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Patterns, Types, and Distributions of Macroplastic Debris Based on Oceanographic Conditions and Community Perspectives: Case Studies In Muara Gembong Downstream of Citarum

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ABSTRACT

Muara Gembong is downstream of Citarum river that still faces the challenge of plastic pollution problem. This research is a multidisciplinary study that combines oceanographic factors and socioeconomic perceptions of local people about macroplastic debris on the coast. The main purpose of research is to understand the local people's perceptions and oceanographic factors' connections towards plastic debris in Muara Gembong. Oceanographic parameters to be analyzed include current, tidal, and wind conditions. The location of plastic debris accumulation hotspots is obtained by GPS (Global Positioning System) marking method along downstream rivers, ecosystems, and coastal areas. To obtain public perception data, FGD (Focus Group Discussion), interviews, and 100 questionnaires by online interview representing local government, Local NGOs, and communities were conducted. The research was conducted based on debris accumulation hotspot marking, interviews, and Focus Group Discussion. Based on the hotspot marking, through the water route, 14 yellow dots were marked from the Citarum river through water route, 18 blue dots indicating debris through land route, and 19 red dots show Local Perspectives on piles of marine debris. Current, wind and tidal patterns have an appropriate data with the answer to the Muara Gembong local residents interview that plastic waste always dominates and is distributed in the West Monsoon Season (WMS) and Early of Transitional Season 1 (TS1) wind blow and current from west to east/northeast. Most local interview respondents answer the plastic garbage comes from outside the Muara Gembong area, namely the CBL and Citarum river also from jakarta bay debris transport.

Introduction

Plastic waste pollution has become a critical global issue (Vriend et al., 2021). Each year, approximately 8 million tons of plastic debris enter the ocean, with 80% of marine debris accumulating on the surface and seabed (IUCN, 2018). Indonesia is among the countries actively addressing this crisis, committing to a 70% reduction in plastic waste and marine debris by 2025 through the National Action Plan on Marine Debris (World Bank Group, 2018). The presence of plastic debris in marine ecosystems poses significant threats, including biodiversity loss and environmental degradation (Kemenlu, 2019).

Persistent solid materials produced or processed by human activities, whether directly or indirectly, intentionally or unintentionally, that are discarded or abandoned in marine environments are classified as marine debris, including plastic waste in the ocean (NOAA, 2013). Plastic waste constitutes the largest proportion of marine debris and continues to increase significantly. In Indonesia, where the population growth rate is 1.36%, plastic consumption increases by approximately 17 kg per capita annually. At least 10 case studies on plastic waste in Indonesia have been conducted, identifying Jakarta Bay as one of the most plastic-polluted areas on Java Island (Lestari & Trihadiningrum, 2019).

Research and monitoring of macro debris in Indonesia have been ongoing since the 1980s. The predominant types of debris include disposable

diapers (21%), plastic bags (16%), plastic packaging (5%), other plastic items (9%), glass and metal (4%), and plastic bottles (1%) (Purba et al., 2019). About 80% of marine debris comes from land-based sources, transported through rivers and estuaries (Mazarrasa et al., 2019). While some that debris sinks to the bottom of the ocean, others remain suspended in the water column (Zhukov, 2017). The buoyancy and morphological characteristics of plastic waste influence its movement; for example, small and thin plastic sheets may become entangled in vegetation, while others may be buried in sediments (Hurley et al., 2020).

In addition to impacting aquatic and coastal biota (Kurniawan et al., 2021; Handayani et al., 2023), marine litter scattered in Muara Gembong significantly affects various human activities, including capture fisheries, aquaculture, and ship traffic (Sagita et al., 2022). This issue poses a major challenge for the local community, disrupting daily activities and negatively impacting the socio-economic sector.

Understanding the patterns, types, and distribution of macroplastic debris is essential for mapping its movement, distribution location, and type of marine litter in the Muara Gembong area. The distribution of marine debris is closely linked to oceanographic factors specific to a region (Jambeck et al., 2015). By knowing the patterns and types of debris, it is easier to map the known distribution channels of plastic debris and the potential effects related to human activities in the interaction between the community and anthropogenic waste (Purba et al., 2021). Research on marine debris trajectories has been conducted in various locations, including Jakarta Bay (Jasmin et al., 2019), Sawu (Purba et al., 2018), and Banten (Rahmania et al., 2020).

Muara Gembong, as a densely populated area, has significant potential to contribute to plastic pollution in the ocean (Faizal et al., 2021; Hasanah et al., 2021). Additionally, studies on community perspectives regarding marine debris have been conducted, particularly in relation to the Penta-Helix Model of Coastal Community Plastic Pollution (Phelan et al., 2020; Hermawan et al., 2021).

This study aims to identify plastic debris accumulation hotspots in the Muara Gembong area and analyze the factors influencing their distribution patterns. Additionally, it examines public perceptions regarding the locations and sources of plastic debris. Despite the environmental significance of this issue, research that integrates oceanographic factors with community perspectives is still limited. By mapping debris distribution through primary data collection on accumulation points and assessing public perception using the Hotspot Monitoring Database (Martens & Huntington, 2012; World Bank Group, 2018; Connan et al, 2021), this data can serve as a foundation for further research and a key reference for stakeholders and the local community in developing effective waste management policies for the Muara Gembong area.

Materials and Methods

Location and Characteristic

This research was conducted in Muara Gembong,

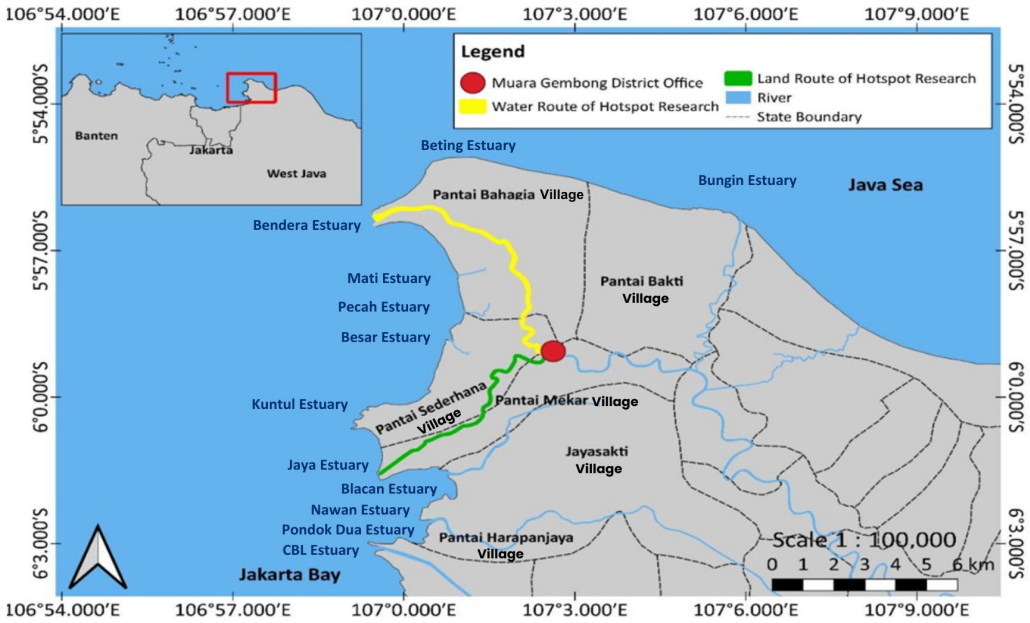


Figure 1. Research Map

Bekasi Regency, located between 106°54'E to 107°09'E and 5°54'S to 6°03'S. Muara Gembong is a sub-district in the northern part of Bekasi Regency, covering an area of 122.90 km². The study focuses on the waters of Muara Gembong, which are traversed by the Citarum River.

The Citarum River splits into two tributaries in this area: Bendera Estuary in the north, as the main estuary, and Jaya Estuary in the south, forming part of the river system. The research was conducted in six villages: Pantai Bahagia Village, Pantai Bakti Village, Pantai Mekar Village, Jayasakti Village, Pantai Sederhana Village, and Pantai Harapanjaya Village (Hermawan & Astuti, 2021). The study also considers plastic waste models in relation to socio-demographic aspects (Sakti et al., 2021). Muara Gembong has 11 part of estuaries, such as Estuary Bungin, Estuary Beting, Estuary Bendera, Estuary Mati, Estuary Pecah, Estuary Besar, Estuary Kuntul, Estuary Jaya, Estuary Blacan, Estuary Nawan, and Estuary Pondok Dua.

Oceanographic Data

The oceanographic parameters analyzed in this study include currents, tides, and wind conditions. Oceanographic data were processed using visualization techniques with secondary data from 2019, as no significant anomalies or variations were observed when compared to 2021 data. Current visualization was conducted using QGIS 3.16 software, with current data obtained from the Marine Copernicus website for coordinates ranging from -6.100 to -5.900° North latitude and 106.900 to 107.100° East longitude.

Tidal visualization was performed using Microsoft Excel software for coordinates -6.0064° N, 106.9872° E, with data retrieved from the https://tides.big.go.id website. Wind visualization was carried out using WRPlot 8.0.2 software for coordinates -5.94° N, 106.97° E at an altitude of 10 meters, obtained from Copernicus. The selection of a 10-meter altitude for wind data follows international standards set by the World Meteorological Organization (WMO) to minimize surface obstruction bias and ensure compatibility with atmospheric models and satellite observations (Badan Meteorologi, Klimatologi, dan Geofisika, 2019).

Current and wind data were recorded daily and averaged into monthly values, whereas tidal data were recorded hourly and subsequently averaged into monthly values. The analysis was conducted based on monsoon seasons, as currents exhibit seasonal variations influenced by monsoonal wind patterns. The distribution of marine debris is therefore dependent on wind, current, and tidal patterns in the Muara Gembong study area. The four seasons such as, West Monsoon Season /WMS (December, January, February), Transitional Season 1 / TS1 (March, April, May), East Monsoon Season /EMS (June, July, August), and Transitional Season 2 / TS2 (September, October, November).

Debris Data

The first primary data source is a Focus Group Discussion (FGD), which was held on April 6, 2021, at the Muara Gembong District Office. The discussion involved participants from each sub-district in Muara Gembong, with a total of 19 representatives. The participants included 5 representatives from Pantai Bahagia Village, 2 from Pantai Bakti Village, 3 from Pantai Mekar Village, 5 from Jayasakti Village, 2 from Pantai Sederhana Village, and 2 from Pantai Harapanjaya Village.

The second primary data source is the Debris Accumulation Hotspot Sampling (World Bank Group, 2018; Connan et al, 2021), conducted from April 6 to 10, 2021. This research utilized Global Positioning System (GPS) marking to track debris carried by river currents and accumulated along riverbanks. The hotspot marking process began at the Muara Gembong District Office and followed two routes: a land route and a water route. The land route was conducted using motorcycles along the Citarum River, extending to the end of the Jaya Estuary tributary. Meanwhile, the water route was carried out by boat along the Citarum River, leading to its main estuary, Bendera Estuary.

The third primary data source is community interviews, conducted with 100 local residents of Muara Gembong Sub-district between August 1 and September 10, 2021. The interviews were carried out using the accidental sampling method via Samsung mobile phone calls, to minimize the risk of COVID-19 transmission. Respondents were selected to ensure representation from each sub-district in Muara Gembong.

Result

Oceanographic Conditions

The visualization of oceanographic conditions in this study includes currents, winds, and tides. The current and wind data cover a 12-month period, while tidal data are represented by observations from January, April, July, and November 2019 as sample of each monsoon season. This study focuses on the movement of macroplastic debris in the Muara Gembong area which is influenced by

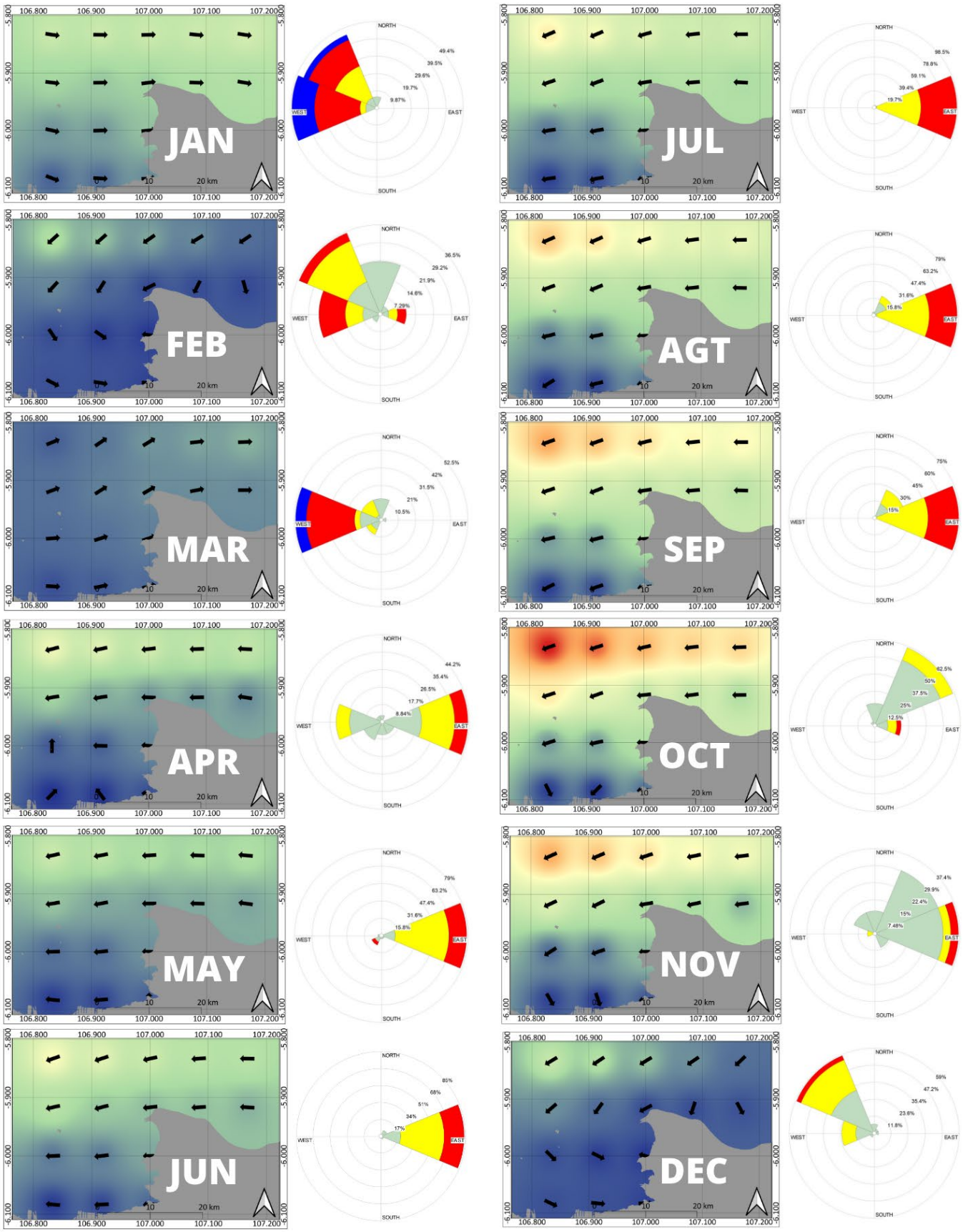


Figure 2. Current and Wind Pattern Condition

oceanographic conditions. The visualization of currents and winds is key to understanding waste transportation dynamics (Djaguna et al., 2019).

During the West Monsoon Season (WMS), the dominant current originates from the west (Fadika et al., 2014), shifting towards the northwest, with a velocity ranging from 0.003 to 0.12 m/s. In December, the current predominantly moves from west to east. By January, this current direction causes debris to disperse from Jakarta Bay and accumulate in the Muara Gembong area, particularly affecting Pantai Sederhana Village, Pantai Mekar Village, and Pantai Harapanjaya Village. February is still included as WMS which causes the current to move towards the east and southeast.

During WMS, the dominant wind direction originates from the west, southwest, or northwest, with wind speeds ranging from 0.5 to 8.8 m/s. The northwest wind is more dominant due to extreme weather conditions. This finding aligns with the research by Jasmin in 2018, who explained that water movement in Jakarta Bay generally flows from the west or northwest to the southeast, driven by the dominance of the west monsoon from offshore. This movement is further influenced by deflection from several islands around Jakarta Bay, forming a current pattern that predominantly directs debris towards the coastline.

During Transitional Season 1 (TS1) in March, the current moves from west to east, as it is still influenced by the West Monsoon Season (WMS). The dominant wind direction also shifts from west to east, with wind speeds ranging from 0.5 to 8.8 m/s and current velocities between 0.003 and 0.12 m/s. This pattern occurs because March is part of TS1, a period where wind patterns tend to be erratic at the beginning of each season. However, the influence of the previous monsoon winds still has a strong influence (Labania et al., 2018).

During the East Monsoon Season (EMS), the dominant wind direction comes from the east (Fadika et al., 2014), with wind speeds ranging from 0.5 to 5.7 m/s and dominant current velocities between 0.003 and 0.36 m/s. June include in the EMS, when winds flow from the Australian continent to the Asian continent, leading to the dry season in Indonesia (Sudarto, 2011). As a result, the current in June flows from east to west.

During Transitional Season 2 (TS2) in September, the dominant current moves from east to west (Fadika et al., 2014), with velocities ranging between 0.003 and 0.48 m/s. Additionally, some currents shift towards the southwest, influenced by winds blowing from the northeast, with wind speeds varying between 0.5 and 5.7 m/s.

The distribution of marine debris is significantly influenced by tidal dynamics, which has a crucial impact in its transport and accumulation. Tidal forces facilitate the movement of debris over long distances, leading to its deposition in specific areas, such as shorelines and estuarine environments (World Bank Group, 2018; Wahid & Mutaqin, 2024).

Based on Figure 3, the dominant tidal types in Muara Gembong are Mixed Tides and Diurnal Tides. Diurnal tides occur when there is only one high tide and one low tide within a 24-hour period. Meanwhile, Mixed Tides exhibit characteristics of both diurnal (single daily) and semi-diurnal (double daily) tides, depending on variations in tidal forces.

In 2019, diurnal tides were observed in January, June, July, August, September, October, November, and December, whereas mixed tides occurred in February, March, April, and May. These findings are consistent with research conducted by Arifin et al. (2014) under the Indonesian Ministry of Marine Affairs and Fisheries (KKP), which also identified that the Jakarta Bay area experiences a tidal cycle with

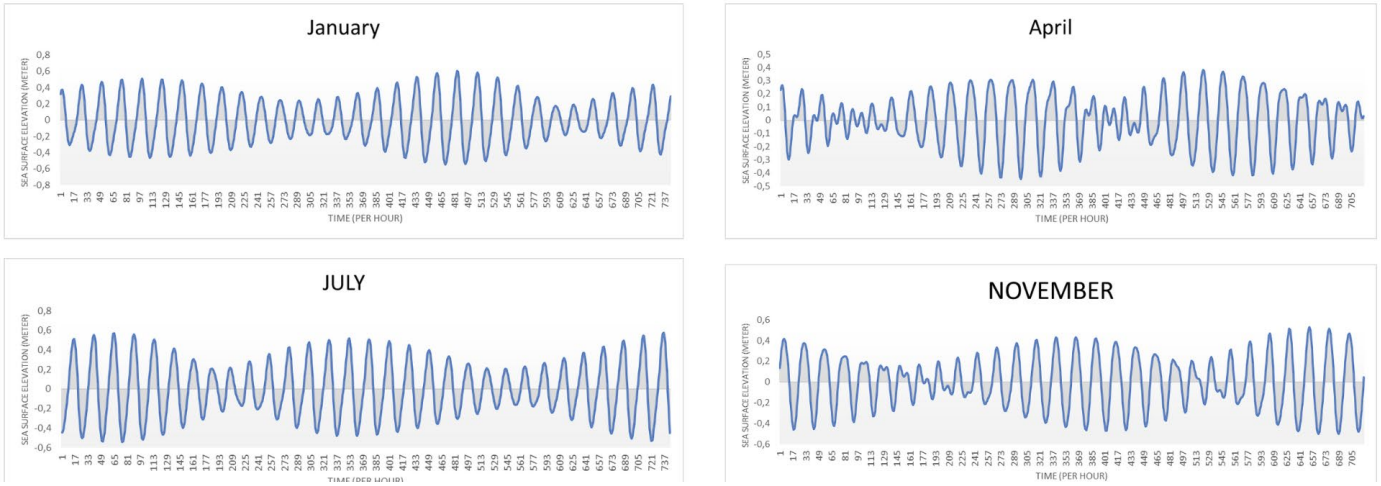


Figure 4. Tidal Pattern on each of Monsoon

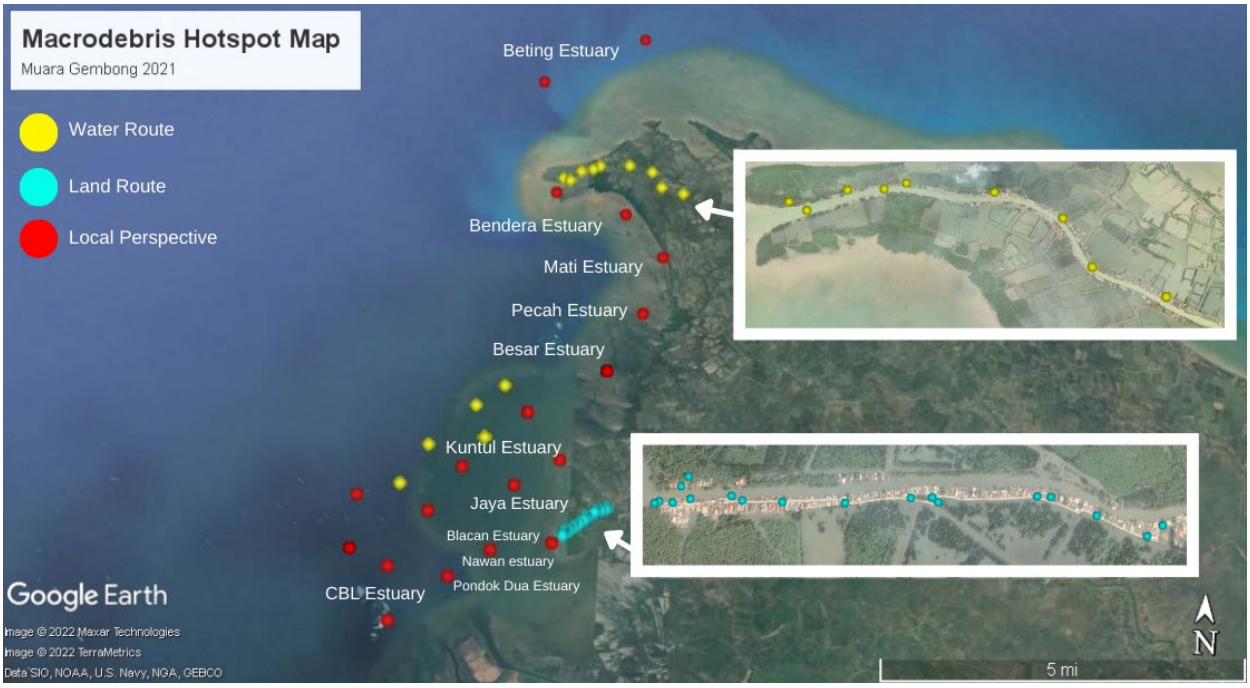


Figure 5. Hotspot of Macroplastic Waste in Muara Gembong

one high tide and one low tide per day, lasting approximately 24 hours and 50 minutes.

The Super Blood Wolf Moon or Total Lunar Eclipse Phenomenon that occurred on January 20–21, 2019, significantly influenced tidal patterns, causing tides to reach further inland. In general, the Moon's position significantly influences the regulation of ocean tides on Earth's surface. During a total lunar eclipse, the combined gravitational forces of the Moon and the Sun on ocean tides reach their maximum intensity, leading to higher-than-normal sea levels. This phenomenon can result in full tides and, in extreme cases, trigger coastal flooding or tidal surges.

Pattern, Types, and Distributions of Debris

The research was conducted based on debris accumulation hotspot marking, interviews, and Focus Group Discussion. Hotspot marking using GPS by researchers is carried out through 3 methods, such as water route, land route, and local perspectives. Based on the research, the area along the Jaya Estuary and Bendera Estuary is dominated by waste from the area leading to the estuary. Based on the hotspot marking, through the water route, 14 yellow dots were marked from the Citarum river to Bendera Estuary, 18 blue dots were marked from land route and 19 red dots were marked by FGD local community perspective.

Interview with the Local Community

Interviews were conducted with 100 local community members consisting of 45% women and 55% men; 11% aged <25 years, 19% aged 25-35 years, 41% aged 35-45 years, and 29% aged over 45 years. Respondents came from 6 areas of Muara Gembong, namely Pantai Bahagia, Pantai Bakti, Pantai Mekar, Pantai Sederhana, Pantai Harapanjaya, and Jayasakti. The people interviewed are residents who in general have lived in the Muara Gembong area for a long time.

Regarding the type of macroplastic waste, 40 respondents answered plastic bottles, 30 respondents for plastic packaging for cleaning products, 15 respondents for plastic cups, 60 respondents answered for food and beverages plastic packaging, 80 respondents for plastic bags, 74 respondents for baby diapers and sanitary napkins, 63 respondents for styrofoam, 15 respondents for synthetic sacks, 10 respondents for synthetic mattresses, and 5 respondents answered other types of plastic. 92% of respondents think that most of the marine debris in

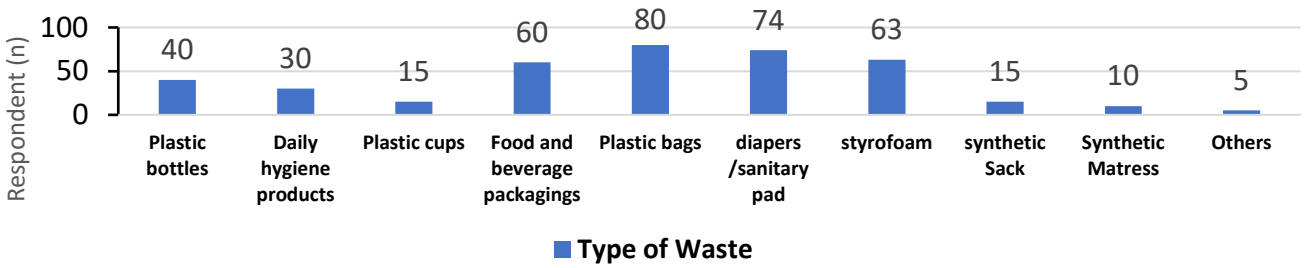


Figure 6. Types of Macroplastic waste that being problem*

*Multiple Responses

the Muara Gembong comes from waste outside / external area of the Muara Gembong area (Sukib, 2019), This means that local household waste from the Muara Gembong local people is not the most dominant source of plastic debris in the Muara Gembong area. 70 respondents answered that the waste came from the Jakarta or Tanjung Priok and Cilincing areas, 96 respondents thought that most of the waste came from the Cikarang Bekasi Laut (CBL) River, and only 48 respondents believe marine debris predominantly comes from the Citarum river.

Regarding the cause of debris dispersion, 52 respondents thought that the debris was transported by the currents of the CBL and Citarum rivers to the estuary, 69 respondents thought that the debris from Jakarta was carried by ocean currents and wind to reach Muara Gembong (Poernomo et al., 2014; Asmal et al., 2021; Nursyahinta et al., 2023), 84 respondents stated that debris originating from the CBL Estuary is carried by ocean currents and distributed evenly along the coast of Muara Gembong, extending to Bendera Estuary and Beting Estuary, 37 respondents thought that debris was carried to the coast and land due to tidal flooding (Ikhsyan et al., 2017), and 65 respondents answered that debris was carried to the coast and land due to high tides (Djaguna et al., 2019).

On interview data, 93 respondents indicated that waste originating from outside the Muara Gembong area predominantly accumulates during the WMS until the early phase of TS1. (Ivar do Sul & Costa, 2013; Devi, 2019), 47 respondents stated that every mid-month high tides will bring marine debris to the mainland, 37 respondents reported that tidal floods occur in Muara Gembong approximately 2-3 times per year., and 35 respondents thought that every day the CBL and Citarum rivers flowed marine debris from upstream to downstream (Djaguna et al., 2019).

Based on the interview data presented in Figure 6, local residents believe that the majority of the local population produces a normal quantity of household waste as part of their daily activities. 73 respondents answered that the waste was burned (Etnayanti et al., 2020; Dobiki, 2018; Nurdianna, 2018), 58 answered that it was given to informal sector collectors and 11 answered that it was thrown into the river. Regarding the reason for the residents to dispose of their waste, 64 answered that it had become a community culture, especially for burned their household waste (Elamin et al., 2018; Dobiki, 2018), 47 answered that there was no other alternative, 39 answered that it was the most effective way. Most local people answered that they have informal sector as plastic collector in the Muara Gembong sub-district area. 80 respondents

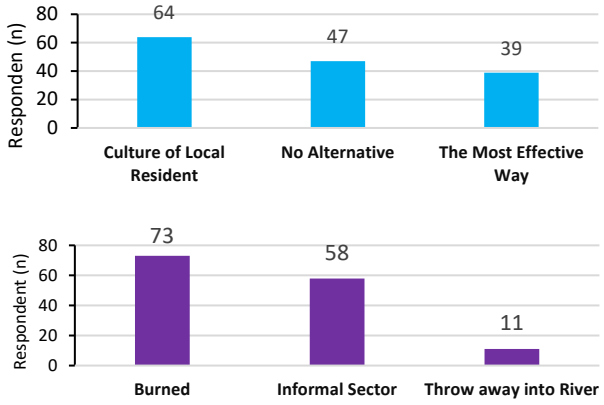


Figure 7. Household Waste Management*

answered that there were scavenger (Darmawati, 2019) and 20 did not know. Regarding plastic waste collected by scavengers (Marliani, 2015; Rengganis, 2021), 80 answered Plastic Bottles, 39 answered Plastic Cups and 13 answered hard plastic.

Based on interview data, most local people reported that the accumulation of plastic waste affects several aspects, 49 answered that it changed people's livelihoods (Devi, 2018), 87 answered that it decreased income because the reducing amount of fish caught per day (Pitria, 2021; Sukib et al., 2019; Johan et al., 2020), 31 answered that it affected education and norms. Some of the daily activities of local communities that are affected by plastic waste include 92 respondents who answered by fishermen (Pramudyanto, 2014; Daihatsu, 2020; Pitria, 2021; Wahyuni, 2017), 43 answered fishfarmers, 87 answered water transportation because it disrupts the works of machine of water transportation, because a lot of debris has trapped and stuck in the ship's propeller. (Pramudyanto, 2014; Daihatsu, 2020), 7 answered the land farming because it disturbs and

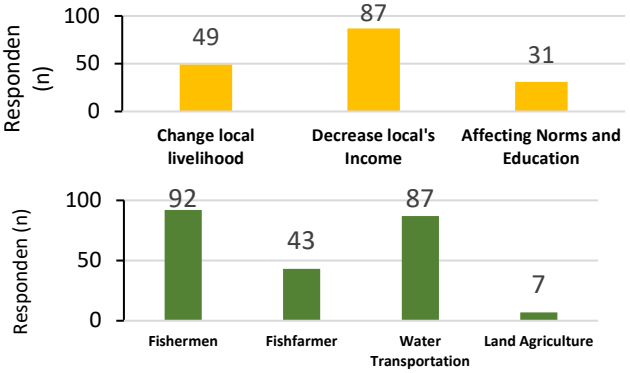


Figure 8. Social and Economic Impact of Plastic Waste*

destroys important organisms in ponds cause of the trapped debris and chemicals has carried by and dissolved from the debris.

The local community also expressed their opinion that the estuary serves as the accumulation point for coastal and marine debris. 93 respondents identified the CBL Estuary as the most heavily

*Multiple Responses

impacted by marine debris (This finding aligns with Krismono and Pranowo (2019), who stated that the CBL area has become a highly polluted estuary, affected by both liquid and solid waste), 73 respondents for Kuntul Estuary, 68 respondents for Jaya Estuary, 43 respondents for Bendera Estuary, 32 respondents answered Pecah Estuary, 28 respondents for Blacan Estuary, 25 respondents answered Mati Estuary, 21 respondents for Nawan Estuary, 11 respondents for Beting Estuary, and 22 respondents answered other estuaries.

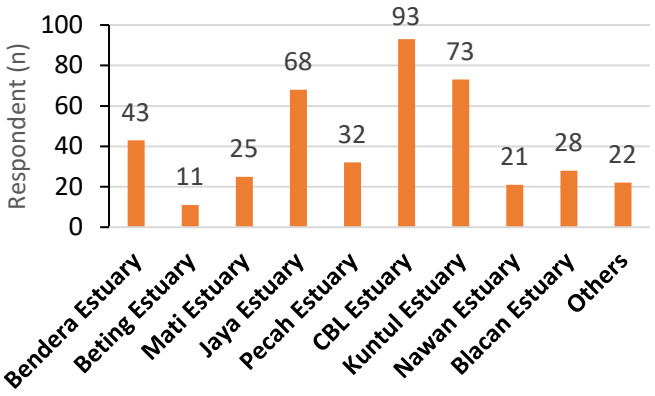


Figure 8. Estuary areas as the problematic plastic waste hotspots*

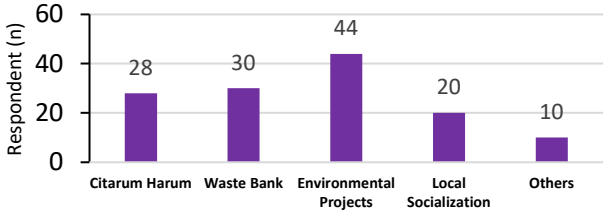
Based on the interview, local community have opinions about the solutions of problematic marine plastic debris. The solutions those have been implemented are, 28 answered Citarum Harum (Zakia et al., 2019), 30 answered Waste Bank (Rengganis et al., 2021), 44 answered environmental projects from universities/social institutions/government (Posmaningsih, 2016; Nurdianna, 2018; Rengganis et al., 2021; Dobiki, 2018) , 20 answered community socialization (Sukerti et al., 2017; Dobiki, 2018), 10 answered others. Regarding local community's opinions for solutions that should be implemented in the future for marine plastic debris issue, 29 answered river normalization (Wigati, 2016), 46 answered debris boom installed on the coast and in the middle of the river (Miliute-Plepiene et al., 2018), 59 answered about government training programs (Posmaningsih, 2016), 58 answered about coastal ecotourism (Sukib et al., 2019), 79 answered waste management displacement (Sukerti et al., 2017; Dobiki, 2018), 75 thought about government regulations (Posmaningsih, 2016; Nurdianna, 2018), and 15 thought other solutions .

Discussion

Based on oceanographic data, the West Monsoon Season (WMS) currents are the most potentially influential currents the transportation of marine debris from Jakarta and CBL Estuary toward the coastline of Muara Gembong, particularly from the Pondok Dua Estuary to the Beting Estuary. This is primarily due to the dominant west-to-east wind direction during the WMS, which enhances the movement of ocean currents and waves. These forces facilitate the transport of marine debris from both the water column and the sea surface, ultimately leading to its accumulation along the Muara Gembong coastline.

During the first transitional season (TS1), March is identified as the most critical period for marine debris transport. This month marks the transition from the west monsoon (December–February) to the east monsoon (June–August), resulting in unstable wind and current patterns. These fluctuations enhance ocean mixing and circulation variability, which in turn increases debris transport (Faizal et al., 2022). Additionally, March still experiences residual rainfall from the west monsoon, leading to higher river discharge. This increased freshwater flow facilitates the transport of debris from rivers into coastal waters, where tidal and wind-driven currents redistribute it (Suryono et al., 2021).

In April, the ocean currents in the Muara Gembong area move westward, while currents from Jakarta Bay shift northward. The variability in current directions is characteristic of TS1, as it is part of the monsoon transition period. During this time, wind patterns remain inconsistent, with a dominant easterly wind and residual influence from the west. Similar to April, in May, the wind continues to predominantly come from the east, with only minor influence from the west. However, the wind tends to move from the east and there is very little wind from the west due to the effect of the east monsoon which is starting to strengthen. Ocean currents in May continue to flow westward from both the Muara Gembong area and Jakarta Bay. The concave shape



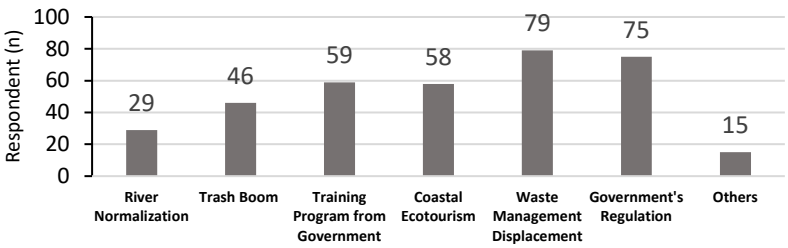


Figure 9. Solutions Regarding Plastic Waste in Muara Gembong*

*Multiple Responses

of the bay has a major influence in debris accumulation, as currents transport and deposit marine debris along the coastline (Wahyuni, 2017).

During the east monsoon season (EMS), ocean currents in July follow the prevailing wind patterns, moving from east to west. Similar to June, the wind direction in July remains predominantly easterly, with strong EMS winds exerting significant influence over ocean circulation. The similarity in wind characteristics between June and July is attributed to their inclusion in the EMS period. In August, the dominant wind direction continues to be from the east; however, it is weaker than in July, indicating that wind influence is not exclusively from the east. During the EMS, the transport of marine debris to the Muara Gembong area is minimal, as both ocean currents and winds primarily move westward, reducing the accumulation of debris along the Muara Gembong coastline.

During Transition Season 2 (TS2), ocean currents in October follow wind patterns moving from the northeast to the southwest. In November, the current direction shifts from Muara Gembong with a subsequent deflection toward the east. September marks the onset of TS2, leading to notable changes in wind parameter profiles compared to August. These variations in wind patterns in November are primarily influenced by the Indo-Australian monsoon, particularly the Borneo-Australian sub-system. Similar to the EMS, the transport of marine debris to Muara Gembong during TS2 is minimal, as both currents and winds predominantly move westward.

Based on visualization results, the Total Lunar Eclipse phenomenon does not significantly impact debris distribution when compared to other months. On average, each month experiences the highest high tide and lowest low tide between the 15th and 25th as known as the middle of the lunar cycle, which has a strong potential for debris dispersal. This observation aligns with local interview data, which indicate that waste accumulation along the Muara Gembong coastline tends to peak during mid-month. The rise in sea level during the highest tide has the potential to transport large volumes of water from the ocean to the mainland, carrying marine debris within the water column. This finding is consistent with previous research by Sitorus (2019) and Zhukov (2017), which highlights the role of tides in influencing debris transport, both from the ocean to land and vice versa.

The hotspot marking map indicates that tidal factors significantly influence the distribution of debris along riverbanks near estuarine areas and coastal settlements in Muara Gembong. High tides and tidal flooding frequently contribute to the accumulation and transport of marine debris, exacerbating waste buildup in these areas. A Focus Group Discussion (FGD) held on April 6, 2021, revealed that all participants strongly believed the primary source of marine debris was the Cikarang Bekasi Laut (CBL) River. The findings from the FGD, which involved 19 participants, aligned closely with interview responses from the local Muara Gembong community, reinforcing the notion that the CBL River significantly contributes in waste transport.

Interview results also identified macroplastic waste types commonly found in the study area. These findings are consistent with previous research on plastic waste composition in coastal regions, which frequently highlight plastic bags, food and beverage plastic/styrofoam packaging, and diapers as dominant waste items (Prasetiawan, 2018; Bangun et al., 2019; Ondara, 2020; Rahmayanti et al., 2020; Sibero, 2020). The majority of this waste originates from the CBL River, a conclusion that aligns with several studies on waste sources in the Jakarta Bay Area and the Bekasi River (Rustam et al., 2021; Dwiyitno et al., 2020; Cordova & Nurhati, 2019).

Most respondents believe that debris originating from the CBL Estuary is transported by ocean currents along the coastline, extending from Muara Gembong to Bendera Estuary and Beting Estuary. This suggests that the accumulation of debris in the Muara Gembong is significantly influenced by oceanographic factors, including ocean currents driven by wind direction and velocity, as well as tidal cycles. This finding aligns with the study by Djaguna et al (2019), which states that marine debris has the potential transported by ocean currents and wind from one place to another, even moved among long distances from its source.

Furthermore, respondents perceive that waste from external sources is most prevalent during the West Monsoon Season (WMS) and the early phase of Transition Season 1 (TS1) (Ivar do Sul & Costa, 2013; Devi, 2019). This indicates that water influx during this period has significant influence in the accumulation and redistribution of waste along the Muara Gembong coastline. Based on oceanographic parameters, the transition from WMS to early TS1 is identified as the most critical phase, exhibiting the highest levels of plastic waste accumulation in the estuary. This phenomenon is primarily driven by oceanographic factors such as wind patterns, currents, and tidal dynamics, which facilitate the

transport of debris within the water column and contribute to its deposition in coastal areas.

Furthermore, the majority of respondents reported that household waste is commonly burned near of their house, as this practice has been ingrained in community culture for many years. In Muara Gembong, the informal sector has significant influence in plastic waste management, with scavengers collecting plastic materials (Darmawati, 2019). Among the collected plastic waste, plastic bottles are the most dominant.

Most local residents believe that plastic waste accumulation has several adverse effects. The majority of respondents stated that plastic waste reduces amount of daily fish catches, leading to a decline in income (Pitria, 2021; Sukib et al., 2019; Johan et al., 2020). This issue primarily impacts fishermen, as plastic debris interferes with fishing activities, thereby decreasing fish yields and economic earnings (Pramudyanto, 2014; Daihatsu, 2020; Pitria, 2021; Wahyuni, 2017). Additionally, plastic waste affects water transportation by obstructing engine performance, as debris frequently becomes trapped in ship propellers, disrupting operations (Pramudyanto, 2014; Daihatsu, 2020).

The marine debris floating in the water column interferes with fishing activities and water transportation. This is in line with research conducted by Zhukov (2017) which states that plastic is the dominant marine waste because plastic is a pollutant that has been globally distributed in all waters due to its easy to float in water column. Regarding local perspective about the most polluted estuary is CBL Estuary (Krismono & Pranowo, 2019), depends on the closest position into the Jakarta Bay with its oceanographic conditions, also the CBL river which carries debris material from upstream. This causes the CBL area to become the estuary which is the most polluted in Muara Gembong.

The most recommended solution from the perspective of the local community is a multi-stakeholder collaboration involving local communities, local and national governments, as well as non-governmental organizations (NGOs) and research institutions. Such collaboration can facilitate the development of the most effective and contextually appropriate solutions for marine debris management. Bendera, CBL and Jaya Estuary are the estuaries which heavily affected by marine debris, with the majority originating from the CBL Estuary. Although the Cikarang Bekasi Laut (CBL) River is not geographically part of Muara Gembong but instead located in Hurip Jaya Village, Babelan Sub-district, Bekasi Regency, it significantly contributes to the marine debris accumulating in Muara Gembong's coastal areas. This finding aligns with interview and Focus Group Discussion (FGD) results, where most participants identified that marine debris in Muara Gembong primarily originates from external sources.

Plastic waste is the dominant pollutant and a major contributor to the waste management challenges in Muara Gembong. The primary types of plastic debris include plastic bags, baby diapers, sanitary napkins, styrofoam, and plastic beverage packaging (Ondara, 2020). This accumulation of waste creates significant disruptions to the daily activities of local communities, particularly in fishing, water transportation, and fish farming.

Correlations between oceanographic data, debris monitoring, interviews, and FGDs further reinforce these findings. Based on oceanographic observations, during the West Monsoon Season (WMS), currents and winds in the Muara Gembong area predominantly move from the west and northwest towards the east and southeast. This shift in wind direction is influenced by seasonal monsoonal wind patterns. During WMS, large-scale atmospheric circulation, particularly the Asian monsoon system, drives prevailing winds from the northwest and west due to pressure differences between the Asian continent and the surrounding oceans (Faizal et al., 2022). As these winds interact with local geographic and oceanographic factors, including coastal topography and sea surface temperature variations, they gradually shift toward the east and southeast (Purba et al., 2021).

Furthermore, from December to February (WMS) and in March (the early phase of Transition Season 1/TS1), a combination of wind and currents from the west and northwest facilitates the transport of marine debris toward the Muara Gembong area. This oceanographic pattern is consistent and related with the result findings from FGDs and interviews with local residents, which indicate that the primary period for marine debris accumulation occurs from December to February (WMS) and continues into March (TS1).

Conclusion

The transport of marine debris in Muara Gembong is primarily driven by oceanographic factors, including currents, wind, and tides. The highest accumulation occurs during the West Monsoon Season (WMS) and the early phase of Transition Season 1 (TS1). The dominant west-to-east movement of currents and winds facilitates the transport of marine debris from Jakarta Bay and the

CBL Estuary area along the Muara Gembong coastline, extending from CBL Estuary to Beting Estuary. Additionally, tidal fluctuations and tidal flooding—particularly during the Supermoon phenomenon in the middle of WMS—intensify the distribution of marine debris, pushing it further inland, especially into riverbank settlements. As a result, plastic waste transported by tidal currents and flooding accumulates along riverbanks, river mouths, and mangrove areas along the Muara Gembong coast. Over time, plastic waste has become a persistent issue in the region, with estuaries filled with debris reaching the open sea and even encroaching on local residents' properties.

Interviews and Focus Group Discussions (FGDs) conducted with local communities provide insight into the composition of waste in Muara Gembong. The most problematic types of plastic waste include baby diapers, sanitary napkins, plastic bags, and styrofoam. Moreover, local communities believe that the majority of marine debris in Muara Gembong area does not originate from the local's but rather from external areas. The widespread presence of plastic waste in coastal waters significantly disrupts residents' daily activities, leading to socio-economic impacts such as reduced fishing yields as fishfarmers, hindered sea transportation, and challenges in fishing operations.

A correlation between oceanographic data and local community observations further confirms these findings. Both oceanographic visualizations and community-based reports indicate a strong relationship between oceanographic processes and the distribution of plastic waste in Muara Gembong. These results align with previous oceanographic research, which highlights that plastic debris distribution along coastal areas is largely influenced by prevailing oceanographic factors, including currents, wind patterns, and tidal dynamics.

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