frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 15 October 2024
DOI 10.3389/fenvs.2024.1396525

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RECEIVED 05 March 2024
ACCEPTED 06 September 2024
PUBLISHED 15 October 2024

CITATION
Talavera AL, Dalida LFM and Diola MBLD (2024) Riverine macroplastic survey along the segments of Tullahan River in Metro Manila, Philippines.
*Front. Environ. Sci.* 12:1396525.
doi: 10.3389/fenvs.2024.1396525

# Riverine macroplastic survey along the segments of Tullahan River in Metro Manila, Philippines

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The Philippines is one of the world's main contributors to global marine plastic pollution. However, field data remains scarce, so model estimates of riverine plastic pollution may be inaccurate. This paper aims to characterize the macrolitter observed along the Tullahan River, with focus on plastics, passing through the *barangays* of Quezon City and Valenzuela City in Metro Manila. The impact of solid waste management and land use activities on plastic flux were also investigated. For the floating litter, visual counting and float method were used to determine the plastic flux and river velocity, respectively. Riverbank litter was collected manually to characterize it based on plastic product and polymer type. Results show that the macroplastic flux was lowest on the site where residential houses are farthest from the stream. Waste characterization revealed that riverbank litter was primarily plastic – 30%–41% were residuals, and 5%–21% were recyclables. Both methods revealed that wrappers and thin PE plastics are the top contributors to riverine macroplastic pollution. Therefore, the entry of macroplastics into the river may be due to land use activities and weak enforcement of existing solid waste management (SWM) policies. The points discussed in the study can help in improving SWM and land use planning. The results can also increase the accuracy of model estimates.

KEYWORDS

**floating plastics, flow velocity, macrolitter, Philippines, plastic pollution, riverbank, Tullahan**

## 1 Introduction

The Philippines is one of the world's main contributors to global marine plastic pollution (Jambeck et al., 2015; Lebreton et al., 2017; Lebreton and Andrady, 2019) and several rivers give way to the transport of land-based plastic litter to the sea. Urban rivers, such as the Tullahan River, are expected to export high amounts of plastic litter from land into the ocean. Along with Pasig and Meycauayan Rivers, the Tullahan River was among the model-based global top five of the most plastic emitting rivers (Meijer et al., 2021). A study by Osorio et al. (2021) has also reported actual abundance of plastics in this river. The mean abundance of microplastics was 11,475 particles/m$^3$ in surface waters and 848 particles/kg in dry sediments. This can be attributed to mismanaged plastic litter leaking from the source, or during collection and disposal.

Marine plastic pollution poses various risks to the marine ecosystem affecting both vertebrates and invertebrates species. This includes entanglement, ingestion, and suffocation. These consequences of plastic pollution and its leakage to the environment are suffered mostly by birds, fish, and marine animals living in polluted areas (Barboza et al., 2019). The drawback does not stop as ingested small-sized plastic particles are eventually transferred into a broader food chain that involves animals and human beings. This uncovers a range of severe health impacts brought by plastics, such as the presence of toxic chemicals, which can cause cancer and can negatively affect the nervous, reproductive, and respiratory systems.

Increasing population levels due to booming economies combined with rapid urbanization result in accelerated municipal solid waste generation in low-income countries like the Philippines. In 2016, the Philippine National Solid Waste Management Commission (NSWMC) reported that 40,087.45 tons of waste were generated per day in the country, with an estimated average *per capita* waste generation of 0.40 kg per day for both urban and rural areas. It exhibited a steady increase from 37,427.46 tons per day in 2012 (Environmental Management Bureau - Department of Environment and Natural Resources, 2008). A study on plastic packaging waste in the country revealed that 760,000 metric tons, or 35 percent of all plastics consumed, leaks into the environment, and only 9 percent is recycled (WWF Philippines, Cyclos GmbH, and AMH Philippines, Inc., 2020).

Residential, industrial, commercial, institutional, and agricultural land uses, along with construction and demolition processes have the most municipal solid waste generation potential (Anilkumar and Chithra, 2016). Such information links land-use and its associated anthropogenic activities to waste generation, but fewer studies discuss the impact of land use on plastic litter accumulation. In fact, in the Philippines, there are almost no studies that investigate the relationship between land use and riverine macroplastic litter accumulation. Lumongsod and Tanchuling (2019) found out that illegally disposed of plastics (e.g., plastic bottles, bottle caps, textiles, and single-use plastic) by residents and passerby are the main sources of microplastics in three creeks in Makati City.

Moreover, the accuracy of present and future models and estimates is challenged by the lack of field data on Philippine urban rivers (van Emmerik et al., 2020). Galarpe et al. (2021) asserted that additional macroplastic and microplastic research in the country is needed because they are crucial in developing appropriate plastic regulation policies.

The main objective of this study is to quantify and characterize floating and riverbank litter in Tullahan River, Quezon City. In doing so, the flux of the floating litter and the composition of riverbank litter are determined. The study also aims to gather information from the local government units through semi-structured interviews to evaluate the impact of land use, vegetation, solid waste management, and human activities on riverine macroplastic pollution. The results are vital in developing appropriate plastic regulation policies and programs to minimize plastic litter and can contribute to the field data for model estimates.

## 2 Materials and methods

### 2.1 Study area

One of the main rivers flowing through Metro Manila or the National Capital Region (NCR) in the Philippines is the Tullahan River. It starts in Quezon City then travels downstream through the cities of Caloocan, Malabon, Navotas, and Valenzuela (CaMaNaVa) until its river mouth in Manila Bay. The river has an approximate length of 27.1 km with several land use types surrounding it. Figure 1 shows the location map of selected sampling stations in the study area. Stations were chosen based on accessibility and the presence of land use-indicative structures along the sides of the stream. Bridges were used to conduct the visual counting method while the manual collection of macrolitter was done on riverbanks. The whole study area is approximately 5.17 km long. Table 1 summarizes the details of each sampling station along with corresponding sampling dates. A total of five sampling points were selected. Floating macroplastics were observed from the North Wind Avenue Bridge, San Bartolome Delta Bridge and Maceda Bridge. On the other hand, macrolitter was manually collected from the riverbanks along the Gozum Street Bridge and San Bartolome Delta Bridge.

### 2.2 Data collection for floating litter

The flow velocity on each sampling site was determined to assess whether it affects the macroplastic flux and to describe the site condition during sampling. Flow velocity was measured following the “Pooh-Sticks” method by Bull and Lawler (1991). A predetermined starting and end point was set using the width of each bridge, a known quantity approximately parallel to the stream. The widths of these bridges vary from 8.75 m to 13.43 m. A pre-existing floating litter was chosen and tracked as it floated from the starting point to the end point. The observers stood on the bridge side facing upstream, then moved to the side facing downstream once the floating object reached the starting point. The time it took to traverse the length was recorded using a stopwatch. The flow velocity (m/s) was obtained by dividing the transect length of the item by its recorded travel time. A total of three trials were conducted to determine the average flow velocity.

To get the macroplastic flux of floating litter, the visual counting method done from bridges, established by González-Fernández and Hanke (2017) and adapted by van Emmerik et al. (2020), was applied with some modifications, such as on the length of bridge segments and observation time. In the study of van Emmerik et al. (2020), the observation time varies from 2 to 20 min depending on the length of the segment and plastic flux. Additionally, the visual counting from bridges employed in the study of Vriend et al. (2020) lasted for 20 min per segment. Therefore, an observation time of 20 min was chosen for standardization purposes since the lengths of the bridges and expected plastic flux vary, as shown in Table 1.

Manual counting and categorization of macroplastics by polymer and plastic types were done from bridges using binoculars, timers, and tally sheets. Each bridge was divided into 10–15 m segments, depending on its length. Observers faced the downstream direction (i.e., standing on the downstream side of the bridge) and counted floating macroplastics flowing down (i.e., away from the observer) within the segment for 20 min—this is considered one observation. Included in the tally were floating and superficially submerged macroplastics. Observations were done within an hour each site, three times per day between 9 a.m. and 4 p.m. at 2-h intervals (e.g., 9 a.m.–10 a.m., 12 p.m.–1 p.m., 3 p.m.–4 p.m.). It was assumed that measurements at each segment were representative of that hour.

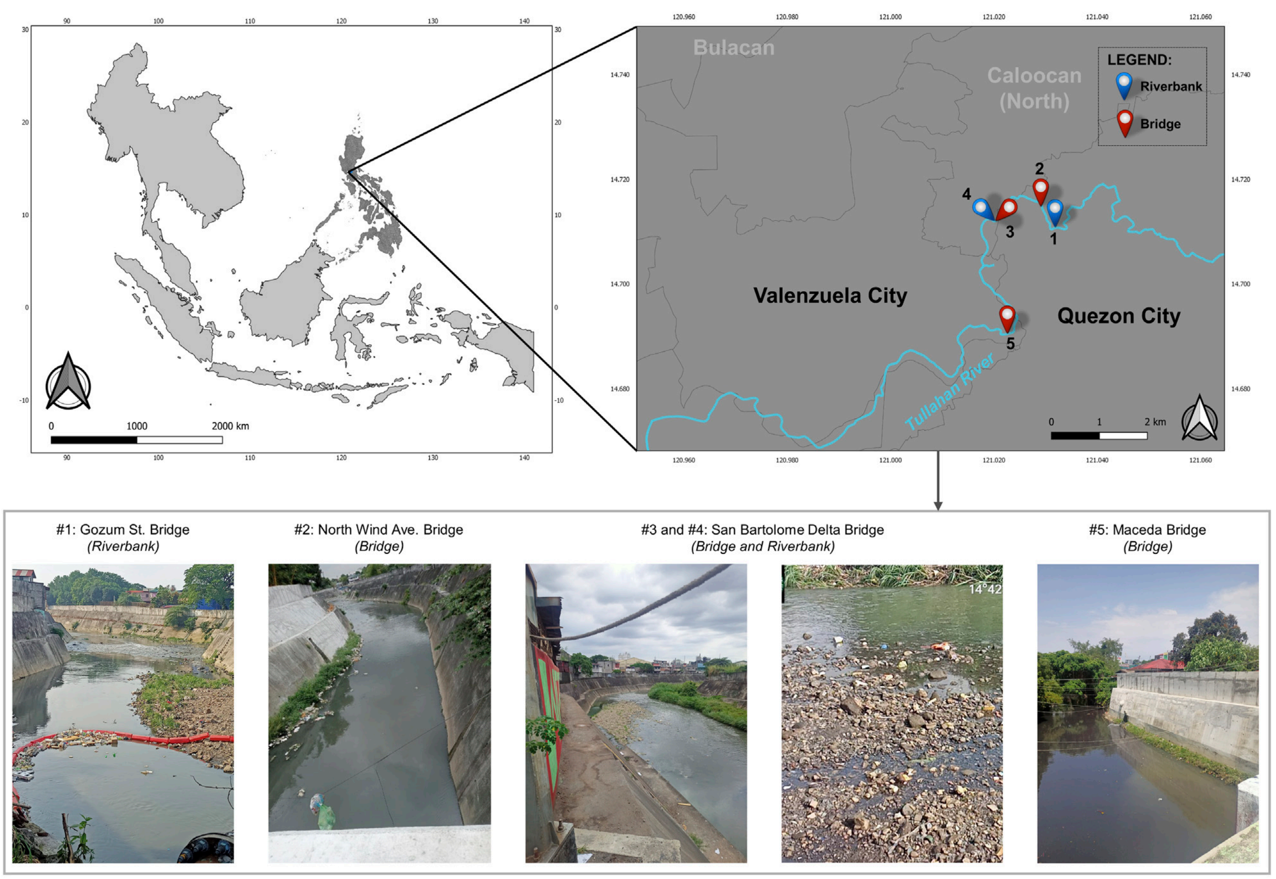

FIGURE 1
Map of study area and sampling stations.

**TABLE 1 Description of sampling stations.**

| Sampling station | Bridge name | Bridge width [m] | Bridge length [m] | Barangay, City | Description of sampling | Sampling day/s |
|---|---|---|---|---|---|---|
| 1 | Gozum Street Bridge | 7.40 | 18.50 | Nagkaisang Nayon, Quezon City | Riverbank | 9 June 2023 |
| 2 | North Wind Avenue Bridge | 9.67 | 16.85 | Nagkaisang Nayon/San Bartolome, Quezon City | Floating Litter | 8 May 2023 (weekday) |
| | | | | | | 14 May 2023 (weekend) |
| 3 | San Bartolome Delta Bridge | 13.43 | 33.24 | Nagkaisang Nayon/San Bartolome, Quezon City | Floating Litter | 3 May 2023 (weekday) |
| | | | | | | 7 May 2023 (weekend) |
| 4 | San Bartolome Delta Bridge | 13.43 | 33.24 | Nagkaisang Nayon/San Bartolome, Quezon City | Riverbank | 9 June 2023 |
| 5 | Maceda Bridge | 9.67 | 20.00 | Ugong, Valenzuela City | Floating Litter | 13 May 2023 (weekend) |
| | | | | | | 15 May 2023 (weekday) |

The total instantaneous macroplastic flux P [items/hr] for the entire river cross-section was obtained using Equation 1, which is adapted from the study of van Emmerik et al. (2020):

$$P = 60 \sum p_i \tag{1}$$

where $p_i = C_i/T_i$ p: plastic flux [items/min] for each segment i.

C: total number of counted plastic [items] in segment i.
T: measurement duration [min] at segment i.
P: total instantaneous plastic flux for the entire river width [items/hr].

The identification of polymer was done with reference to a seven-category protocol used by van Emmerik et al. (2020). This is based on typical items that belong to these categories (Supplementary Table S11). An extra category labeled as "others" was added to take note of items not in the initial list but were determined by the researchers to be vital due to frequency and context (e.g., face masks and diaper/sanitary napkins). Plastic cutlery items, which are commonly made of polypropylene and polystyrene, were all categorized as polypropylene following the informative video made by Sentinel UpCycling Technologies (2022) on distinguishing plastics that look the same but are not. It showed that polystyrene sinks in water while polypropylene floats. Polystyrene has a higher specific gravity than water so it would most likely sink to the river bed.

Visual counting was done for two (2) days on each bridge sampling station in May 2023 – 1 day for weekday observations and another for weekend observations. The weather conditions during the sampling days were partly sunny to overcast, and no precipitation was observed. Hence, solid wastes that were observed along the river may have been leaked from land-based sources or disposed of directly by the residents and pedestrians.

## 2.3 Statistical analysis

The Pearson and Spearman correlation coefficients were calculated per site to determine the relationship between the macroplastic flux and river velocity. Both calculations were performed to identify the monotonic (Spearman) and linear (Pearson) relationship between the two variables. A level significance of 0.05 was used to test whether the correlation was statistically significant. Computed $p$-values greater than 0.05 suggest no statistically significant correlation between macroplastic flux and river velocity. Otherwise, there is a statistically significant correlation between the two.

## 2.4 Data collection for riverbank litter

Adapting the procedures of United Nations Environment Programme (UNEP, 2020), as applied in the plastic diagnostics in the Philippines study of the World Bank published in 2024 (World Bank, 2024), macrolitter were collected from the riverbanks along the San Bartolome Delta Bridge and Gozum Street Bridge. The monitoring strategy employed is categorized under sampling methods with a main goal of debris collection to analyze composition, polymer type and item type. The sampling site in San Bartolome Delta Bridge was characterized by pebbles and smaller aggregates with some grass weeds scattered along the area. The same was observed in the Gozum Street Bridge site, except that it had more grass weeds which are taller and bundled together on half of its perimeter. For each sampling site, one-square meter quadrant was laid for every five to 10 m. On the riverbank along the San Bartolome Delta Bridge, three quadrants were sampled, while seven quadrants were laid on the riverbank along the Gozum Street Bridge. The number of quadrants for each site was limited by the safe and accessible area along the riverbanks.

The macrolitter inside the quadrants were collected up to a depth of 5 cm for characterization. This was the approximate depth of accumulated litter in the area. After the samples were obtained, the macrolitter were sorted and characterized. Afterwards, the macrolitters were disposed of properly by putting them in their respective trash bins that were readily available in the area.

After the manual collection of riverbank litter, macrolitter characterization was done by manually segregating the obtained samples from the riverbanks into their categories first. These categories (Supplementary Table S9), were established by cross-referencing the NSWMC (2020) Waste Analysis and Characterization Study (WACS) manual and classification of the National Oceanic and Atmospheric Administration (NOAA). Then, the weight and by-piece quantity of each category were recorded.

The macroplastics from the macrolitter sample were isolated for further characterization. Following the methodology of Pietz et al. (2021), the macroplastic samples were categorized according to their plastic type and polymer type. Then, the weight and by-piece quantity of each classification were determined. Because there are existing plastic litter in the Philippines that do not fit the NOAA classification, both the NOAA classification and NSWMC WACS manual were used as references to develop the plastic type categories. These categories are shown in Supplementary Tables S1, S3, S5, S9.

## 2.5 Semi-structured interviews with the *barangays*

Semi-structured interviews were conducted in the *barangays* that governed the sampling sites to obtain further context about their demographic profile, land use, and solid waste management (SWM) practices. Open-ended questions about the dominant land use, frequency of waste collection, *barangay*-level solid waste management initiatives, and presence of materials recovery facilities (MRF) and solid waste management committee were asked. However, only the *barangay* officials and SWM officers were interviewed. The answers gathered from the interviews were used to relate human activities, such as SWM practices and land use, to the abundance of observed and collected litter.

# 3 Results

## 3.1 Characteristics of floating litter

In Table 2, the highest number of macroplastics during the weekday plastic surveys was observed in Site 5 (Maceda Bridge),

TABLE 2 Number of floating macroplastics observed per time and per site.

| | Site 2 (North Wind Avenue Bridge) | | Site 3 (San Bartolome Delta Bridge) | | Site 5 (Maceda Bridge) | |
|---|---|---|---|---|---|---|
| | Plastic count [pieces] | Duration [mins] | Plastic count [pieces] | Duration [mins] | Plastic count [pieces] | Duration [mins] |
| Weekday | | | | | | |
| 9:00 | 127 | 20 | 101 | 20 | 124 | 20 |
| 12:00 | 213 | 20 | 123 | 20 | 213 | 20 |
| 15:00 | 141 | 20 | 97 | 20 | 201 | 20 |
| Total | 481 | 60 | 321 | 60 | 538 | 60 |
| Weekend | | | | | | |
| 9:00 | 220 | 20 | 96 | 20 | 134 | 20 |
| 12:00 | 298 | 10 | 101 | 20 | 160 | 20 |
| 15:00 | 410 | 20 | 111 | 20 | 166 | 20 |
| Total | 928 | 50 | 308 | 60 | 460 | 60 |

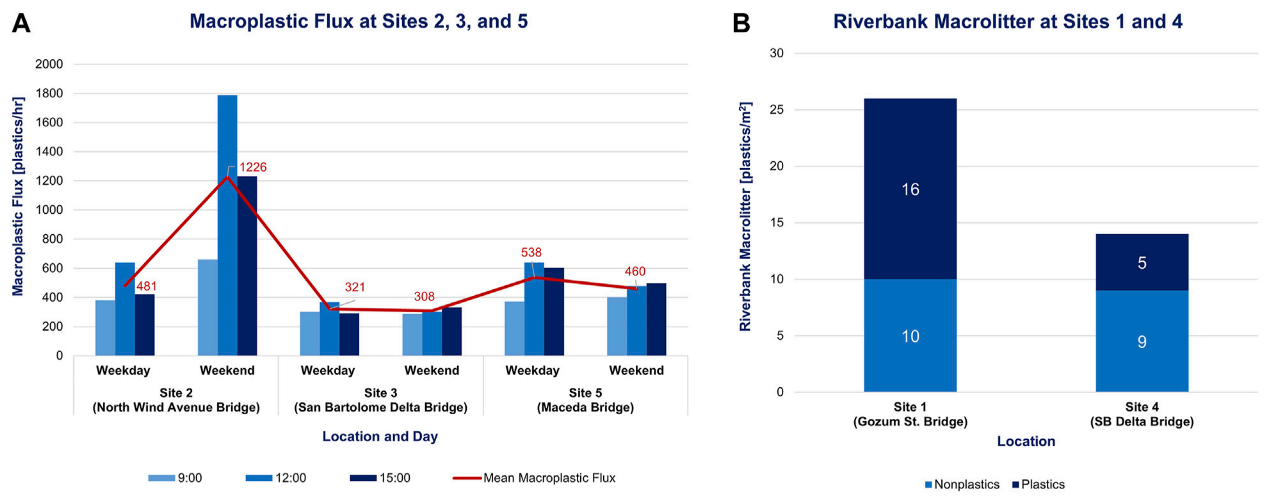

FIGURE 2
**(A)** Macroplastic flux at sites 2, 3, and 5. **(B)** Riverbank macrolitter at sites 1 and 4.

with 538 plastic pieces recorded for an hour. For the weekend observations, the highest was observed in Site 2 (North Wind Avenue Bridge), where 928 plastic pieces were tallied in a cumulative span of 50 min. Site 2 also generated the highest total of plastic pieces. In contrast, Site 3 (San Bartolome Delta Bridge) produced the least number of plastic pieces. Figure 2 presents the hourly macroplastic flux at Sites 2, 3, and 5.

During the weekday plastic surveys in all three sites (Table 2), the pieces of macroplastics observed at noontime (213, 123, and 213 pieces at respective sites) were the highest. Contrastingly, the pieces of macroplastics observed in the afternoon (410, 111, and 166 pieces at respective sites) were highest during the weekend plastic surveys. Furthermore, weekday observations recorded higher pieces of macroplastics than weekend observations except at Site 2.

In all three sites, food or drink wrapper was consistently the most frequently occurring plastic type, followed by thin PE plastics, as presented in Figure 3. The observations in all sites consisted of around 34%–47% food and drink wrappers and 17%–26% thin PE plastics. Most of these wrappers were junk food and candy wrappers, while the thin PE plastics were mainly composed of thin film plastic bags, which are locally known as plastic *labo*.

For the macroplastic composition, the dominant polymer type was multilayered plastic, followed by soft polyolefins ($PO_{soft}$), as shown in Figure 4. Multilayered plastics include sachets, wrappers,

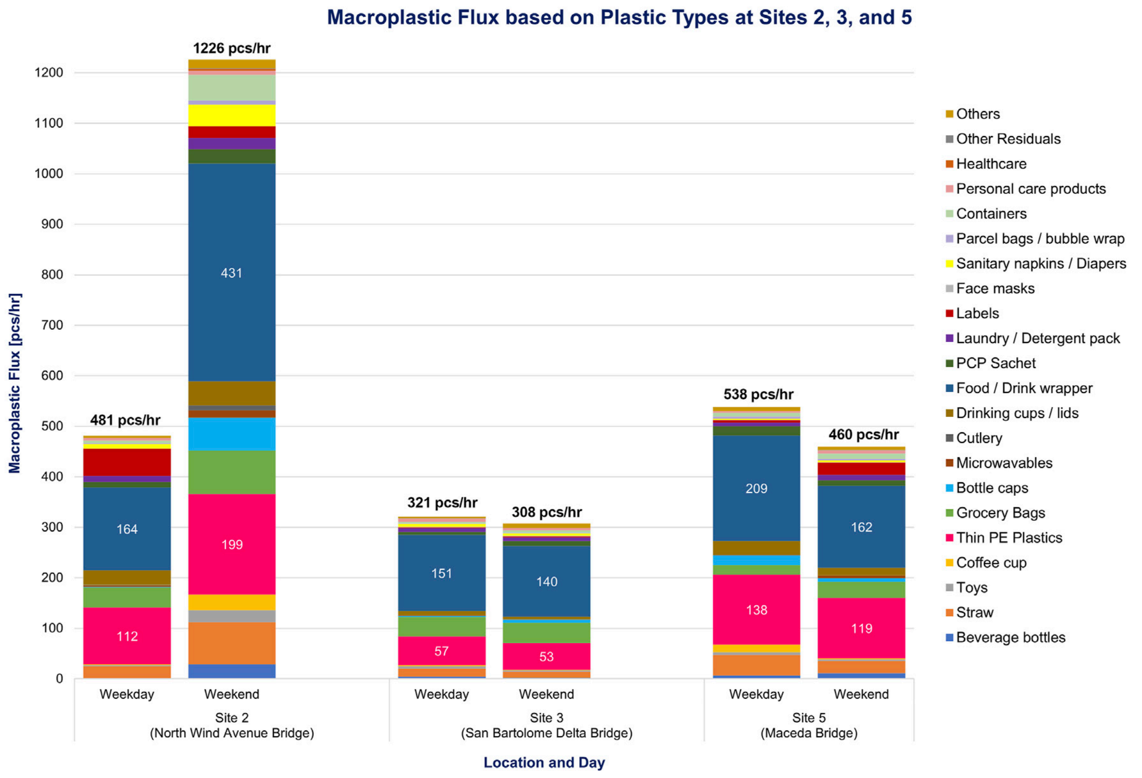

FIGURE 3
Macroplastic flux based on plastic types at Sites 2, 3 and 5.

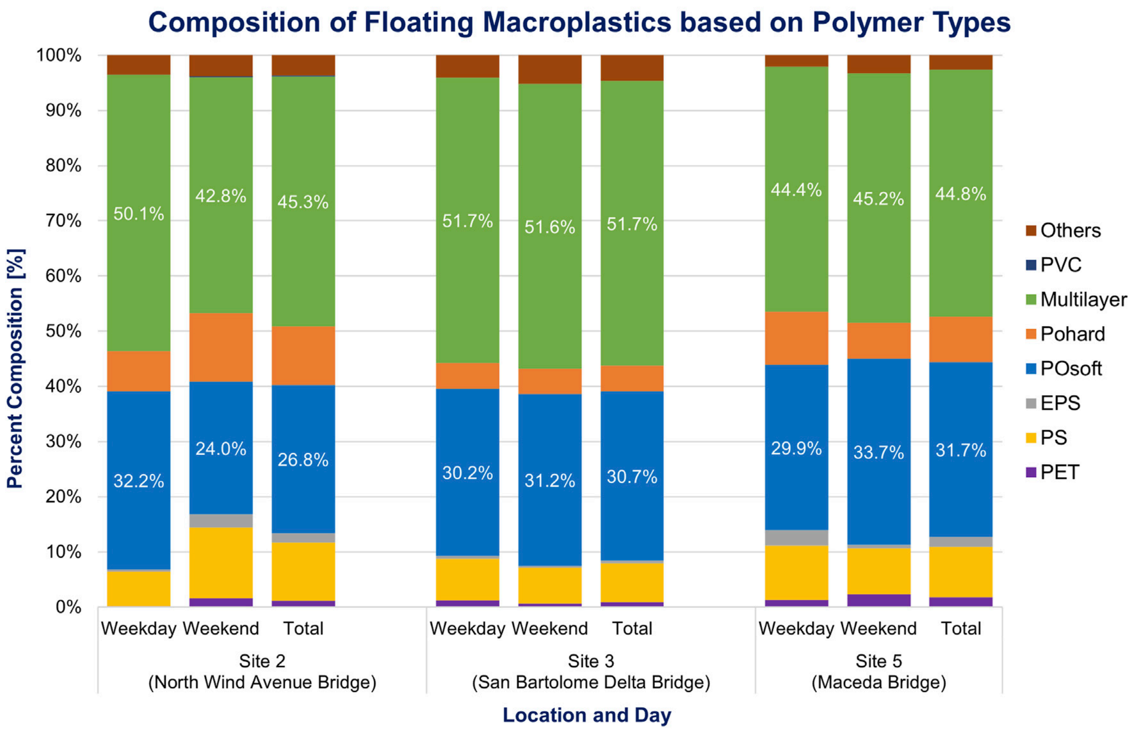

FIGURE 4
Composition of floating macroplastics based on polymer types at Sites 2, 3 and 5.

TABLE 3 Summary of visual counting results.

| | Site 2 (North Wind Avenue Bridge) | | Site 3 (San Bartolome Delta Bridge) | | Site 5 (Maceda Bridge) | |
|---|---|---|---|---|---|---|
| | Weekday | Weekend | Weekday | Weekend | Weekday | Weekend |
| Plastic Flux [pieces/hr] | 481 | 1226 | 321 | 308 | 538 | 460 |
| River Flow Velocity [m/s] | 0.366 | 0.681 | 0.744 | 0.710 | 0.207 | 0.166 |
| Least frequent plastic waste category | PET | PVC | EPS | EPS | PET | EPS |
| Most frequent plastic type | (1) food or drink wrappers<br>(2) thin PE plastics | | | | | |
| Most frequent polymer type | (1) multilayered<br>(2) soft polyolefins ($PO_{soft}$) | | | | | |

labels, and laundry packs. Approximately 43%–52% of the macroplastics observed were multilayered polymers. Conversely, grocery bags, plastic shopping bags (*sando* bags), and thin PE plastics were categorized under soft polyolefins ($PO_{soft}$). They constituted around 24%–34% of the macroplastics observed.

In contrast, polyvinyl chloride (PVC) and polyethylene terephthalate (PET) and expanded polystyrene (EPS) were the least occurring polymer types. Only 0.21%–2.4% of the plastics recorded were PET. Moreover, PVC plastics were only recorded during the weekend plastic survey at Site 1 (North Wind Avenue Bridge).

### 3.1.1 Floating litter observed at Site 2 (North Wind Avenue Bridge)

During the weekday plastic survey at Site 2, a total of 127 macroplastics were observed in the morning, 213 at noon, and 141 in the afternoon. On the other hand, the weekend plastic survey observed 220 macroplastics in the morning, 298 at noon, and 410 in the afternoon (Table 2). Hence, the plastic flux for the weekday and weekend observations were 481 pieces per hour and 1226 pieces per hour, respectively (Table 3). Note that all plastic surveys were done for 20 min except for the weekend survey at noon, which only lasted 10 min because the flow velocity (1.077 m/s) was relatively faster than the usual flow velocities (0.325–0.506 m/s) recorded. Some plastics may have been overlooked and not recorded due to the increased river velocity, so the observation time was shortened.

Food and drink wrappers were the frequently occurring plastic type in both the weekday and weekend observations, followed by thin PE plastics (Supplementary Figure S1). The weekday observations comprised around 34% food and drink wrappers and 23% thin PE plastics. Similarly, the weekend observations consisted of 37% food and drink wrappers and 17% thin PE plastics.

In terms of polymer type, the composition of macroplastics was mainly multilayered plastics, followed by soft polyolefins ($PO_{soft}$). For the weekday observations, 50% were multilayered plastics and 32% were $PO_{soft}$. For the weekend observations, 43% were multilayered plastics and 24% were $PO_{soft}$ (Figure 4).

### 3.1.2 Floating litter observed at Site 3 (San Bartolome Delta bridge)

For the weekday observations at Site 3, a total of 101 macroplastics were tallied in the morning—123 at noon, and 97 in the afternoon. On the other hand, the weekend observations tallied 96 macroplastics in the morning, 101 at noon, and 111 in the afternoon (Table 2). Hence, the plastic flux for the weekday and weekend observations were 321 pieces per hour and 308 pieces per hour, respectively (Table 3).

Food and drink wrappers, followed by thin PE plastics, were still the frequently occurring plastic types (Supplementary Figure S2). For the weekday plastic surveys, 47% were food and drink wrappers and 18% were thin PE plastics. For the weekend observations, 45% were food and drink wrappers and 17% were thin PE plastics.

The composition of macroplastics in terms of polymer type was predominantly multilayered plastics, followed by soft polyolefins ($PO_{soft}$). The weekday observations comprised around 52% multilayered plastics and 30% $PO_{soft}$. Similarly, the weekend observations consisted of 52% multilayered plastics and 31% $PO_{soft}$ (Figure 4).

### 3.1.3 Floating litter observed at Site 5 (Maceda Bridge)

For the weekday plastic survey at Site 5, 124 macroplastics were recorded in the morning, 213 at noon, and 201 in the afternoon. On the other hand, the weekend plastic survey recorded 134 macroplastics in the morning, 160 at noon, and 166 in the afternoon (Table 2). Hence, the plastic flux for the weekday and weekend observations were 538 pieces per hour and 460 pieces per hour, respectively (Table 3).

Similar to the observations in other sites, food and drink wrappers, and thin PE plastics were the predominant plastic types (Supplementary Figure S3). The weekday plastic surveys consisted of 39% food and drink wrappers and 36% thin PE plastics. On the other hand, the weekend observations comprised 35% food and drink wrappers and 26% thin PE plastics.

Based on polymer types, the macroplastics were mainly composed of multilayered plastics, followed by soft polyolefins ($PO_{soft}$). For the weekday plastic surveys, around 44% were multilayered plastics and 30% were $PO_{soft}$. For the weekend plastic surveys, 45% were multilayered plastics and 34% were $PO_{soft}$ (Figure 4).

## 3.2 Correlation of macroplastic flux and river velocity

The results presented in Figure 5 exhibit a positive correlation between macroplastic flux and river velocity at all sites. Specifically, a

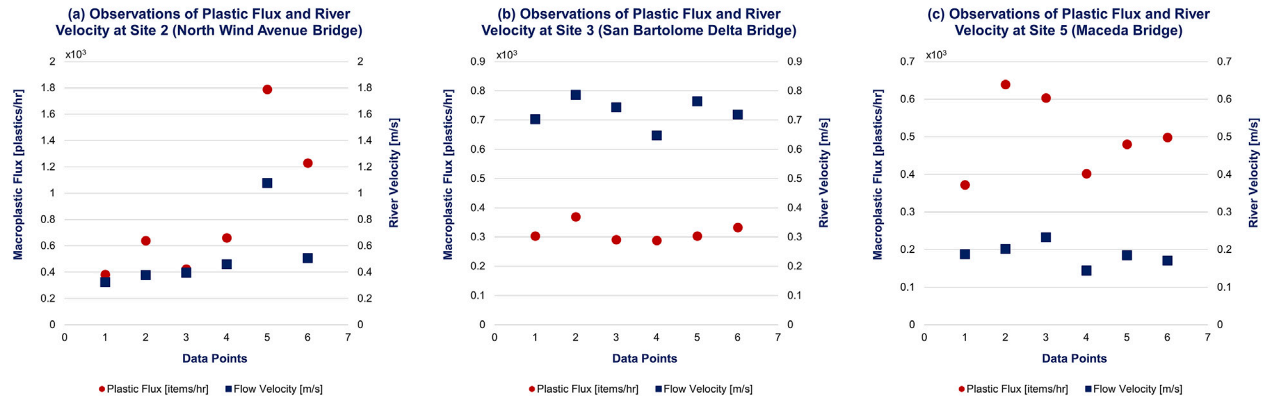

FIGURE 5
Observations of plastic flux and river velocity at sites 2, 3, and 5.

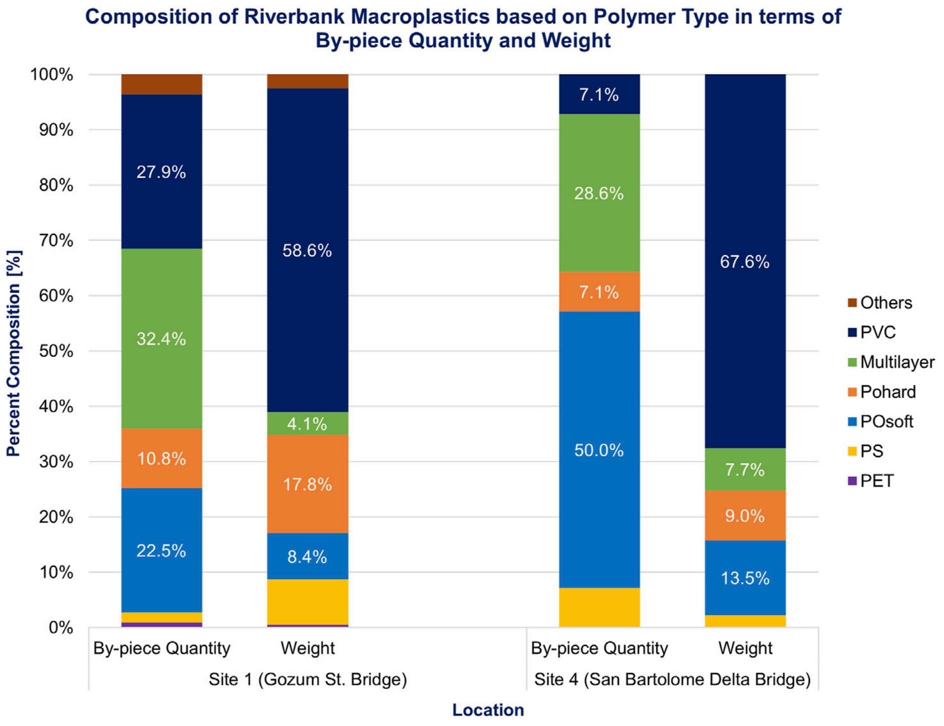

FIGURE 6
Composition of riverbank macroplastics based on polymer type in terms of by-piece quantity and weight.

very high positive correlation was observed at Site 2 (Spearman: 0.943, Pearson: 0.92), while moderate to high positive correlations were observed at Site 3 (Spearman: 0.638, Pearson: 0.605) and Site 5 (Spearman: 0.543, Pearson: 0.685) (Supplementary Table S10).

In checking the statistical significance of these values, it was discovered that the *p*-values of Site 3 (Spearman: 0.173 and Pearson: 0.204) and Site 5 (Spearman: 0.266 and Pearson: 0.134) are not statistically significant. On the contrary, the results of Site 2 with *p*-values of 0.005 (Spearman) and 0.009 (Pearson), suggest that the computed correlations are statistically significant. Therefore, the macroplastic flux at Site 2 increases with river velocity.

## 3.3 Characteristics of riverbank litter

Manual collection of riverbank macrolitter from Sites 1 (Gozum St. Bridge) and 4 (San Bartolome Delta Bridge) was done on 9 June 2023. Heavy rain was observed the day prior which was considered to have influenced the results. Seven quadrants were surveyed at Site 1 (Gozum St. Bridge) while three were surveyed at Site 4 (San Bartolome Delta Bridge). All of these were situated by the riverbank which become submerged in water when water level rises, especially as a result of significant precipitation.

At Site 1 (Gozum St. Bridge), about 62% of the collected macrolitter were plastics (Supplementary Figure S4). 41% of these were residual (e.g., wrappers, plastic bags, sanitary napkins and diapers) while the remaining 21% was represented by recyclable plastics (e.g., PET food and beverage containers). Non-plastic pieces were predominantly glass fragments. In terms of weight, 70% was attributed to recyclable plastics which are significantly bigger and denser compared to residuals at 11%. At Site 4 (San Bartolome Delta Bridge), glass pieces recorded the highest percent composition in both by-piece quantity (55%) and weight (72%).

Figure 6 presents the composition of riverbank macroplastics in Sites 1 and 4 based on polymer type. Majority of the plastics, by piece quantity, were multi-layer plastics, polyvinyl chloride (PVC), and $PO_{soft}$.

### 3.3.1 Riverbank macroplastic collected at Site 1 (Gozum St. Bridge)

The most recorded macroplastic type in this site was wrappers at 36 pieces out of the 111 total plastics collected. It was followed by thin PE bags and linoleum fragments at 18 and 16 pieces, respectively (Supplementary Figure S5). Other items include a cigarette lighter, four thick dining plate fragments, and a motorcycle part.

Linoleum plastics, weighing 950 g, were the heaviest among the macroplastics collected on this site (Supplementary Figure S5). This was followed by PVC pipes weighing 480 g. Both items are commonly made of polyvinyl chloride (PVC), having a relatively high density compared to most plastics with a specific gravity of around 1.4.

### 3.3.2 Riverbank macroplastic collected at Site 4 (San Bartolome Delta bridge)

At seven pieces, thin PE bags dominated the small amount (14) of macroplastics collected on this site. All the other items were less than five, with wrappers at four, containers at two, and one piece of linoleum fragment (Supplementary Figure S5).

Similarly, linoleum recorded the highest weight at 150 g despite having the least number of pieces. As previously mentioned, it is relatively denser compared to most plastics.

## 3.4 Land use of sampling sites

The 2016 Zoning Map of Barangay San Bartolome shows that almost all adjacent areas to the river were dedicated as industrial zones. Other parts were predominantly residential, as the *barangay* is home to several *sitios* and subdivisions. The same can be observed in the 2016 Zoning Map of Barangay Nagkaisang Nayon, where industrial and residential zones both dominate. Areas adjacent to the river were also allotted for the former.

Meanwhile, Barangay Capri is characterized by socialized housing zones, as apparent in its 2016 Zoning Map. This may be related to its high population density, which is almost 800% of the city's population density. This reality is not unknown to the residents and the local government unit (LGU) since a *barangay* official mentioned having cases of multiple families in one household, according to the interviews conducted.

Therefore, Sites 1 to 4 are predominantly industrial and residential zones. Contrastingly, Site 5 is a socialized housing zone.

# 4 Discussion

## 4.1 Characteristics of floating litter

The macroplastic flux in the Tullahan River mouth is around 1000 items per hour (van Emmerik et al., 2020). As shown in Figure 2, only the highest macroplastic flux observed at Site 2 (North Wind Avenue Bridge) at 1226 plastics per hour shared the same order of magnitude with this result. The macroplastic flux in other sites only ranged from 308 plastics per hour to 538 plastics per hour. These values are closer to the macroplastic flux in Pulauan River at 304 plastics per hour (Requiron and Bacosa, 2022) and Mahiga Creek at 468 plastics per hour (Bardenas et al., 2023).

Similar to the results of van Emmerik et al. (2020), the macroplastic flux and river velocity show strong positive correlations (Spearman: 0.543–0.943 and Pearson: 0.605–0.920) at all sites (Supplementary Table S10). However, a statistically significant correlation with a *p*-value of 0.005 (Spearman) and 0.009 (Pearson) was observed only at Site 2. A nearby funeral took place on the weekend observation at this site. Hence, the results suggest that during regular days and at usual river conditions, there is no statistically significant correlation between macroplastic flux and river velocity. In contrast, macroplastic flux increases with river velocity during days with unusual events or events that regularly do not occur, such as holidays and funerals. Despite this, increasing the number of observations during days with unusual events is still necessary to accurately assess its impact on macroplastic emissions.

Multilayered and $PO_{soft}$ plastics are the frequently occurring polymer types in both the floating (Figure 4) and riverbank plastic surveys (Figure 6). Likewise, van Emmerik et al. (2020) observed that the same polymer types were highest in the Tullahan and Pasig river mouths in the Philippines. Similarly, the macroplastics observed in the Rhine River of Europe are mainly composed of $PO_{soft}$ plastics (Vriend et al., 2020). This could be attributed to the high presence of food or drink wrappers and thin PE plastics not only in the Tullahan River but also in other freshwater, such as Pulauan River (Requiron and Bacosa, 2022), Mahiga Creek (Bardenas et al., 2023), and roadside ditches of New York (Pietz et al., 2021).

### 4.1.1 Impacts of human activities to floating litter

As seen in Figure 2, the mean macroplastic flux of the weekday observations is higher than its weekend counterpart except at Site 2. Weekdays are usually associated with typical working and school days, so more ambulant people may cause leakage of plastic litter. Aside from that, garbage collection is generally scheduled on Tuesdays, Thursdays, and Saturdays. Therefore, fewer pieces of macroplastics were observed during the weekend because the litter had already been collected a day prior. Additionally, weekday observations usually fall on Mondays, so more pieces of macroplastics were observed because there were no scheduled garbage collection on Sundays and the next collection was on Tuesdays.

In contrast, the weekend macroplastic flux was higher at Site 2. This is because there was a funeral nearby on the day of the observation. As a result, high amounts of polystyrene coffee cups, plastic cups, food and drink wrappers, and plastic utensils were observed resulting from poor waste management.

The mean macroplastic flux of the noon observations is the highest at all sites (Supplementary Table S8). This is probably because work and school lunch breaks usually happen at noon. Therefore, the high presence of plastics related to food consumption (i.e., food and drink wrappers, plastic utensils, plastic *labo* from local eateries or *carinderias*, and drinking cups) was observed. It is also worth noting that straws are usually inside thin PE plastics and drinking cups. Thin film plastic bags (plastic *labo)* with straw (inside the plastic) was typically observed in residential areas where neighborhood sundry stores (or *sari-sari* stores) are prevalent because the store owners use them as convenient packaging for soft drinks.

Aside from the packaging practices of local eateries (*carinderia*), the piece-meal mentality (or *tingi* culture) is prevalent in the Philippines because buying in large portions is more expensive. Corporations take advantage of the consumer's inability to purchase goods in bulk by repackaging these items in a way that contributes to the 'sachet economy' (Ang and Sy-Changco, 2007). The presence of single and multilayer sachets observed along the Tullahan River exhibited the influence of the sachet economy in our country.

Corporations and company promotions can also influence human activities to boost customer engagement and promote their brand. The K-POPromo of Coca-Cola Far East Limited (CCFEL) offers participants nationwide a chance to win different prizes by typing the code at the back of the label of participating products (Coca-Cola Philippines, 2023). It has been in effect since the first week of March and is set to end on the last day of June 2023. Before this, they had a similar initiative during the first quarter of 2022, which also involved checking labels. As a result of the increased consumption and 'label-peeling' practices, most floating labels observed were those peeled from soda or soft drink PET bottles.

### 4.1.2 Effects of SWM practices to floating litter

From the floating litter observations, plastic shopping bags (or *sando* bags) and thin PE bags (mostly composed of plastic *labo*) were among the frequently occurring plastic types. These were commonly used by nearby makeshift market stalls (*talipapa*) and neighborhood sundry stores (*sari-sari* stores) as packaging material. Despite the city-wide plastic bag ban in Quezon City, the presence of these thin plastic bags in the river stream remained abundant because the makeshift market stalls (*talipapa*) and neighborhood sundry stores (*sari-sari* stores) are not covered by the plastic ban. This ordinance only applies to commercial establishments and similar retailers under the Type 1 classification, as stated in Ordinance No. SP-2868.

Domestic or residential wastes in bulk inside a plastic shopping bag (*sando* bag) was observed in all sampling sites. This indicated the practice of direct garbage dumping into the river stream. Similar to the study of Osorio et al. (2021), rampant garbage dumping occurs in areas with large residential settlements. In line with this, they also collected significant amounts of microplastic films that could have originated from plastic bags.

The presence of plastic bags in the open environment may also be attributed to the lack of recycling opportunities for these items. According to interviews with various junkshop operators in Quezon City, single-use plastics (SUPs), including straws and sachets, are not accepted (World Bank, 2022). Therefore, SUPs will likely be left out during collection, disposed of improperly, and carried into waterways.

On the other hand, PET bottles are among the least occurring plastic types in the river stream. PET is the most recycled plastic in the world (Sarda et al., 2021). Waste pickers also prefer collecting PET bottles because these can be sold in junkshops at approximately ten pesos per kilo (Yan, 2022). In line with this, Brgy. San Bartolome employs a system of providing incentives in exchange for recyclable wastes. Residents may trade their recyclable wastes for groceries or cash. The implementation of this kind of incentivized system manifested in the low number of PET bottles in both weekday and weekend observations at Site 3, which is governed by Brgy. San Bartolome.

The schedule of waste collection may also influence the macroplastic flux. Quezon City implements an everyday Barangay Dedicated Waste Collection Program, which employs a separate waste collection schedule for biodegradable and non-biodegradable wastes to promote a segregation-at-source policy. From the interviews, biodegradable wastes are collected every Monday, Wednesday, and Friday; Tuesdays, Thursdays, and Saturdays are for non-biodegradable wastes. Other waste management operations of the Department of Sanitation and Cleanup Works of Quezon City (DSQC) are Bulky Waste Collection, Main Road Collection, Identified Markets, Schools, and Other Institutions Waste Collection, and Disaster-Relief and Cleanup Support (Department Of Sanitation And Cleanup Works Of Quezon City Citizen's Charter, 2022). Meanwhile, according to a resident of Barangay Ugong in Valenzuela City, their waste collection only takes place on Tuesdays and Thursdays, wherein no at-source segregation is practiced. As a result, the highest number of floating macroplastics during the weekday observations was recorded at Site 5, the sampling station in Valenzuela City.

## 4.2 Characteristics of riverbank litter

A study by World Bank (2024) reveals that snack and drink wrappers were constantly included in the top 10 macroplastics collected on all riverbank sites along Pasig River and its tributaries during the dry season. In this study, the same was only observed at Site 1 (Gozum St. Bridge) where wrappers consist almost a third of the total collected macroplastics by piece. Meanwhile, wrappers were also present at Site 4 (San Bartolome Delta Bridge) but it was dominated by thin PE bags. It is worth noting that the total plastic count in Site 4 is significantly lower than Site 1.

For non-plastic items, glass ranked third, along with rubber, in the same study by World Bank (2024). Results from both Site 1 and Site 4 of this study exhibit rubber as the top non-plastic item in terms of by-piece quantity and weight.

As the extent of litter accumulation and accessible area of the riverbank caused variation in the number of quadrants, comparison of the results from riverbank survey through statistical analysis was not performed. Instead, a qualitative approach was done to investigate possible effects of human activities and other factors on macrolitter accumulation.

At Site 1 (Gozum St. Bridge), recyclable and residual plastics constituted more than half (62%) of the riverbank macrolitter collected. Relatively low plastic count (35%) was recorded at Site 4 (San Bartolome Delta Bridge) due to human intervention, such as clean-up drive done in the morning prior to surveying.

On the other hand, some human activities have a negative impact on riverbank litter accumulation. High-density non-plastics (e.g., glass fragments) and plastics (e.g., linoleum) were observed in both sites. These have specific gravities higher than water, so it is unlikely for these to be washed away by river currents. This is an implication of poor waste disposal practices such as direct dumping into waterways.

### 4.2.1 Factors affecting macrolitter accumulation

Accumulated litter was dug up to an extent of 5 cm at Site 1 (Gozum St. Bridge), indicating accumulation prior to those carried by the currents caused by the recent heavy rain. A significant number of residual wastes were also observed on vegetations such as tall grasses on both sites. The relevance of vegetation to macroplastic trapping has also been studied by Cappa et al. (2023) where they determined mangrove roots as biological agents which facilitate macroplastic trapping. Moreover, the density of a material could also influence its likelihood to accumulate as seen on the results wherein high-density macrolitter appeared on both sites.

With Tullahan River being a major tributary of Manila Bay, it has been part of several cleanup projects and initiatives of private and public institutions. Estero Rangers (ER) are deployed across Metro Manila for waterways cleanup under the Department of Environment and Natural Resources (DENR). The Department of Sanitation and Cleanup Works of Quezon City (DSQC) regularly partners with DENR Estero Rangers for Tullahan River cleanups within the city. Local street sweepers of Barangay San Bartolome also help the ERs every Tuesday and Friday with their cleanups at Odelco (Site 1: Gozum St. Bridge) and California Village (Site 4: San Bartolome Delta Bridge), respectively. Meanwhile, no documentation or news articles of Valenzuela City LGU participation were found.

During ocular inspections in the Valenzuela City area, high amounts of litter can be found trapped in vegetation along the stream. At the same time, some are gathered afloat in areas where water is almost stagnant. On the other hand, most parts of the stream are inaccessible, and some have fast currents, which may be dangerous even for cleanup operations utilizing floaters.

## 4.3 Relating land use to plastic pollution

The part of Tullahan River that traverses the *barangays* of Nagkaisang Nayon, Capri, and San Bartolome in the study is lined with big factories and manufacturing firms, such as Pioneer Food Corp., General Metal Container Corporation, Nutritive Snack Food Corp., Cathay Pacific Steel Corp., Piñakamasarap Corporation, Berkeley Packaging Solutions, Rebisco Foundation Incorporated, A1+ Multinational Packaging Inc, and XDE Novaliches. The existence of these establishments could be connected to the high presence of food and drink wrappers among the floating and riverbank litter observed.

In terms of legal easements, Barangays of Nagkaisang Nayon, San Bartolome and Capri in Quezon City implement a 6-m no build zone on areas beside major waterways including the Tullahan River. This is compliant to the required three (3) meter legal easement under DENR Administrative Order No. 2021–07 but still falls short on the ten (10) meter Environment Protection Area setback requirement under Quezon City Comprehensive Zoning Ordinance of 2016. According to the *barangays*, informal settlers who had resided in these areas were relocated when the implementation took place. On the other hand, no legal easements were implemented in Valenzuela City as ocular inspection revealed presence of residential houses immediately beside the river.

Due to the residential areas in the *barangays*, multilayer packaging of household products (i.e., condiments, powdered beverages, junk foods, biscuits, detergent, shampoo) made up the majority (45%–52%) of floating plastics on all bridge sites. Therefore, the lowest total macroplastic count (629 pieces) was recorded in Site 3 (San Bartolome Delta Bridge), where residential houses are farthest from the stream on both sides due to the legal easement enforced.

In line with this, more than two-thirds of the total riverbank macrolitter can be attributed to Site 1 (Gozum St. Bridge) which is located in Barangay Nagkaisang Nayon. Most of these are household products. The 2016 Zoning Map of Barangay Nagkaisang Nayon shows that areas adjacent to the river are predominantly residential.

## 4.4 Solid waste management in Quezon City and Valenzuela City

The Metro Manila Development Authority (MMDA) manages the solid waste disposal in Metro Manila. The Quezon City LGU discards its collected wastes to the Rizal Provincial Sanitary Landfill (RPSLF). The collected wastes from Valenzuela City are disposed of in the New San Mateo Sanitary Landfill (NSMSLF). The RPSLF and NSMSLF have a remaining life span of 14.25 and 4.5 years, respectively. This emphasizes the need for further development of waste regulation legislation and more effective waste diversion initiatives to further minimize the volume of wastes that end up in landfills.

Since 2019, the Valenzuela City LGU has implemented the *May Balik sa Plastic Program* in partnership with Nestlé Philippines. Residents trade laminates and SUPs for Nestlé Products at *barangay* redemption centers. These plastics are shredded in a bailing station and are taken by Republic Cement for co-processing in cement kilns (Nestlé, 2020; World Bank, 2022). The city also has more than 90 recycling facilities, four of which were materials recovery facilities (MRFs) on 33 *barangays*. One of these is in Barangay Ugong, which has been upgraded, sustained and operational according to its last monitoring in 2018. Furthermore, Barangay Ugong had been one of the top three *barangays* for residual waste collection in 2020.

Meanwhile, Quezon City currently has no existing citywide programs for SUP recycling. Waste diversion within the city is done through its 61 MRFs in 142 *barangays*. Among these, Barangay San Bartolome has an active MRF, while the MRF operation of Brgy.

Capri has been discontinued since the onset of COVID-19 pandemic.

The private sector, through the junkshops, also contributes to waste diversion. In *barangays* with no MRFs, materials recovery system (MRS) arrangements between the *barangay* and junkshops were made. MRS refers to the memorandum of understanding between a *barangay* and a junkshop, which states that recyclables recovered from *barangay* waste collection will be sold directly to the junkshop. There are 84 MRS in Quezon City, while Valenzuela City has 29 (World Bank, 2022).

Population density and SWM practices are related to the discharge of plastics into freshwater bodies (Wang et al., 2024). The results of the study highlight the importance of proper solid waste management, from implementation to participation. In proposing effective SWM systems, it is vital to evaluate the physical and socio-economic features of a community, such as the existence of road networks, the location of recycling facilities, population density, population growth, and poverty incidence.

All *barangays* involved in the study have narrow streets. Barangay Capri had the narrowest road networks among all the *barangays*. LGU collection trucks and *barangay*-managed collection systems often cannot cover areas that can only be accessed through narrow roads, such as depressed or slum areas. The gap in the collection system may increase the possibility of plastic leakage into the open environment. Accordingly, investing in vehicles that could access these areas (i.e., pushcarts, skip bins, and small collection vehicles) is suggested.

On the other hand, the presence of recyclable plastics and SUPs in the river indicates the existence of a recycling gap among the *barangays*. Recycling opportunities for SUPs are little to none, so it would be better to have *barangay* plastic trading centers that would cater specifically to the most frequently occurring plastics based on WACS performed in the *barangay*.

Lastly, the reduction of waste generated is also a way of solving the problem at source. Reinforcing plastic ban relations and developing information, education, and communication (IEC) materials and campaigns are essential to raise awareness and participation levels among residents and other stakeholders.

## 4.5 Application and limitations of the study

Although statistical analysis has been applied to determine the relationship between macroplastic flux and river velocity, increasing the observations per site is recommended to generate more data points. Another challenge encountered in this study was the identification of polymer type of plastic items during the visual counting. Plastic bags and other SUPs (i.e., plastic *labo*) can be made with HDPE and LDPE, so they were generally classified as “PE bags” for a safe approximation. In addition, cutlery items do not have an engraved resin identification code. Polystyrene has a higher specific gravity than water, so it would most likely sink to the bottom. Therefore, it was then decided to identify all cutlery items (i.e., plastic spoons, forks, drinking cups) as polypropylene, following the informative video by Sentinel UpCycling Technologies (2022). With this, submerged plastics were not included in the visual counting because they were not visible to the observers.

Kumar et al. (2021) provided an overview of the adverse effects of plastic pollution on various disciplines and scales. All 17 sustainable development goals (SDGs) of the United Nations are affected by plastic pollution, directly or indirectly. Proper waste management could, directly or indirectly, help achieve the objectives of the SDGs. One of the targets of Life Below Water, SDG 14, is centered on reducing land-based plastic debris in the ocean by 2025. Rochman et al. (2016) highlighted synergizing science and policy as a solution to global plastic waste management by means of scientific studies on plastics.

The results of this study can be used for modeling and increasing the accuracy of field data estimates of the Tullahan River. The Tullahan River segment in this study is relatively far from the river mouth but near residential and industrial zones. Combining the results of this study and the field data from the Tullahan River mouth (van Emmerik et al., 2020), more accurate model estimates can be generated leading to more suitable conclusions and recommendations. Aside from that, the discussion of the impacts of solid waste management practices and land use on plastic flux could be used to develop appropriate plastic regulation policies and improve the solid waste management and land use planning of the nearby cities. It could also be utilized for public awareness and community involvement. Moreover, results from the study could also be used to reinforce the need to develop stricter policies on zoning and legal easements due to its impact on macrolitter leakage.

## 5 Conclusion

This paper aimed to quantify, characterize and analyze the composition of macroplastics observed along the Tullahan River, one of the top rivers contributing to marine plastic pollution. The data obtained from visual counting was used to compute the plastic flux in the upstream, midstream, and downstream of the river. Results show that the macroplastic flux, which ranged from 308 to 1226 plastics per hour, fluctuated along the river stream. A decrease was observed at midstream followed by an increase further downstream. At normal river conditions, there is no significant correlation between macroplastic flux and river velocity. However, a significant correlation between the two was observed during days with unusual events, such as holidays or funerals.

Furthermore, the characterization of the riverbank macrolitter reveals that it is composed of 30%–41% residual plastics and 5%–21% recyclable plastics in terms of by-piece quantity. In terms of weight, the riverbank macrolitter consists of 6%–11% residual plastics and 19%–70% recyclable plastics. Residual plastics are usually lightweight and small, so it is expected that recyclable plastics contribute more in terms of weight. Despite this, residual plastics come in higher frequency, so they contribute more in terms of by-piece quantity.

Lastly, the plastic surveys conducted conclude that food or drink wrappers and thin PE plastics are the top contributors to riverine macroplastic pollution. In turn, multilayered and $PO_{soft}$ plastics are the most frequently occurring polymer type in the river stream. Human activities and nearby establishments could have influenced the entry of these wastes into the river stream. Hence, improvements in plastic regulation policies along with strict enforcement are suggested. Wide dissemination of information regarding its sustainable alternatives is also encouraged.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

## Author contributions

AT: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing–original draft, Writing–review and editing. LD: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing–original draft, Writing–review and editing. MD: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing–review and editing.

## Funding

The authors declare that financial support was received for the research, authorship, and publication of this article. This research work was funded by the MRBII Construction Thesis Support Grant and Murata Science Foundation Research Grant through the UP Engineering Research and Development Foundation, Inc. (UP ERDFI), and the Philippine Department of Science and Technology-Science Education Institute (DOST-SEI). The publication was supported by the Engineering Research and Development for Technology (ERDT) Program, and the University of the Philippines Diliman, through the Office of the Vice Chancellor for Research and Development.

## Acknowledgments

The authors would like to acknowledge the assistance of the officials of Barangays Capri, Ugong, and San Bartolome in the fieldwork. The authors are also grateful to the reviewers of the initial draft paper for their constructive feedback, comments and suggestions which helped in improving this manuscript.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2024.1396525/full#supplementary-material

## References

Ang, R. P., and Sy-Changco, J. A. (2007). The phenomenon of sachet marketing: lessons to be learned from the Philippines. *Enhancing Knowl. Dev. Mark.* 5.

Anilkumar, P. P., and Chithra, Ar.K. (2016). Land use generator based solid waste estimation for sustainable residential built environment in small/medium scale urban areas. *Indian J. Sci. Technol.* 9 (6). doi:10.17485/ijst/2016/v9i6/87699

Barboza, L. A., Cózar, A., Gimenez, B., Barros, T. L., Kershaw, P. J., and Guilhermino, L. (2019). "Chapter 17 - macroplastics pollution in the marine environment," in *World seas: an environmental evaluation* Editor C. Sheppard (Academic Press), 305–328. doi:10.1016/B978-0-12-805052-1.00019-X

Bardenas, V., Dy, M. N., Ondap, S. L., and Fornis, R. (2023). Exploring factors driving macroplastic emissions of Mahiga creek, cebu, Philippines to the estuary. *Mar. Pollut. Bull.* 193, 115197. doi:10.1016/j.marpolbul.2023.115197

Bull, P. A., and Lawler, D. M. (1991). "Flow measurements and water tracing," in *Caving practice and equipment*. Editor D. Judson (United Kingdom: Cordee-Leicester/British Cave Research Association), 167–178. Available at: https://www.researchgate.net/profile/Damian-Lawler/publication/244995361_Flow_measurement_and_water_tracing/links/00b7d523593b107ed0000000/Flow-measurement-and-water-tracing.pdf.

Cappa, P., Walton, M. E., Paler, M. K., Taboada, E. B., Hiddink, J. G., and Skov, M. W. (2023). Impact of mangrove forest structure and landscape on macroplastics capture. *Mar. Pollut. Bull.* 194, 115434. doi:10.1016/j.marpolbul.2023.115434

Coca-Cola Philippines (2023). K-POPromo [review of K- POPromo]. Available at: https://www.coca-cola.com.ph/promos/K-POPromo.

Department Of Sanitation And Cleanup Works Of Quezon City Citizen's Charter (2022). Available at: https://quezoncity.gov.ph/wp-content/uploads/2021/10/DSQC-CITIZENS-CHARTER-2022.pdf.

Environmental Management Bureau - Department of Environment and Natural Resources (2008). National solid waste management status report. Available at: https://emb.gov.ph/wp-content/uploads/2019/08/National-Solid-Waste-Management-Status-Report-2008-2018.pdf.

Galarpe, V. R. K. R., Jaraula, C. M. B., and Paler, M. K. O. (2021). The nexus of macroplastic and microplastic research and plastic regulation policies in the Philippines marine coastal environments. *Mar. Pollut. Bull.* 167, 112343. doi:10.1016/j.marpolbul.2021.112343

González-Fernández, D., and Hanke, G. (2017). Toward a harmonized approach for monitoring of riverine floating macro litter inputs to the marine environment. *Front. Mar. Sci.* 4. doi:10.3389/fmars.2017.00086

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., et al. (2015). Plastic waste inputs from land into the ocean. *Science* 347 (6223), 768–771. doi:10.1126/science.1260352

Kumar, R., Verma, A., Shome, A., Sinha, R., Sinha, S., Jha, P. K., et al. (2021). Impacts of plastic pollution on ecosystem services, sustainable development goals, and need to focus on circular economy and policy interventions. *Sustainability* 13 (17), 9963. doi:10.3390/su13179963

Lebreton, L., and Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. *Palgrave Commun.* 5 (1), 6. doi:10.1057/s41599-018-0212-7

Lebreton, L. C. M., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., and Reisser, J. (2017). River plastic emissions to the world's oceans. *Nat. Commun.* 8 (15611), 15611. doi:10.1038/ncomms15611

Lumongsod, S. L. R., and Tanchuling, M. A. N. (2019). "Microplastic characterization and analysis in three Makati city creeks," in *Proceedings on the 4th symposium of the international waste working group-Asian regional board (IWWG-ARB) 2019, Bangkok, Thailand, 20–22 February 2019.*

Meijer, L. J. J., van Emmerik, T., van der Ent, R., Schmidt, C., and Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. *Sci. Adv.* 7 (18), eaaz5803. doi:10.1126/sciadv.aaz5803

Nestlé (2020). Valenzuela city mark 100 days of may Balik sa Plastik. Available at: https://www.nestle.com.ph/stories/100-days-may-balik-sa-plastik.

NSWMC (2020). Waste analysis and characterization study: a manual. Available at: https://faspselib.denr.gov.ph/sites/default/files/Publication%20Files/Waste%20Analysis%20and%20Characterization%20Study_A%20Manual.pdf.

Osorio, E. D., Tanchuling, M. A. N., and Diola, M. B. L. D. (2021). Microplastics occurrence in surface waters and sediments in five river mouths of Manila Bay. *Front. Environ. Sci.* 9. doi:10.3389/fenvs.2021.719274

Pietz, O., Augenstein, M., Georgakakos, C. B., Singh, K., McDonald, M., and Walter, M. T. (2021). Macroplastic accumulation in roadside ditches of New York State's finger lakes region (USA) across land uses and the COVID-19 pandemic. *J. Environ. Manag.* 298, 113524. doi:10.1016/j.jenvman.2021.113524

Requiron, J. C., and Bacosa, H. (2022). Macroplastic transport and deposition in the environs of Pulauan River, dapitan city, Philippines. *Philipp. J. Sci.* 151 (3). doi:10.56899/151.03.33

Rochman, C. M., Cook, A., and Koelmans, A. A. (2016). Plastic debris and policy: using current scientific understanding to invoke positive change. *Environ. Toxicol. Chem.* 35 (7), 1617–1626. doi:10.1002/etc.3408

Sarda, P., Hanan, J. C., Lawrence, J. G., and Allahkarami, M. (2021). Sustainability performance of polyethylene terephthalate, clarifying challenges and opportunities. *J. Polym. Sci.* 60 (1), 7–31. doi:10.1002/pol.20210495

Sentinel UpCycling Technologies (2022). On this weeks's #RecyclablReady, we'll show you an easy way to distinguish between plastics that look the same but aren't [Video]. *Facebook*. Available at: https://www.facebook.com/SentinelUpCyclingTechnologies/videos/778331929844113.

UNEP (2020). Monitoring plastics in rivers and lakes: guidelines for the harmonization of methodologies. Available at: https://www.unep.org/resources/report/monitoring-plastics-rivers-and-lakes-guidelines-harmonization-methodologies.

van Emmerik, T., van Klaveren, J., Meijer, L. J. J., Krooshof, J. W., Palmos, D. A. A., and Tanchuling, M. A. (2020). Manila River mouths act as temporary sinks for macroplastic pollution. *Front. Mar. Sci.* 7. doi:10.3389/fmars.2020.545812

Vriend, P., Van Calcar, C., Kooi, M., Landman, H., Pikaar, R., and van Emmerik, T. (2020). Rapid assessment of floating macroplastic transport in the Rhine. *Front. Mar. Sci.* 7, 10. doi:10.3389/fmars.2020.00010

Wang, T., Li, B., Shi, H., Ding, Y., Chen, H., Yuan, F., et al. (2024). The processes and transport fluxes of land-based macroplastics and microplastics entering the ocean via rivers. *J. Hazard. Mater.* 466, 133623. doi:10.1016/j.jhazmat.2024.133623

World Bank (2022). *An assessment of municipal solid waste plans, collection, recycling and disposal of Metro Manila*. Washington DC.

World Bank. (2024). Plastic diagnostics in the Philippines: field and remote sensing, river monitoring and microplastics assessments. Washington, DC.

WWF Philippines (World Wildlife Fund, Philippines), Cyclos GmbH, and AMH Philippines, Inc. (2020). *EPR scheme assessment for plastic packaging waste in the Philippines*. Quezon City: WWF Philippines. Available at: https://wwfph.awsassets.panda.org/downloads/epr-scheme-assessment-for-plastic-packaging-waste-in-the-philippines-full-report.pdf.

Yan, G. (2022). Cash for trash: ‘bakal, bote, Plastik at dyaryo. *Posit. Filip*. Available at: https://www.positivelyfilipino.com/magazine/cash-for-trash-bakal-bote-plastik-at-dyaryo.