 'monolith' was taken from a quadrat of 30x30 cm on the riverbank surface and all material including sediments, waste, vegetation were removed to a depth of 10 cm. All material was then weighed using an electronic scale. Three replicates along the length of the bank and three replicates across the bank of about 2-3 m apart that more or less cover the whole bank width were planned to be taken (figure 2) to represent the spatial heterogeneity of riverbank contamination, so in total nine monoliths were to be taken. However, due to time constraints and weather conditions, only six monoliths were taken at St. 1. Once removed and weighed, all the material was disaggregated thoroughly to separate out all the constituent pieces, and all macrolitter of >0.5 mm in size were removed. The non-plastic fraction and its composition were weighed and categorized. The plastic fraction was classified into different categories and then counted and weighed. The categories pertain to different types of plastic, including drinking bottles, caps of drinking bottles, buckets, toys, dinnerware, straws, sachets, cups, mica, pipes, plastic bags, clear plastic packaging, styrofoam, tetrapak, thick plastics, plastic with aluminum, toothpaste tube, cigarette package, other multilayers, cigarette butts, ropes, fishing lines, and other plastics. Percentages of each litter category were obtained from the proportion of total weight of the litter category to the total weight of all monolith taken at each station.

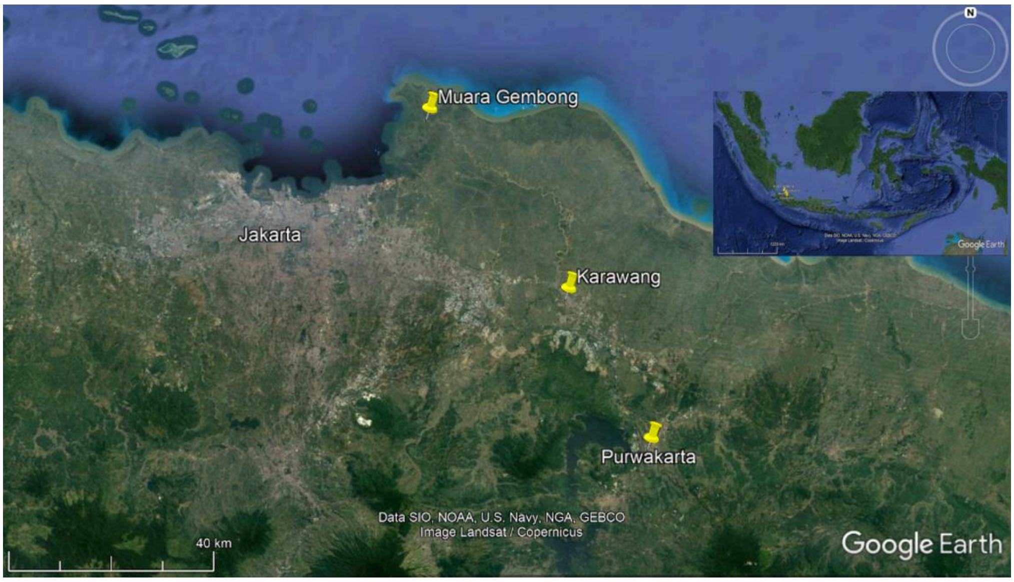

Figure 1. Lower Citarum riverbank sampling locations in Purwakarta, Karawang, and Muara Gembong. Map Source: Google Earth

Figure 2. Riverbank sampling along and across the bank

3. Results and Discussion

The characteristics of each observed river segment determine the type and abundance of macrolitter found. Table 1 shows the summary of observation results from the three sampling locations. St. 1 has a relatively steeper topography and this river segment was mostly dominated by sand and located after a bend with a rocky cliff upstream of the station. The macrolitter deposited in this location was dominated by high density litter (glass: 22 pieces and ceramics: 4 pieces), with rounded edges resulted from grinding effect of the mostly rock and gravel riverbed. Only three pieces of plastics were found at this location across all monoliths. St. 2 has a relatively milder topography and is mostly dominated by fine-grain clay sediments. Plastics (111 pieces) were the dominant litter type, followed by textiles (3 pieces). No higher density macrolitter was found in sampled monoliths in this location. The plastic litter types that were most frequently found here were plastic bags and packaging. St. 3 is located near the estuary with concrete walls as a flood protection structure present along both riverbanks. Plastics (53 pieces) dominated the composition of macrolitter found in the sampled monoliths. Table 2 presents the different litter types as a proportion to all the litter found during the survey.

Compared with the other two sampling locations, St. 2, which is located in the urban area of Karawang Regency, was found to be the most suitable site for long-term riverbank macroplastic monitoring. The location is easily accessible, the river is relatively straight at the location and the surrounding area of the bank is not directly occupied by local people, which is mostly found along the bank in other sites. Figure 3 shows the condition of St. 2 during the dry season (August 2019), the transition from rainy to dry season (May 2020), and the rainy season (December 2020). During the peak of the rainy season (Fig 3c), almost the entire riverbank was inundated. This allows for repeat sampling to establish processes of storage and remobilization due to different hydrological conditions at this site.

Table 1. Results of riverbank macrolitter observation in Purwakarta (St. 1), Karawang (St.2), and Muara Gembong (St. 3). Percentages of litter category were obtained from the proportion of total weight of the litter category to the total weight of all monolith taken at each station

Station	**St. 1**	**St. 2**	**St. 3**
Number of monoliths	6	9	9
Organics* (%)	0.0034	0.1060	1.0682
Plastics (%)	0.0025	0.7763	0.1364
Textiles (%)	0	0.1501	0.0011
Ceramics (%)	0.0317	0	0
Glass (%)	0.0566	0	0.0001
Metals (%)	0.0006	0	0
Hazardous materials** (%)	0	0.0487	0
Total percentage of litter (%)	0.0948	1.0811	1.2058

*all forms of large organic material in the sediments
**materials that can endanger the health or survival of humans and other living things such as used electronics, diapers, drug packages, pressurized can etc.

Table 2. Percentages of litter types as a proportion to all the litter found

Station	**St. 1**	**St. 2**	**St. 3**
Organics (%)	3.58	9.80	98.64
Plastics (%)	2.69	71.81	1.26
Textiles (%)	0	13.89	0.10
Ceramics (%)	33.43	0	0
Glass (%)	59.70	0	0.01
Metals (%)	0.60	0	0
Hazardous materials (%)	0	4.50	0
Total percentage (%)	100	100	100

Figure 3. Sampling location (St. 2) in the urban area of Karawang Regency during the dry season in August 2019 (a), the transition from rainy to dry season in May 2020 (b), and the rainy season in December 2020 (c). The arrow in b indicates the flow direction at this site. Map Source: Google Earth

Figure 4 shows the breakdown of riverbank litter in Karawang (St. 2). Plastic litter was found in all monoliths, ranging from 0.7-301 g of plastic litter per monolith. The plastic litter types that most frequently found were plastic bags and packaging. Figure 5 shows an example of litter composition of the monolith. The largest proportion of plastic contamination in the riverbank was 2.85% of a single monolith weight, showing that plastic contamination is prevalent at the river segment. Contamination from plastic litter and all forms of macrolitter investigated in this study was highly heterogeneous across the different monoliths, indicating complexity in the deposition, storage, and remobilization of different densities of litter across relatively small spatial scales. Monoliths closest to the water line contain more plastic litter, so plastic is deposited close to the water line.

Fewer plastics were found at St.3 (figure 6), where both sides of the bank have been modified using concrete walls for flood protection. The riverbank is used for planting bananas at this site, which explains the higher proportion of organic litter found. Plastic litter was only detected in four of the monoliths taken at this site. In contrast with St.2, which represents a natural channel, St. 3 represents an engineered channel that might alter the pattern of litter distribution. Plastics in this station are found further up the bank that might be transported during the high water and retained there in the presence of vegetation. No plastic was found in monoliths along the waterline, as the current at this location is relatively strong that possibly wash away deposited plastics near the waterline. Graph from St. 1 is not shown due to the limited type and quantity of litter found.

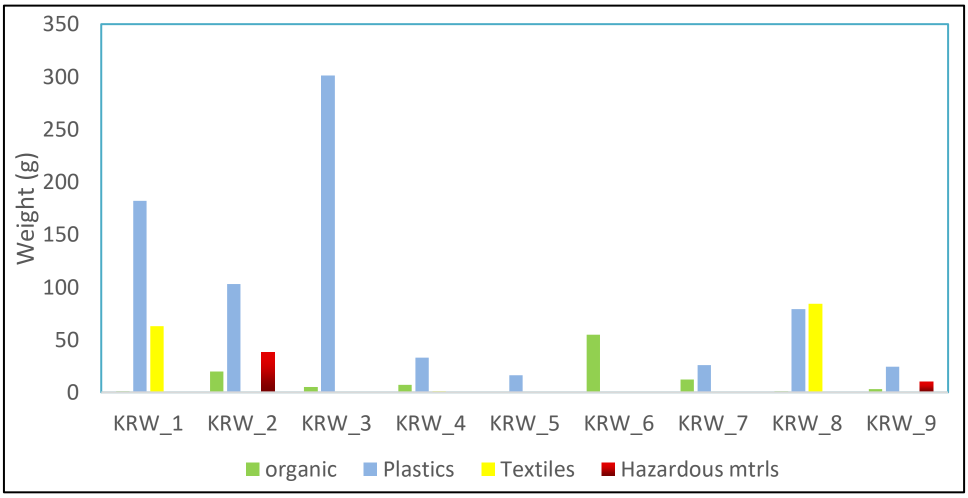

Figure 4. Riverbank litter composition in Karawang.

Figure 5. Example of litter composition of the middle row monolith in Karawang.

The bank of the Citarum river in Karawang (St. 2), where we took the sampled monolith in April 2021, was inundated during the next survey in May 2021 due to high rainfall intensity in the Citarum catchment. The flow condition during our sampling in May was landward (water flowed upstream) due to the backwater effect from the Cibeet River, a tributary of Citarum just downstream of our sampling site in Karawang. This condition is often found in lowland rivers, where backwater effects from tributaries, lakes, and tides modify flows and water levels [9]. A study on macroplastics found that sediments of river sections experiencing low stream power are expected to be hotspots for deposition of microplastics [10], which is likely to be also the case the for macroplastics. Plastics are generally lightweight and are normally found floating on water surfaces and drifting along with the river flow. It is likely that this backwater effect, along with the mostly clay sediment composition, may accommodate the deposition of lightweight riverine litter, including plastics, when this riverbank is inundated. The increased discharge comes with increased water levels and flow velocity, which occurs during a storm event and can remobilize settled or accumulated plastics on riverbanks [2]. However, from the observation at St. 2 we found that once stuck with the clayey sediment, the plastic litter tends to retain in the riverbank sediment, which hardens as it dries out.

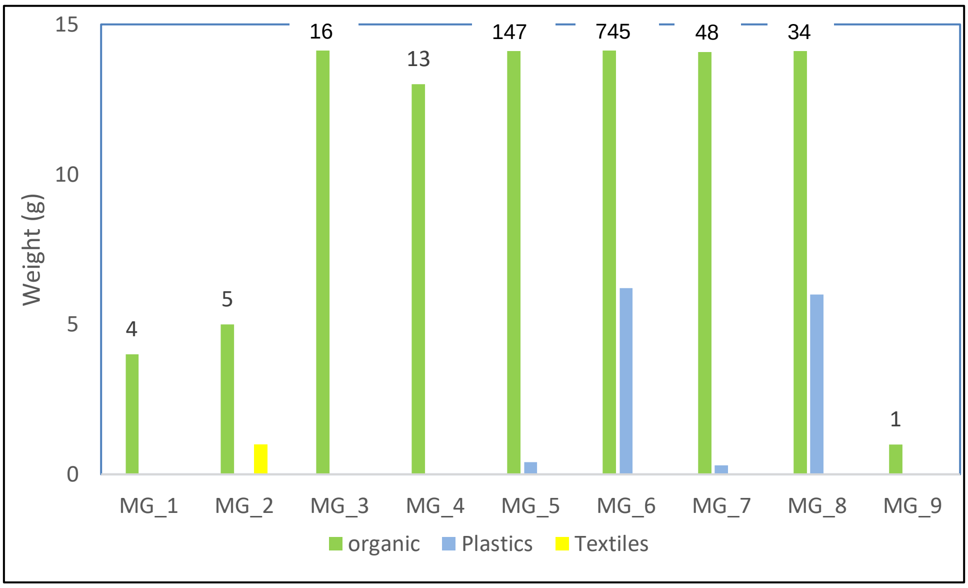

Figure 6. Riverbank litter composition of St. 3 in Muara Gembong. Organic litter dominated at this site, so the values have been added at the top of each column to represent the weight, which often exceeds the y-axis shown here.

This study can be considered as a frontier in plastic pollution research methodology in Indonesia as a limited number of similar studies are available. Among the proposed methods are by collecting everything attributable to humans at a certain transect along the river [11] and agricultural land [12]. However, these methods only consider litters on the soil surface. New methods for macroplastic monitoring provide opportunities for the upscaling of spatio-temporal data collection [13]. Generally, plastic contamination is found in all the three survey locations of the lower Citarum River. This result indicates that plastic litters, mostly of domestic source, have been accumulated on the riverbanks of the river. Regular monitoring data would be helpful to support policy and decision-making, among others, in assessing initiatives in reducing land-derived litter transported through the river [14]. To tackle further plastic contamination of the riverbank, enhancing waste management, reducing single-use plastics as well as plastic recycling are recommended.

4. Conclusion

Field surveys have been performed to find the practical methodology on riverbank macro debris observation in the lower Citarum River. Three locations in Purwakarta, Karawang, and Muara Gembong were selected as the potential sampling locations for riverbank monitoring. Compared with the other two sampling locations, the station located in the urban area of Karawang Regency (St. 2) was found to be the most suitable location for long-term riverbank macroplastic monitoring. The location is easily accessible, the river is relatively straight, and most importantly, the land of the bank is not occupied by local people, which is mostly found along the bank in other locations. We have quantified the abundance and the types of plastic waste in the Citarum riverbank zone. The plastic litter types that were most frequently found were plastic bags and packaging. The most significant proportion of plastic contamination in the riverbank was 2.85% of a single monolith weight showing that plastic contamination is prevalent at the river segment. To tackle further plastic contamination several actions need to be carried out, including enhancing waste management, reducing single-use plastics as well as plastic recycling.

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