

Abundance and polymer composition of macroplastic debris along the Somber River, Balikpapan City, East Kalimantan

Muhammad Syahrir R. | Hamdhani Hamdhani* | Daisy Rahma Rizal | Reny Herlindah | Wa Ode Siti Safiyah | Angelica Lusiana Permatasari

Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Mulawarman University
Jl. Gunung Tabur No. 1. Kampus Gn. Kelua Samarinda 75123

*E-mail: hamdhani@fpik.unmul.ac.id

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ABSTRACT

Plastic debris accumulating along rivers reflects the intensity of human activities in their catchments. This study assessed the abundance, item types, and polymer composition of macroplastic debris on the riverbank of the Somber River, Balikpapan City, East Kalimantan, a river approximately 23.6 km long with a catchment of about 3,932 ha that discharges into Balikpapan Bay. Sampling was conducted at three stations selected by purposive sampling from upstream to downstream. At each station, macroplastic items larger than 0.5 cm were collected from three 1 × 1 m plots along a 15 m transect, classified by item type following the NOAA marine debris guidelines, and identified for polymer type using Fourier transform infrared spectroscopy (FT-IR). The number, weight, density, and polymer composition of the debris were calculated, and the relationship between upstream–downstream distance and macroplastic density was tested using simple linear regression. A total of 21 macroplastic items weighing 59.16 g were collected, giving a mean density of 2.33 items/m² and 6.57 g/m². Density increased from 0.67 items/m² at the upstream station to 5.33 items/m² at the downstream station. Food packaging (42.9%) and plastic bags (19.0%) were the dominant item types, while polypropylene was the dominant polymer (55.44% by weight), followed by polyethylene (21.25%), olefin fiber (20.50%), and polyester (2.81%). Distance along the river explained 77% of the variation in macroplastic density ($R^2 = 0.77$). These findings indicate that plastic pollution in the Somber River originates mainly from the household activities of riverside communities and highlight the need for integrated waste management to protect the river and the coastal ecosystem of Balikpapan Bay.

INTRODUCTION

Water is essential for all living organisms because it directly sustains life. Rivers are bodies of freshwater flowing from upstream to downstream that form complex ecosystems (Wijayanti et al., 2021; Hamdhani et al., 2023). River ecosystems play a vital role in supporting human activities, including transportation, clean water supply, and fisheries, as well as in maintaining the hydrological balance of swamps and wetlands. Consequently, rivers are important not only ecologically but also socially and economically.

The Balikpapan Bay watershed is a strategic area in East Kalimantan because it supports the ecological functions of the bay and the activities of the Balikpapan seaport. The bay receives inflows from several large and small rivers, including the Somber, Wain, Semoi, Sepaku, and Riko rivers (Wulandari et al., 2020). The Somber River is approximately 23.6 km long and has a catchment area of about 3,932 ha (Nulissa et al., 2024). This setting makes the Somber River one of the main water pathways into Balikpapan Bay, so its environmental quality strongly influences the health of the coastal ecosystem.

Various anthropogenic activities, such as settlements, industry, and trade, take place along the Somber River and can generate pollution, particularly in the form of plastic waste (Nur et al., 2022; Hamdhani et al., 2026). Plastics are synthetic polymers produced by monomer polymerization and are highly stable, so they degrade very slowly in nature. The common practice of using rivers as dumping sites further degrades aquatic environments. Plastic accumulation in rivers not only reduces aesthetic value but also affects water quality, the health of aquatic biota, and the overall balance of the ecosystem (Kurniawan et al., 2023).

Despite these pressures, information on the abundance and characteristics of macroplastic debris in the Somber River remains limited, as previous studies in the area have focused on estuarine water quality (Wulandari et al., 2020) and microplastics in fish (Nulissa et al., 2024). This study therefore addressed three questions: how abundant macroplastics are on the riverbank of the Somber River, which types of plastic waste contribute most to the pollution, and to what extent human activities influence plastic waste generation in the area.

Accordingly, this study aimed to (1) quantify the abundance of macroplastic debris on the riverbank of the Somber River, (2) identify the dominant item types and polymer types of the plastic waste, and (3) assess the relationship between anthropogenic activities and plastic waste generation along the river, using the upstream–downstream position of the sampling stations. The results are expected to provide a basis for more effective river management, particularly for controlling plastic pollution in Balikpapan Bay, and to support aquatic resource management policies in East Kalimantan.

METHODOLOGY

Time and study location

This study was conducted in Juni-Juli 2026 on the riverbank of the Somber River, Balikpapan City, East Kalimantan. Samples were collected at three stations distributed from the upstream section (Station 1) through the middle section (Station 2) to the downstream section near Balikpapan Bay (Station 3) (Figure 1).

Tools and materials

The tools used in this study were a measuring tape, rope, wooden stakes, scissors, a shovel, plastic buckets, plastic sample bags, face masks, gloves, a camera, and stationery. The material analyzed was macroplastic debris collected from the riverbank.

Research procedure

The study consisted of four stages: preparation, observation and station selection, sample collection, and sample identification.

Preparation

All tools and materials were prepared before fieldwork to avoid errors during sample collection and in the use of equipment and materials in the field.

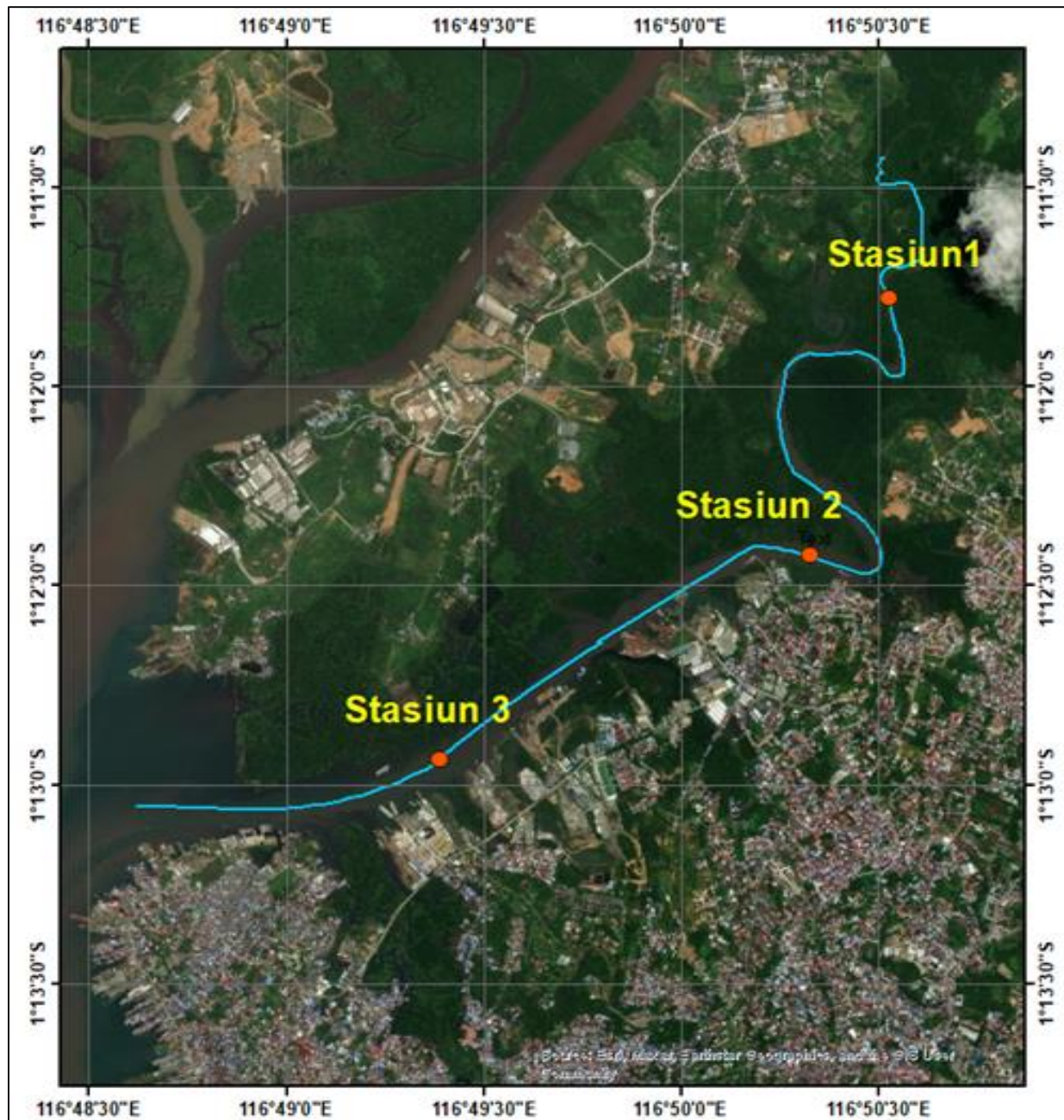


Figure 1. Map of the study area and sampling stations on the riverbank of the Somber River, Balikpapan City

Observation and station selection

A field observation was carried out to obtain an overview of the study area. Sampling stations were determined by purposive sampling, in which several stations were established along the riverbank.

Sample collection

At each station, macroplastic debris was collected along a 15 m transect containing three sampling points. Each sampling point consisted of a 1×1 m plot, following the marine debris monitoring guidelines of the Indonesian Ministry of Environment and Forestry (Kementerian Lingkungan Hidup dan Kehutanan

[KLHK], 2020). All plastic items larger than 0.5 cm found within each plot were collected and placed in labeled sample bags.

Sample identification

The collected samples were cleaned of attached sand and mud particles and then sorted by station and item type. The polymer type of each item was identified using Fourier transform infrared (FT-IR) spectroscopy.

Data analysis

Macroplastic debris was classified by item type following the National Oceanic and Atmospheric Administration (NOAA, 2015), and the number and weight of the items were then calculated for each station. The total number and total weight of each debris type were calculated following Sriwahyuni et al. (2024) using Equations (1) and (2):

$$J_{n,tot} = J_{n,I} + J_{n,II} + J_{n,III} \quad (1)$$

$$B_{n,tot} = B_{n,I} + B_{n,II} + B_{n,III} \quad (2)$$

explanation:

$J_{n,tot}$: total number of debris type n (items)

$J_{n,I}, J_{n,II}, J_{n,III}$: number of debris type n in transects I, II, and III, i.e., Stations 1, 2, and 3 (items)

$B_{n,tot}$: total weight of debris type n (g)

$B_{n,I}, B_{n,II}, B_{n,III}$: weight of debris type n in transects I, II, and III (g).

The mean number and mean weight of each debris type were calculated using Equations (3) and (4):

$$\bar{J}_n = \frac{J_{n,I} + J_{n,II} + J_{n,III}}{X} \quad (3)$$

$$\bar{B}_n = \frac{B_{n,I} + B_{n,II} + B_{n,III}}{X} \quad (4)$$

explanation:

$\bar{J}_n$: mean number of debris type n (items)

$\bar{B}_n$: mean weight of debris type n (g)

X : number of transects.

Macroplastic abundance per unit area was calculated using Equation (5):

$$A = \frac{N}{L} \quad (5)$$

explanation:

A : macroplastic abundance (items/m²)

N : total number of macroplastic items (items)

L : sampled area (m²).

Weight-based density (g/m²) was calculated in the same way by replacing N with the total weight of macroplastics (g).

The composition of macroplastic debris was calculated from the weight of each type following Nursari et al. (2023) using Equation (6):

$$K_n = \frac{X_n}{\sum_{i=1}^k X_i} \times 100\% \quad (6)$$

explanation:

K_n : composition of debris type n (%)

X_n : weight of debris type n (g)

$\sum X_i$: total weight of all debris types (g).

The percentage of each item type was calculated in the same way based on the number of items.

Statistical analysis

Data were processed using Microsoft Excel and Stata version 15.1 (StataCorp, College Station, Texas, USA). The relationship between the distance of each station from the upstream station (independent variable, X) and macroplastic density (dependent variable, Y) was analyzed using simple linear regression.

RESULT AND DISCUSSION

Macroplastic abundance

A total of 21 macroplastic items were collected from the three stations on the riverbank of the Somber River. The number of items varied markedly among stations, ranging from 2 items at Station 1 to 16 items at Station 3, with Station 2 containing 3 items. This spatial pattern indicates that macroplastic accumulation was not uniform along the riverbank and that the downstream section represented the most important accumulation zone among the sampled locations. The corresponding item densities are presented in Table 1. Although the overall sample size was relatively small, the pronounced difference among stations provides an initial indication of spatial heterogeneity in macroplastic deposition along the Somber River.

Table 1. Number and density of macroplastic items on the riverbank of the Somber River, Balikpapan City

Station	Number of items	Density (items/m ²)
Station 1	2	0.67
Station 2	3	1.00
Station 3	16	5.33
Mean	7	2.33

Note: The sampled area at each station was 3 m² (three 1 × 1 m plots).

The highest macroplastic density was recorded at Station 3 (5.33 items/m²), approximately eight times higher than the density at Station 1 (0.67 items/m²), whereas Station 2 had an intermediate density of 1.00 item/m². The overall mean density was 2.33 items/m². The strong increase toward Station 3 suggests that downstream areas may function as depositional zones where plastic transported from upstream is retained on the riverbank. Such spatial concentration is consistent with the understanding that plastic distribution in rivers is controlled not only by the amount of waste entering the system but also by hydrological and geomorphological processes, including river discharge, flow velocity, flooding, rainfall, and channel characteristics (Riskiana et al., 2020; Rahma et al., 2022). Thus, the relatively low density at the upstream station should not necessarily be interpreted as an absence of plastic inputs; rather, plastics may be transported farther downstream before becoming stranded or accumulated.

The 21 items had a combined mass of 59.16 g, with station-level masses ranging from 1.98 g at Station 1 to 43.54 g at Station 3 (Table 2). The corresponding weight-based densities increased from 0.66 g/m² at Station 1 to 4.55 g/m² at Station 2 and 14.51 g/m² at Station 3. This pattern broadly mirrors the item-density pattern, but the magnitude of the differences also demonstrates why both abundance and mass should be reported when assessing macroplastic pollution. For example, Stations 1 and 2 contained only two and three items, respectively, yet their total masses differed by 11.66 g. This indicates that individual items can vary substantially in size, thickness, and material density. Consequently, item counts alone may underestimate the potential physical burden of larger or denser debris, whereas weight alone may obscure the prevalence of numerous lightweight single-use products.

Table 2. Weight and weight-based density of macroplastic debris on the riverbank of the Sombor River, Balikpapan City

Station	Total weight (g)	Density (g/m ²)
Station 1	1.98	0.66
Station 2	13.64	4.55
Station 3	43.54	14.51
Mean	19.72	6.57

The mean weight-based density of macroplastic debris was 6.57 g/m², with Station 3 contributing the largest share of the observed mass. The simultaneous increase in item-based and weight-based densities toward the downstream station strengthens the interpretation that the lower river section is an important accumulation area. Nevertheless, accumulation should be interpreted as the combined outcome of source inputs and transport processes. Rainfall can mobilize improperly managed waste from terrestrial surfaces into drainage pathways and river channels, while currents and flood events can redistribute the material and subsequently strand it along riverbanks (Sriwahyuni et al., 2024; Rahma et al., 2022). These processes may produce highly uneven distributions over short distances, particularly in rivers bordered by settlements.

Relationship between station distance and macroplastic density

Simple linear regression produced the equation $y = 1.0604x + 0.0005$, with $r = 0.87$ and $R^2 = 0.77$ (Figure 2). The positive coefficient indicates that macroplastic density increased with downstream distance, while the R^2 value suggests that station position accounted for a substantial proportion of the observed variation in density within the sampled reach. Ecologically, this pattern is plausible because rivers act as transport pathways: plastics introduced in upstream and middle reaches can be conveyed downstream and subsequently retained in areas where hydraulic conditions favor deposition. At the same time, downstream reaches may receive additional inputs from settlements and other human activities located along the river corridor. Therefore, the observed downstream increase should be understood as the combined effect of longitudinal transport, local inputs, and retention processes rather than distance alone. The remaining variation may reflect river flow, rainfall, flooding, bank characteristics, waste-management practices, and local sources, all of which have been recognized as important controls on plastic distribution (Riskiana et al., 2020; Rahma et al., 2022). Because only three stations were included in the regression, the statistical relationship should be considered indicative rather than definitive. A larger number of sampling stations, replicated surveys, and repeated observations across wet and dry periods would be needed to robustly separate longitudinal transport effects from local source effects.

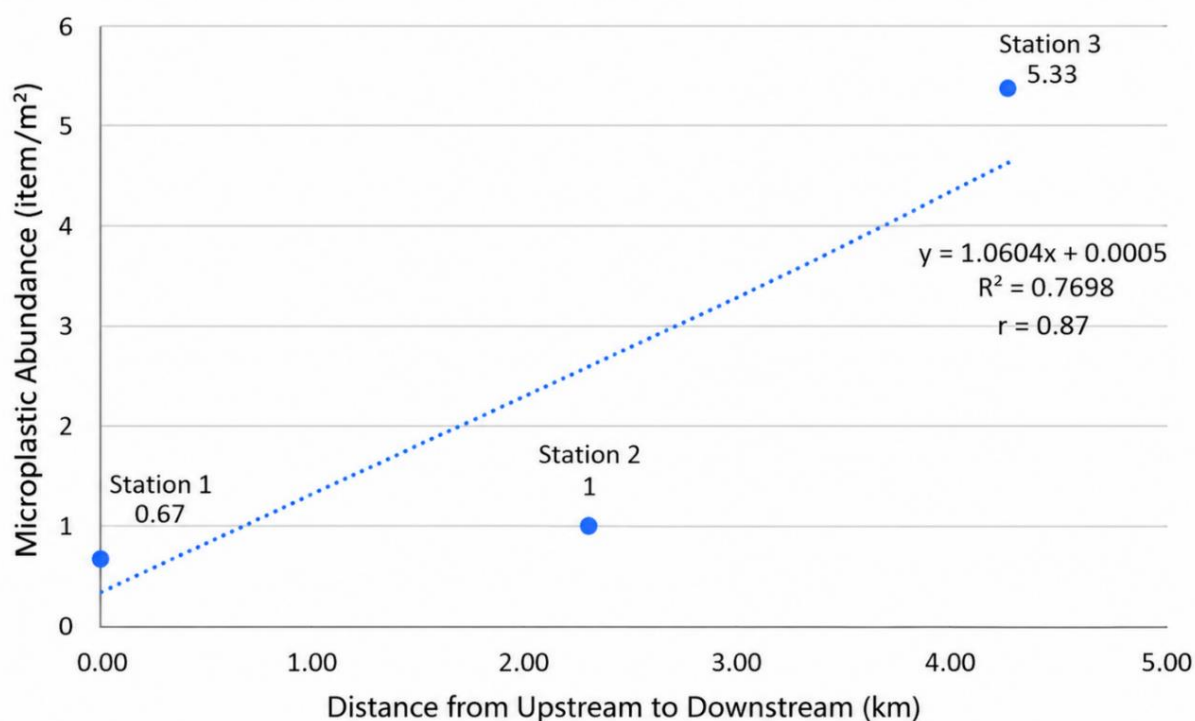


Figure 2. Relationship between distance from upstream to downstream and macroplastic density on the riverbank of the Somber River, Balikpapan City

Characteristics and distribution of macroplastic debris

The observed composition suggests a strong connection between macroplastic debris and everyday household consumption. The presence of food packaging, beverage bottles, plastic bags, straws, bottle caps, and detergent packaging is consistent with products commonly used in domestic activities. Previous work in the Somber River estuary has also identified household-related plastic items and highlighted the influence of settlements and human activities on riverine pollution (Wulandari et al., 2020). The proximity of riverside settlements can increase the probability that inadequately managed waste enters the river directly or is transported through drainage systems. Thus, the occurrence of macroplastics in the Somber River should be viewed not only as a downstream transport problem but also as a source-management problem within the river catchment.

Six major item categories were identified: food packaging, plastic bags, bottle caps, beverage bottles, straws, and detergent packaging (Table 3). Food packaging was the dominant category, accounting for 9 of the 21 items (42.9%), followed by plastic bags (4 items; 19.0%) and bottle caps (3 items; 14.3%). Beverage bottles and straws each contributed 2 items (9.5%), while detergent packaging accounted for 1 item (4.8%). This composition is broadly comparable with observations from other Indonesian rivers, where food packaging, bags, bottles, caps, and other consumer-related products commonly constitute a substantial portion of plastic debris (Wulandari et al., 2020; Rahma et al., 2022). The dominance of these categories points to frequent leakage of short-lived, single-use consumer products into the aquatic environment. The absence of styrofoam and several other categories reported elsewhere also indicates that local consumption patterns and waste sources influence the composition of riverine debris.

Table 3. Item types of macroplastic debris on the riverbank of the Somber River, Balikpapan City

No.	Item type	Number of items
1	Beverage bottles	2
2	Food packaging	9
3	Detergent packaging	1
4	Bottle caps	3
5	Straws	2
6	Plastic bags	4
Total		21

Polymer types and quantities of macroplastics

FT-IR analysis identified four polymer groups among the 21 macroplastic items: polypropylene (PP), polyethylene (PE), polyester, and olefin fiber (Table 4). PP was the most frequent polymer, occurring in 11 items, followed by PE in 7 items, polyester in 2 items, and olefin fiber in 1 item. The predominance of PP and PE is consistent with their extensive use in consumer products and packaging. Their occurrence across several item categories also indicates that plastic pollution in the Somber River is associated with a broad range of everyday products rather than with a single source or product type.

Table 4. Number and weight of macroplastic items by polymer type on the riverbank of the Somber River, Balikpapan City

Polymer type	Number of items	Weight (g)
Polyester	2	1.66
Polypropylene	11	32.80
Olefin fiber	1	12.13
Polyethylene	7	12.57
Total	21	59.16

Polypropylene also had the greatest mass, at 32.80 g, followed by polyethylene (12.57 g), olefin fiber (12.13 g), and polyester (1.66 g). By weight, PP represented 55.44% of the collected macroplastics, whereas PE represented 21.25%. The relatively large contribution of PP is important because the polymer was distributed among several commonly encountered consumer items, including beverage-related products, food packaging, and straws. Comparison with the Mahakam River study by Sriwahyuni et al. (2024) shows both shared and distinct polymer signatures. Both studies detected PP and PE, whereas polystyrene was reported in the Mahakam River but not in the Somber River. Conversely, polyester and olefin fiber were detected in the present study but not in that study. Such differences may reflect variation in local sources, consumer products, catchment characteristics, and transport or retention processes.

Overall, the four polymer types indicate a mixture of packaging- and consumer-related plastics entering the Somber River system. The weight-based composition was dominated by PP (55.44%), followed by PE (21.25%), olefin fiber (20.50%), and polyester (2.81%) (Figure 3). The difference between item frequency and weight contribution is noteworthy: olefin fiber accounted for only one item but contributed 20.50% of the total mass. This demonstrates that a small number of relatively heavy items can substantially influence mass-based estimates. For monitoring purposes, reporting both item number and mass therefore provides a more complete description of plastic pollution and facilitates comparison among studies that may use different metrics.

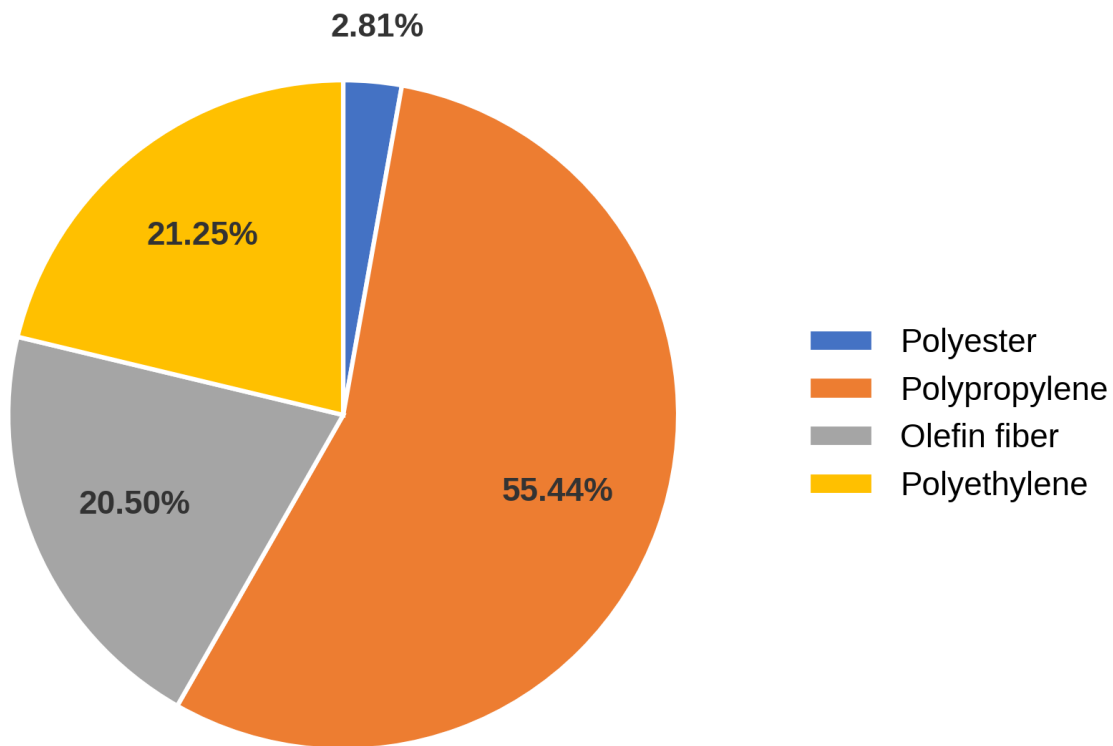


Figure 3. Weight-based composition of macroplastic polymer types on the riverbank of the Somber River, Balikpapan City

Item types in relation to polymer types

Food packaging was the dominant item category (42.9%), followed by plastic bags (19.0%), bottle caps (14.3%), beverage bottles and straws (9.5% each), and detergent packaging (4.8%) (Figure 4). This distribution is consistent with the idea that riverine plastic pollution is strongly connected to the consumption and disposal of commonly used household products. However, the observed composition cannot be attributed solely to local consumption because plastics can be transported from upstream locations and redistributed during high-flow conditions. River discharge, rainfall, flooding, wind, channel morphology, and river meanders can all affect the transport and retention of debris, while waste-management systems, settlement density, urban infrastructure, and human behavior influence the quantity of plastic available for transport (Riskiana et al., 2020; Rahma et al., 2022).

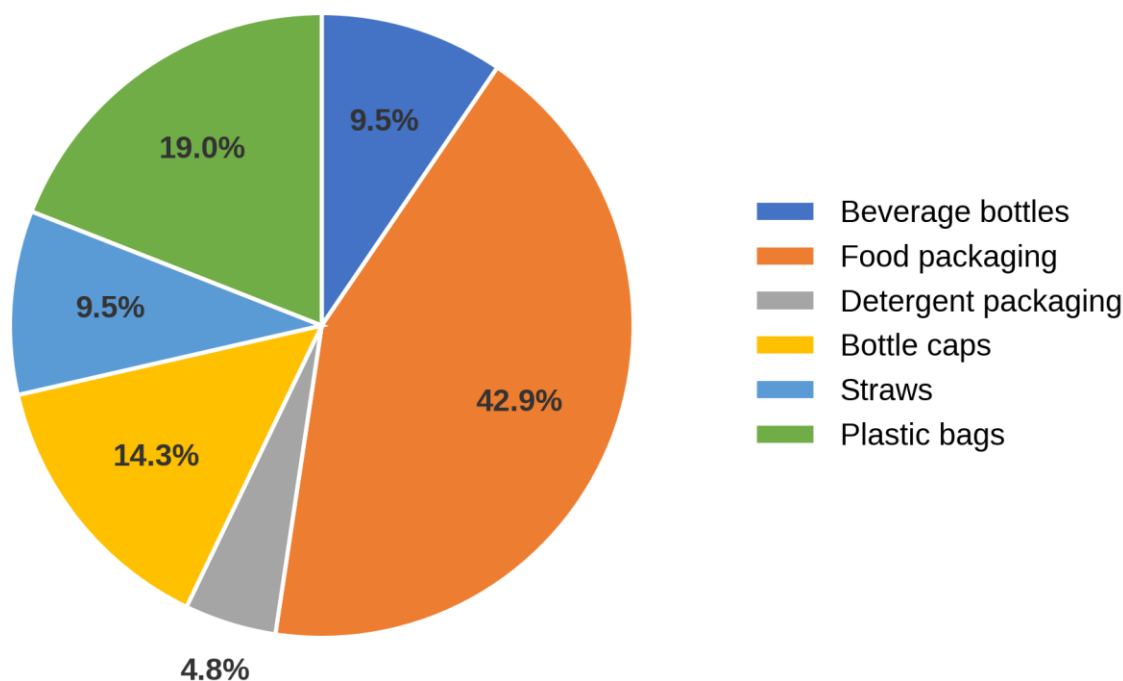


Figure 4. Percentage of macroplastic item types on the riverbank of the Somber River, Balikpapan City

High plastic consumption increases the opportunity for plastic products to leak into the environment when collection and disposal systems are insufficient (Yona et al., 2020). In the Somber River, rainfall and river currents may further enhance this leakage by moving waste from terrestrial surfaces into the river channel and redistributing floating or stranded debris. During periods of heavy rainfall, the increased runoff can mobilize accumulated waste, while subsequent changes in flow may deposit it at particular sections of the riverbank (Sriwahyuni et al., 2024). These processes help explain why plastic density may differ substantially among stations even when the stations are located within the same river system. Consequently, effective management should combine source reduction and improved waste collection with monitoring of downstream accumulation zones.

The association between item categories and polymer types provides additional insight into potential sources of the debris (Table 5). PP was associated with beverage bottles, food packaging, and straws, whereas PE was associated with plastic bags and bottle caps. These associations are consistent with the widespread use of PP and PE in disposable and short-use consumer products. Their dominance therefore reinforces the interpretation that household consumption is an important contributor to the observed macroplastic burden. At the same time, the polymer profile should not be treated as definitive evidence of a specific source because the same polymer can occur in many products and may be transported from other parts of the catchment. The combination of item-type identification, polymer analysis, and spatial monitoring is therefore more informative than any single indicator alone. From a management perspective, the dominance of food packaging and bags suggests that interventions targeting single-use consumer plastics, riverbank waste collection, and community-based waste management could directly address a substantial fraction of the observed debris.

Table 5. Polymer types of macroplastic debris by item type

No.	Item type	Example products	Polymer type
1	Beverage bottles	Indomilk and Golda Coffee bottles	Polypropylene
2	Food packaging	Milo and Masako sachets	Polyester
		Snack packaging	Polypropylene
3	Detergent packaging	Daia	Olefin fiber
4	Bottle caps	Le Minerale and Parvum	Polyethylene
5	Straws	Black straws	Polypropylene
6	Plastic bags	Black plastic bags and sugar packaging bags	Polyethylene

The findings highlight the need for integrated management of plastic waste throughout the Somber River catchment, particularly in areas with riverside settlements and in downstream zones where debris accumulates. Management strategies should prioritize source reduction, improved household waste collection and disposal, prevention of direct dumping, routine riverbank clean-up, and community participation in monitoring. Because rainfall, river currents, flooding, and local waste-management conditions can modify the distribution of debris, future studies should expand the number of sampling stations and incorporate repeated sampling across wet and dry seasons. Such monitoring would improve understanding of plastic transport and retention processes and provide stronger evidence for targeted interventions to reduce the delivery of macroplastics from the Somber River to Balikpapan Bay.

CONCLUSION

The composition of the debris indicates that everyday household and consumer activities are important contributors to macroplastic pollution in the Somber River. Food packaging was the dominant item category (42.9%), followed by plastic bags (19.0%) and bottle caps (14.3%), while beverage bottles, straws, and detergent packaging contributed smaller proportions. FT-IR analysis identified four polymer types, with polypropylene dominating by both item number and weight. By weight, polypropylene accounted for 55.44% of the debris, followed by polyethylene (21.25%), olefin fiber (20.50%), and polyester (2.81%). The combination of consumer-related item types and dominant PP and PE polymers indicates that plastic pollution is closely associated with the use and inadequate management of common single-use products.

This study demonstrates that macroplastic debris is present along the riverbank of the Somber River and that its abundance varies substantially among sampling stations. A total of 21 items weighing 59.16 g were collected, corresponding to a mean density of 2.33 items/m² and 6.57 g/m². Both item-based and weight-based densities increased toward the downstream section, with the highest values recorded at Station 3 (5.33 items/m² and 14.51 g/m²). The regression analysis showed a strong positive association between downstream distance and macroplastic density ($r = 0.87$; $R^2 = 0.77$), suggesting that the downstream area functions as an important accumulation zone. However, because only three stations were included, this relationship should be interpreted as an initial indication rather than definitive evidence of a longitudinal transport effect.

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