Distribution of marine debris in Jakarta Bay and its implication to the coastal ecosystem

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Abstract. Citarum River, which ended up in Muaragembong, Bekasi Regency-West Java Province, is known recently as one of the most polluted rivers globally, including pollution caused by plastic litter. This research was conducted in the surrounding river, estuary, and mangrove ecosystem in Muaragembong, which aimed to determine macro debris and analyze its impact on the coastal ecosystem. Marine debris sampling in the mangrove ecosystem was done by line transect, while the net using for marine debris sampling surrounding river and estuary. The result showed that debris composition in Muaragembong consisted of 80% inorganic and 20% organic, where plastic debris dominated with 50-81% and was distributed throughout the estuary and mangrove ecosystem. The highest density was found in the mangrove ecosystem in the Kali Mati Estuary (Pantai Sederhana Village) with 222.67 waste/m², while the heaviest waste was found in the Bendera Estuary (Pantai Bahagia Village) 4,663.64 grams/m². This condition explained the lack of marine debris management in the Muaragembong estuary, where most inorganic debris originated from household litter. This research also supports data and information for baseline Indonesia's marine plastic debris due to comprehensive data needed to reduce 70% of marine plastic debris by 2025.

Keywords: Marine Debris, Pollution, Composition, Muaragembong

1. Introduction

Marine debris or marine litter pollution is becoming a worldwide issue nowadays, especially plastic debris due to its potential impact on the environment. The increase of plastic debris was correlated with increasing the number of plastic products such as clothes, packaging, and other plastic application. UNEP [1] defined marine debris as a persistent, produced, or unused solid material disposed of, discarded, or abandoned adjacent to the marine and coastal environment. Marine debris adversely affects the environment, the economy, human health, and wildlife [2]. Based on the World Bank report [3] (2017), almost 80% of marine litter originates from land-based sources, and around 30% is plastic debris, where plastic pollution is mainly generated from land and transported through rivers into the oceans [4]–[6]. The vast amount of plastic debris accumulated in the marine environment left another problem that might disturb the marine and coastal ecosystem [7], which is considered a crucial issue related to the plastic pollution in the waters. The amount of mismanaged plastic waste is estimated at 4.8 – 12.7 million tons will enter the sea every year [8], where the combination between inland and at sea sources contribute a further 75,000 to 1.1 million tonnes and 0.3 to 3.25 million tonnes of plastic waste, respectively [9].

Marine debris has become a hot issue in Indonesia since it was declared the second largest country globally that contributes plastic waste to the sea [8], with Java island as the most populated island and predicted as the main source of debris and litter. Citarum River, which ended up in Muaragembong, Bekasi Regency-West Java Province is known recently as one of the most polluted rivers in the world,
including pollution caused by plastic litter. Several rivers traverse the Muaragembong area, one of which is the Citarum River, a watershed area (DAS) of 6,614 km² with more than 50% of its flow passing through urban areas industrial areas [10] as well as the coastal ecosystem of Muaragembong, mainly mangroves. Muaragembong is a coastal area located at the eastern end of Jakarta Bay whose existence has been degraded by human activities, especially aquaculture activities, by converting natural mangrove ecosystems covering 10,480 ha, leaving around 540.72 ha in 2001 [11]. Government programs, both central and regional, in restoring the environment have recently begun to be massively carried out, namely in the form of mangrove rehabilitation activities in the Muaragembong area, so that in 2010 there was an increase in mangrove area to 822.24 ha.

The existence of estuary and mangrove ecosystems in the coastal area makes this region a solid waste disposal area, exceptionally unprofessional domestic waste management from the coastal area itself and the land above it. It is said that 80% of waste in the sea comes from land waste that is not well managed [12]. It is known that mangrove ecosystems have ecosystem services as a regulator, one of which is the ability to trap sediment with a unique root system. This trapping ability is not solely for sediment purposes only, but all objects larger than the sediment will be trapped, for example, macro and meso-sized trash. The existence of trapped waste will affect the mangrove ecosystem, both mangroves and the biodiversity therein. It is known that mangroves also breathe through lenticels in the trunk and roots of mangrove breath [13]. If the stems and roots of mangroves are covered with garbage, the mangrove metabolism system will be disrupted, and sediment respiration by the biota, which ultimately affects the growth and biota in it. The waste trapped in mangrove and coastal ecosystems is plastic compared to other types [14]–[17].

This study aims to determine macro-sized marine debris, mainly plastic, and analyze its impact on coastal ecosystems, especially the Muaragembong mangrove ecosystem. The results of this study are expected to be one of the baseline data about the presence of marine debris in a significant watersheds in Java Island and can be used as material for policymaking in waste management both on the coast and on land.

2. Methodology

2.1. Study Area

This research was conducted in Muaragembong, Bekasi Regency, West Java Province, where Muaragembong is part of the Jakarta Bay area. Sampling location of marine debris was done surrounding the river, estuary, and mangrove ecosystem. The research method was carried out by purposive sampling, which is expected to represent the condition of marine debris in the river, estuary, and mangrove ecosystem, whether by boat or walk. The samplings of marine debris in the mangrove ecosystem were done by line transect adopted from the ecological method. Sampling was done using a quadrat transect method with a 50 cm x 50 cm size and systematically conducted every 10 m from the coastline to the outer part. The method used for surface marine debris sampling surrounding estuary waters was adopted from NOAA [18]. The study of marine debris in mangrove ecosystems and estuary areas was conducted at Pantai Bahagia Village (seven stations) and Pantai Sederhana Village (six stations), Muaragembong District picture below.
2.2. Methods

The sampling area consisted of seven stations in the Pantai Bahagia Village, two stations in the mangrove ecosystem and five stations on the water surface. For water surface located surrounding Citarum Estuary (three stations: middle, left, and right), while another two stations taken along the Citarum River to settlements/ponds as far as ± 4 km (Figure 1). Samples in six stations were taken in the Pantai Sederhana Village, with three stations surrounding the estuary (Kali Mati Estuary), two stations along the river, and one in the mangrove ecosystem. Each station in the mangrove ecosystem consists of substations arranged systematically from the outermost mangrove boundary (close to the sea) to the most profound (close to land) with an interval of 10 m. Waste sampling collection includes visible debris at the top of the macro-sized sediment > 2.5 cm. Each transect sampling area is recorded with a GPS position to get the exact area coverage of the station.

Parameters taken from each station were the percentage of debris. The steps taken were filtering the waste with a garbage filter with a pore diameter of 0.5 cm; drying and cleaning waste from water and sand; sorting waste based on waste classification on each transect; identification of waste (plastic, glass, wood, metal, cloth, and others); grouped and counted and weigh the waste.

The tools and materials used during the research [15], [18] scales; camera; calculator; GPS; magnifying glass/loop; roll meter; drain; hand trowel/cement trowel; garbage sieves (0.5 cm and 2.5 cm), garbage clip sticks; scissor; cutter/folding knife; gloves; face mask; sack size 50-100 kg; un-used tarpaulins or banners for sample sorting; flags/sticks or squared frames as sampling barriers; stationery (pencils, clipboards, permanent markers, markers; ropes (mine, raffia); 3-5 kg clear plastic bags for samples. Sample analysis was carried out at basecamp for identification, sorting, and weighing.

The data collected is mainly data from direct observation and in situ measurements. The steps taken are: Filtering garbage using a garbage filter with a pore diameter of 0.5 cm; Dry and clean garbage from water and sand; Sorting waste based on the waste classification in each transect; Identification of
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solid waste (plastic, glass, wood, metal, cloth, and others); grouped and counted and weighed the waste. Segregation of meso-sized marine debris is taken if the sediment is in a wet condition, then during filtration with a 5 mm sieve, it is rinsed with clean water.

The observation in sediment quality measurement is related to the distribution of macro, meso, and microplastic in the sediment. After the samples in the form of marine debris are collected, proceed with the sample cleaning process and grouping the samples into categories in plastic, rubber, metal, glass, and wood and their derivatives. Each species was counted in number and weight on each transect. In addition, a related parameter such as mangrove density was also taken in the created transect line to determine the density of the vegetation at the study site. The transects were extended perpendicular to the coastline and the mangrove vegetation, where each station consisted of three sub-stations, and each substation was placed in five plots. Vegetation data located in each transect was taken utilizing a 10m X 10m rectangle plot, such as biological sample in the form of components of leaves, flowers, and fruit to identify mangrove species and measured adopting the guidelines from Noor et al. [19].

2.3. Data Analysis
The total type and weight of waste calculation follow the following equation [18], [20].

a. The composition of coastal waste is calculated as a percentage, namely the weight of waste per type (x) per total waste in the survey area:

\[ \text{Percentage } x (\%) = \frac{x}{\sum_{i=1}^{x}x} \times 100\% \]  

(1)

b. Solid waste density (K) is calculated from the amount of waste per type per m²

\[ K = \frac{\text{type}}{\text{area}} \]  

(2)

To calculate the density of mangrove, calculated the average distance of each tree with the following formula [21]:

Mangrove density (D) is calculated from the number of trees per area (m²)

\[ D = \frac{n_i}{A} \]  

(3)

3. Result and Discussion

3.1. Existing condition in the study site
The location of the waste sampling in the mangrove ecosystem in the Pantai Bahagia Village consists of two stations, namely in the north of Bendera Estuary, a protected area for the Javan Lutung (S1) and in the south of Bendera Estuary (S2). The only type of mangrove found in Javan Lutung is Avicennia marina, with a density ranging from 1,500 to 2,300 trees/ha with an average of 1900 trees/ha. The location of Bendera Estuary found two types of mangroves, namely Avicennia marina and Avicennia alba, with densities ranging from 800 – 1300 trees/ha with an average of 1050 trees/ha. It can be seen from the density of mangroves at station S1, which is denser than S2 because station S1 is one of the conservations/guarded locations for Javan langur habitat, while station S2 is a location that is relatively high in human activity with the existence of ponds and fishing settlements. Sediment in the mangrove ecosystem is a type of mud and is black.

The mangrove ecosystem in the Pantai Sederhana Village is located north of Kali Mati Estuary (part of the Citarum watershed) (S3) found two types of mangroves Avicennia marina and Rhizophora mucronata. The Rhizophora mucronata found were still in the form of seedlings with a density of 600 seedlings/ha, while the Avicennia marina species were trees. Mangrove density ranges from 300-1700 trees with an average of 1300 trees per hectare. The location of solid waste sampling in the Pantai Sederhana Village mangrove ecosystem looks visually more trash than in the Pantai Bahagia Village.
The presence of waste in the research location, especially along the Citarum River, looks visually clean, with not much floating garbage. However, it can be seen that garbage piled up in several locations along the Citarum River from the local community (Figure 3). The existence of piles of garbage on the banks of the river based on personal interviews with residents is waste produced by the local community, which will later have a waste sorting process by scavengers from outside the village who will choose so that it can be ascertained that waste that has no selling value will fall into the river and eventually to the sea.

The Muaragembong mangrove ecosystem is part of the protected forest/conservation area of Muaragembong, covering an area of 11 thousand hectares, but based on the Decree of the Minister of the Environment Number 475 of 2005, half of the area located at the far end of the Bekasi Regency was cleared for production forest. The forest cutting causes the conservation area to be threatened and shrink due to many land clearings for ponds. As a result, the mangrove ecosystem as a coastal protector that does not function causes abrasion and increases the frequency of tidal floods that disrupt community activities; with a sea-level rise of 0.6997 cm/year, the area of tidal inundation in 2015 was 3,097.19 Ha and the area of tidal inundation. The largest area, which is 1,405.95 Ha, is in Pantai Bakti Village [22].

Figure 2. Mangrove density in the Muaragembong estuary
Figure 3. The condition of the Citarum River waters that look clean of garbage (above) and domestic waste can be seen piling up on the banks of the Citarum River (bottom)

3.2. Identification and composition

The research results obtained from waste sampling at the research location are generally dominated by inorganic waste. Sampling in floating waters and seen using a boat in a specific area, namely in two estuaries and river bodies, namely Bendera Estuary and the Citarum River and the estuary of Kali Mati, a tributary of the Citarum River. They collected macro waste in the mangrove ecosystem at three locations: the mangrove ecosystem in Javan Lutung, Bendera Estuary, and Kali Mati Estuary.

The identification of waste obtained from 7 categories with 41 types of waste based on LIPI categorized obtained waste found in Muaragembong District, Bekasi, in five categories with 25 types of waste. The type of waste found consisted of 80% inorganic waste with plastic and rubber as much as 72%. The remaining 20% is organic waste, wood and its derivatives, and other categories in the form of animal carcasses (fish) and plants (leaves and twigs). The results of garbage collection at the research location during the July 2020 survey based on residents, a few were floating or stranded in Muaragembong because the conditions during the research were the dry season so that no garbage from the upstream area or the land above it was carried away by the Citarum River.
Based on the study results, it was found that macro debris in Muaragembong from five locations, including two in the location, was garbage floating in the waters of the estuary and rivers. Three locations are waste that is stranded in the mangrove ecosystem. The results obtained from the five locations show that plastic waste is the most significant waste found. Generally, the waste found is crackle plastic, plastic sachets, especially snacks and styrofoam fragments (Figures 4 and 5). The Javan Lutung mangrove ecosystem has the smallest amount of waste compared to other locations, where the highest number of types of waste is in the waters of Pantai Bahagia Village, with the highest category in the waters of Pantai Bahagia Village (Figure 4).

![Macro Debris Composition](image)

**Figure 4.** Macro debris composition found at Muaragembong estuary, July 2020

![Waste Selection Process and Macro-sized Waste](image)

**Figure 5.** Waste selection process (A) and macro-sized waste found in Muaragembong (B-D)
The composition of floating waste is dominated by plastic categories ranging from 62-81% of the total collected waste, as shown in Figure 6. The dominant types are plastic sachets used to wrap food and household necessities such as soap, as shown in figure 5. The Pantai Bahagia Village waters are pretty clean from floating waste, especially during the dry season, in contrast with the wet season where the rain potentially brings the waste from land towards the Citarum River and estuary. There was no garbage found at Station A3, located in the southern part of Citarum River estuary or Bendera Estuary, which can be caused by the sampling activities during the low tide so that the current movement from the sea pushes the floating garbage into the main river.

The results are the same as the research location in Pantai Sederhana Village (Figure 7); for floating waste, the plastic and rubber waste categories are dominated, with compositions ranging from 50 – 80 %. Plastic waste was found at all sampling points, dominated by the same type, namely plastic sachets, plastic crackers, and styrofoam fragments, where 15 types of 19 types of plastic waste were found in the Pantai Bahagia Village and 14 types in the Pantai Sederhana Village.
The identification and composition of macro-sized waste in the Muara gembong coastal waters dominated by plastic show the high use of plastics and unprofessional waste management, as shown by the high level of plastic leaking in both rivers' waters estuaries. The plastic leakage in the Muara gembong region can affect biological and non-biological ecosystems, especially macro-sized plastic waste, by affecting the amount of microplastic-sized waste in the waters, and affecting the food chain, as shown by Bangun et al. [23], explained by the positive correlation of 0.765 between the abundance of macroplastics and microplastics in Jaring Halus Village, Langkat, North Sumatra.

3.3. Distribution and litter abundant
The abundance and distribution of macro-sized waste in the research location found that the abundance of floating waste was higher in the Pantai Sederhana Village than in the Pantai Bahagia Village (Figure 8). The density of waste that is stranded or trapped in the mangrove ecosystem is higher than that of floating waste (Figure 9), which shows the amount of waste, especially plastics that leaks into nature and trapped in the mangrove ecosystem, and potential to affect the existence of the mangrove ecosystem and the biota in the mangrove ecosystem or the cultivated biota in ponds located between the mangrove ecosystem.

Figure 7. Floating macro waste composition in the Sederhana Village waters
The high density and weight of waste in the mangrove ecosystem compared to the waters also shows the influence of community behavior in managing waste, which can be seen from the research results in July 2020, where there was much waste in mangrove ecosystems close to land or residential areas (Figure 9). Muaragembong is known for its dense area and a high population growth rate associated with the high sedimentation rate in the region. The presence of soil arising from sedimentation triggering people to exploit and occupy the new land reclamation and then use it as a shelter, while on the other hand, there is also a severe abrasion, which impacted significantly to the ponds when the high-tide or rob flood occurs and partially submerged [22].
Figure 9. Density and distribution of macro debris trapped in mangrove ecosystem in Pantai Bahagia Village (Javanese lutung and Bendera Estuary), Pantai Sederhana Village (Kali Mati Estuary) Muaragembong, July 2020. Explanation P1= facing the sea; P2= middle and P3= close to land

The distribution of waste in Muaragembong District based on the study location in the Pantai Bahagia Village and Pantai Sederhana Village showed that more types of floating macro-sized garbage were found than in mangrove ecosystems. Meanwhile, the highest density is in the mangrove ecosystem. The low presence of waste in the waters is due to the shorter residence time of waste in estuary waters than rivers and mangrove ecosystems (stranded), and the supply of leaked waste is greater from local than from outside the location due to the dry season, which is different during the rainy season. The hydrodynamic simulation by Kreeling et al [24] found the differences in waste types between the coastal, estuary, and ocean compartments, both in terms of the integrity of the waste, which indicated the source of the waste. The waste stranded on the beach is thought to come from the surroundings estuary, where the time to carry waste is shorter than by the high seas and washed up on the beach in the form of fragmentation. According to Purba et al. [25] the debris trajectory patterns in Muaragembong vary in the two monsoons, and waste from the two estuaries flow towards the south and southwest. More trash moved further south and was washed up on the surrounding coastal areas.

There are 5 categories out of 7 categories of marine debris found in Muaragembong. Found 25 types of waste from 41 marine debris types that are more than 60% is plastic waste. Cordova & Nurhati [4] also found that plastic debris dominated in the Bekasi River, both by abundance and weight (20,066 ± 10,074 items or 2.61 ± 1.31 tons). Most types of waste were found in the waters of the Pantai Bahagia Village, with the highest density in the Kali Mati Estuary mangrove ecosystem, which is close to settlements. This research was conducted in the dry season so that research is needed in the rainy season, which will affect the amount of waste that enters Muaragembong through the Citarum River due to flooding in the upper reaches of the river so that more in-depth analysis can be carried out to formulate a policy in solid waste managing.

4. Conclusion
The lack of marine debris management in the Muaragembong estuary causes most of the inorganic debris originated from household litter where plastic debris dominated with 50-81% and was distributed throughout the estuary and mangrove ecosystem. The rainy season data is not yet studied, we suggested to complete the data in order to supporting policymaking in solid waste management both on the coast and on land.
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