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Debris Drift from Estuaries: A Study Case in Muara Gembong, Jakarta Bay

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ABSTRACT

Citarum River is one of the largest rivers in West Java, Indonesia. With a length of 297 km, it transfers the debris from the urban area, industry, and settlement to the ocean. This research aims to explore Marine Debris (MD) trajectories from two estuaries in Jakarta Bay. The method was included lagrangian particles with ocean currents, wind, and bathymetry conditions using GNOME software. There were three classes of simulation done in this research. MD observations were conducted in mangrove areas to validate the simulations. These simulations occurred during the northwest and southeast Monsoon period. The results showed that the debris trajectory patterns vary in the two monsoons, and waste from the two estuaries flow towards the south and southwest. In NWM, more waste moved further to the south and was stranded in the surrounding coastal areas. In SEM, waste moved towards the Jakarta bay and surrounding islands in the western and southern side of the estuaries. MD, especially the ones from Jaya estuary, affect other areas.

***Keywords*:** Jakarta Bay, Lagrangian, Marine debris, Muara Gembong, Plastics, Citarum River

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1. INTRODUCTION

Nowadays, we are facing a new challenge in marine areas. After climate change issues, Marine Debris (MD) become more severe after many publications mentioned that it is a global concern. MD or ocean garbage is a crucial issue for every coastal country. It is a massive problem for archipelagic countries, especially Indonesia, which has many rivers and coastal regions. Previous studies have shown that most land waste ends up in the ocean [1], [2], [29], [30]. One of the waste origins are rivers; about 80% of waste in the oceans come from rivers [3]. Several Indonesian rivers are included in the top rankings of polluted rivers. Most of these MD mainly comes from household waste, plastic packaging, and foams [2]. Finally, terrestrial debris could eventually be found in water columns, coastal areas [4], ecosystems [5], and bottom sediments.

This waste cause disturbances in the balance of nature, such as entering the biota's bodies and influencing the aquatic ecosystem [6]. To respond to this issue, the Indonesian government announced a presidential declaration on waste pollution in 2017, which stated that Indonesia is committed to reducing 70% of marine debris by 2025. One of the points in identifying and figuring out the MD's patterns in marine areas, including ecosystems and coastal regions. Identification could be made by direct data sampling [7], [8], satellite data [9], and model simulation using hydrodynamic parameters [10], [11].

This research focused on modelling marine debris that exit river estuaries in the Muara Gembong district. In Indonesia, one of the rivers that pollutes the oceans is Citarum [12], and its end into the Muara Gembong District, Bekasi Regency. The Citarum River is one of Indonesia's longest and largest rivers, 297 kilometres from upstream towards the estuaries in Jakarta Bay. Based on recent publications, the most dominant findings from plastic waste samplings are thin plastic wraps and Styrofoam [13].

The Citarum River is an important water source for many industries. Therefore, its water quality must be maintained. Microplastic waste in downstream areas has also been found in fish, sediments and water columns [14]. From 2018 until the present, led by the Coordinating Minister of Maritime Affairs, "Citarum Harum" was held to restore the river's quality. The study would use an oceanographic approach using GNOME to observe the waste movements from the Gembong estuary. The use of modelling with numerical analysis has succeeded in mapping the MD direction [10], [15]. Previous researches have successfully used a free software called GNOME (The General NOAA Operational Modelling Environment) to model marine debris [1], [16].

2. DATA AND METHOD

2. 1. Geographic characteristics

Two primary sources of waste were chosen for this study. Two Estuaries are located in Jakarta Bay, near the capital of Jakarta. Jaya Estuary in the northern side (-5.946416°S, 106.980994°E) and Bendera estuary on the southern side (-6.016358 °S, 106.986201°E). These two estuaries are parts of the Citarum River and flow into Jakarta bay (Fig. 1). The population density is very high along the river and other land areas [17]. Apart from being inhabited by residents, areas around the rivers and water bodies are also used for fishponds, industries and fishers' housings.

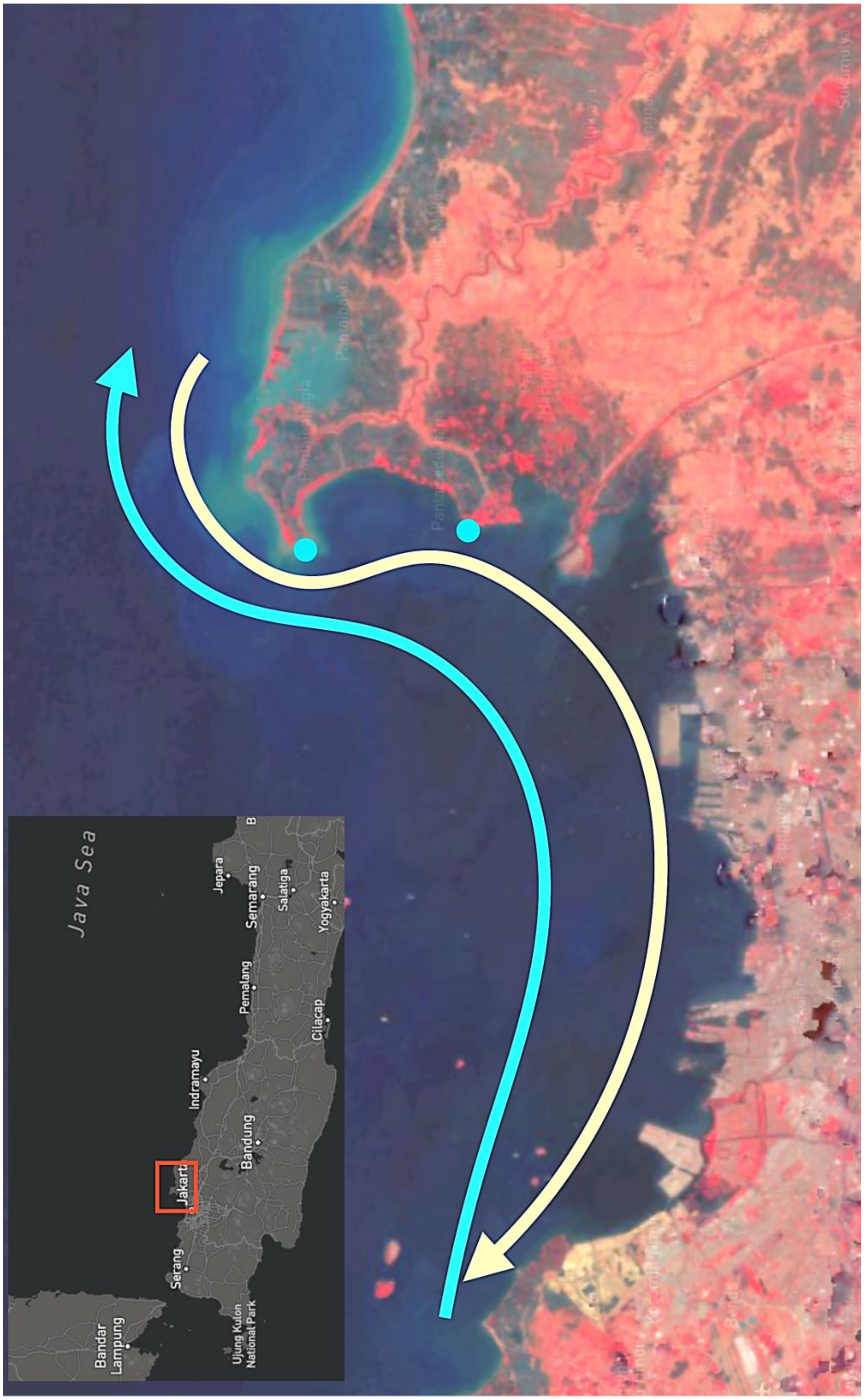

Figure 1. The geographic location in Jakarta Bay overlaid with urban areas (red spots) and current ocean patterns (tide currents). Blue dots represent the starting point of marine debris.

In general, the oceanographic conditions in this area are strongly influenced by tides (blue lines and yellow lines) [10]. Furthermore, as the site is part of the Java Sea, the current conditions in the waters of Jakarta Bay are influenced by monsoon winds and Java sea currents [18].

The currents in these waters can move back and forth according to tidal conditions. The moving currents usually enter the Jakarta bay, following the land's contour, rotating and returning to the Java Sea.

2. 2. Data

This research was conducted using survey methods and waste trajectory modelling. Debris tracking simulation or other particle trajectories is one technique to determine the marine environment's particles' movements.

This technique was used the Lagrangian method, which mainly focuses on oceanographic parameters [19]. The primary concept of debris trajectory is to transport particles based on the moving particles and add dispersion using a specific period. This research considered oceanographic factors such as wind patterns and ocean currents which are the main factors of the marine debris' movement.

GNOME is a powerful software that requires specific parameter inputs, including specific map and boundaries, bathymetry, ocean currents, wind, and windage range [20]. The windage range is a percentage of the wind that moves the debris [1]. In this case, two seasons were used as this area is mainly influenced by Monsoons that move periodically. The model was run for two seasons: December to February represent northwest-monsoon (NWM), and June to August represent southeast-monsoon (SEM). Wind and current data used are SEM in 2020 and NWM in 2021 (Table 1).

Table 1. Data, source and resolution of data.

No.	Data	Resolution	Remarks
1.	Wind (U^{10})	Weekly, 0.30	ECMWF Copernicus Climate Data (https://cds.climate.copernicus.eu/)
2.	Ocean currents	Weekly, 0.30	CMEMS Copernicus Resources Marine (https://resources.marine.copernicus.eu/)
3.	Shoreline and terrestrial	Long/Lat	GNOME base map (https://gnome.orr.noaa.gov/goods/)
4.	Bathymetry	Six arc second	(http://tides.big.go.id)
5.	Windage	0-3%	[1], [21]

Particle tracking (PT) simulation or particle trajectory is one way to determine the movement of objects or particles in the aquatic environment. The primary method behind particle trajectory is to transport particles based on the moving particles and add dispersion using a random run time. The pattern of the particle trajectory model depends directly on the number of particles in the domain. The problem can be solved quickly if the mass in this domain is only divided into a few particles, and the same problem will be solved more slowly if the mass is divided into many particles. The addition of floating particles in the waters generated from surface winds affects the surface trajectory, which can also be simulated [22], [23].

2. 3. Method

Three scenarios used with different windage classes to represent the various types of debris found in the ocean [21], [24]. The three windage classes are as follows: 0-1% (low), 1-2% (medium), 2-3% (high); the common windage is 1-4% [21]. Examples of low windage debris are fishing nets, small plastic fragments and bottle caps; medium windage: polystyrene, foam sheet, PET bottles partially filled with seawater, and glass bottle; high windage: empty PET bottles and fishing buoys [21].

A complete survey was conducted on 1-8 April 2021 to validate the type of debris. In-situ waste data gathered by collecting the types of waste around the river estuaries to support this research. Waste was analyzed and weighed to determine their class in the simulation. The analysis was carried out by observing the types of waste and their distribution in Jakarta Bay.

3. RESULT AND DISCUSSION

3. 1. Types of debris

Waste in Muara Gembong is mainly generated from household activities, such as foam, rubber, plastic, and organic materials (wood and paper) (Fig. 2). These types of waste are primarily found in boundary areas between mangroves and fishponds and mangrove areas with water bodies.

The waste that was found was damaged or broken pieces, whereas some were still undamaged. Most of them piled up in river banks or coastal areas trapped in vegetation or mangrove areas. Based on the local community's perception, these kinds of waste originally come from upstream and other nearby rivers such as Jakarta. Mainly of this debris will not move to other areas and stranded in mangrove for an extended period. Previous research stated that waste in the river comes from direct disposals and upstream sources [2].

In situ sampling, it found that the distribution and characteristics of macro debris in each location are almost similar. One category of macro debris was not found in the North and South of Muara Gembong, i.e. Ceramic.

The most common MD category is Single-Use Plastics like plastic packaging. Moreover, there were also paper and wood. Waste that was often found is Single-Use Plastic (SUP), Recyclable Plastic (ReP), Rubber (Rb), Textiles (Tx), Wood (Wd), Metal (Mt), Glass (Gs), as well as Toxic and Hazardous Waste (Hzd) [26], [27], [28]. These types of waste are also frequently found in the waters around Jakarta bay.

The waste weight varied from meso to macro debris and was representative of the three simulated classes. They were found in dry and wet conditions. This indicates that the waste in this area could be disposed of directly or carried away by water flow.

Figure 2. Types of macro debris in the study site:
a) foam, **b)** rubber, **c)** plastic, **d)** food plastic packaging

Figure 3. Marine Debris in Mangrove including some plastics;
Stranded (left) or Floating (Right)

3. 2. Oceanographic condition

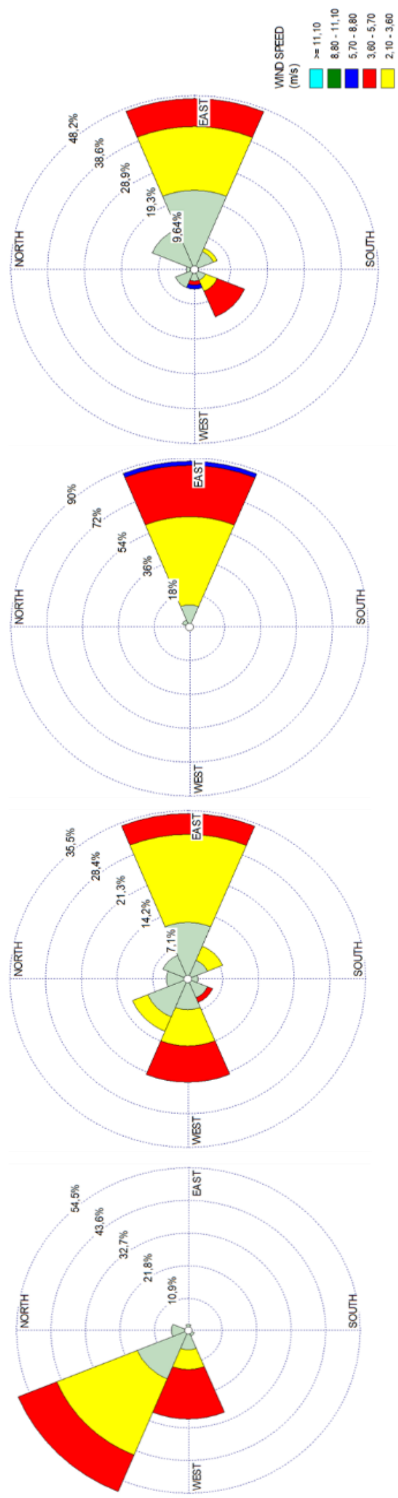

Figure 4. Wind Speed in Jakarta Bay for one year in each monsoon. Starting from North-West Monsoon (left) to South-East Monsoon (right)

Overall, the current velocity around Muara Gembong during the maximum tide period ranges from 0.07 - 0.25 m/s, with the ocean current moving dominantly from the north to the south. In the northernmost part of Muara Gembong, the ocean's direction is split to the eastern area, influenced by land morphological factors. The sea level elevation in this condition ranged from 0.33 m from the Mean Sea Level (MSL). At the maximum low tide, the current velocity ranged from 0.03 - 0.25 m/s, with the current moving dominantly from the south towards the north and its sea-level elevation ranging -0.24 m from the MSL. The current propagation influenced by sea-level elevation and wind, where wind drag could affect the direction of surface current propagation. This condition was the phase where the current would reverse in the opposite direction from the previous one.

The wind blows over Jakarta Bay, influenced by the monsoon situation. Wind direction changes every three months. Mainly in a year, the wind blows from Asia from December to February and from southern Indonesia (Australia) from June to August (Fig. 3). Wind speeds in Jakarta Bay range from 2.1 - 5.7 m/s in each season, with dominant wind speeds of 2.1 - 3.6 m/s, with 20-30% of the total wind speed in Jakarta Bay.

The presence of Jakarta Bay strongly influences ocean current conditions in these waters. Circulations in these waters tend to go back and forth and rotate to follow the contours of the land. The dynamics in these waters are also influenced by the monsoon [24]. The wind speed data obtained in Jakarta Bay illustrates the pattern of wind movements that move in line with the current movement patterns during specific monsoon periods (Fig. 4).

The hydrodynamic simulation results of 3 months (DJF and JJA) show the current patterns around Muara Gembong waters, dominated by tidal currents of the reversing current type or alternating current. This is consistent with previous research, which stated that Jakarta Bay is predominantly influenced by tidal conditions [25]. Based on the hydrodynamic simulation results, it is discovered that the type of tide in the research area is a mixed tide prevailing diurnal.

The hydrodynamic simulation results showed current patterns around the Muara Gembong waters, dominated by tidal currents of the reversing current or alternating current type. The hydrodynamic simulation results also discovered that the type of tide in the research area was mixed tide prevailing diurnal.

3. 3. Marine debris trajectories

MD trajectories in NWM usually had similar patterns for each class, and their distribution patterns shifted between December and February (Fig. 5). In this monsoon, the MD distributions of the three categories moved towards the south from the estuaries. Waste density increased more in February. The best guest model also suggested that the MD would be stranded on the southern coast of the estuaries.

For 0-1% windage, the waste distribution pattern is visible within three months. In December, waste only settled near the estuary in the south. All of them nearly stranded on the beach. This is also following the interview results with the community, who stated that MD was seen around the beach. Furthermore, in January, waste moved away from the estuaries but headed to the south. A small portion of the waste was on water surfaces near the Jaya estuary. In the third month, more waste was spotted along the coast. The waste density of this month is higher than the previous ones. This waste could also be seen in the DKI Jakarta area.

For 1-2% windage, the waste patterns are almost the same as class 0-1%. Waste originating from the two estuaries moved to the south.

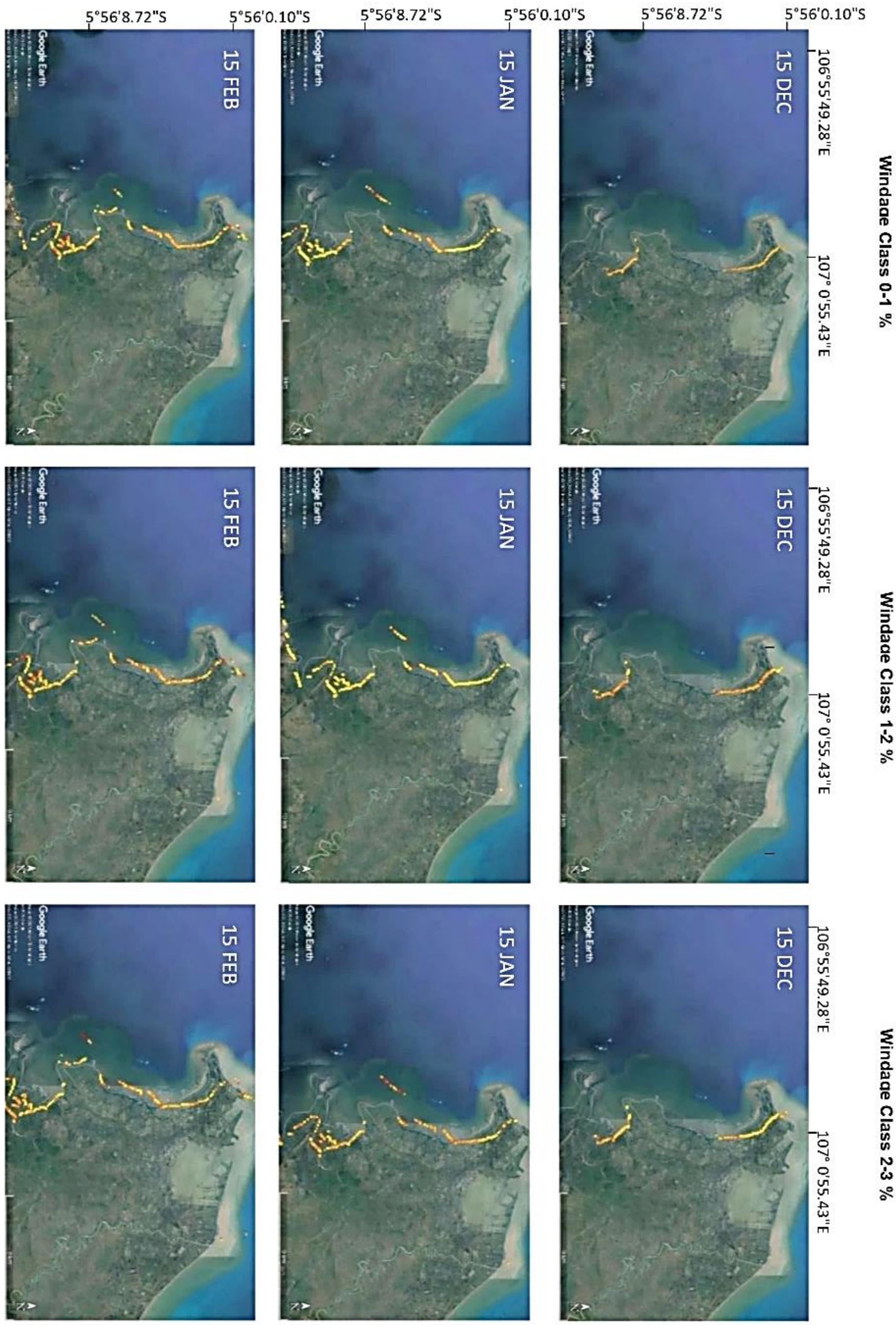

Figure 5. Debris patch during northwest monsoon: (red dot) best guest model, (red-cross) stranded marine debris, (green) debris' monthly movement

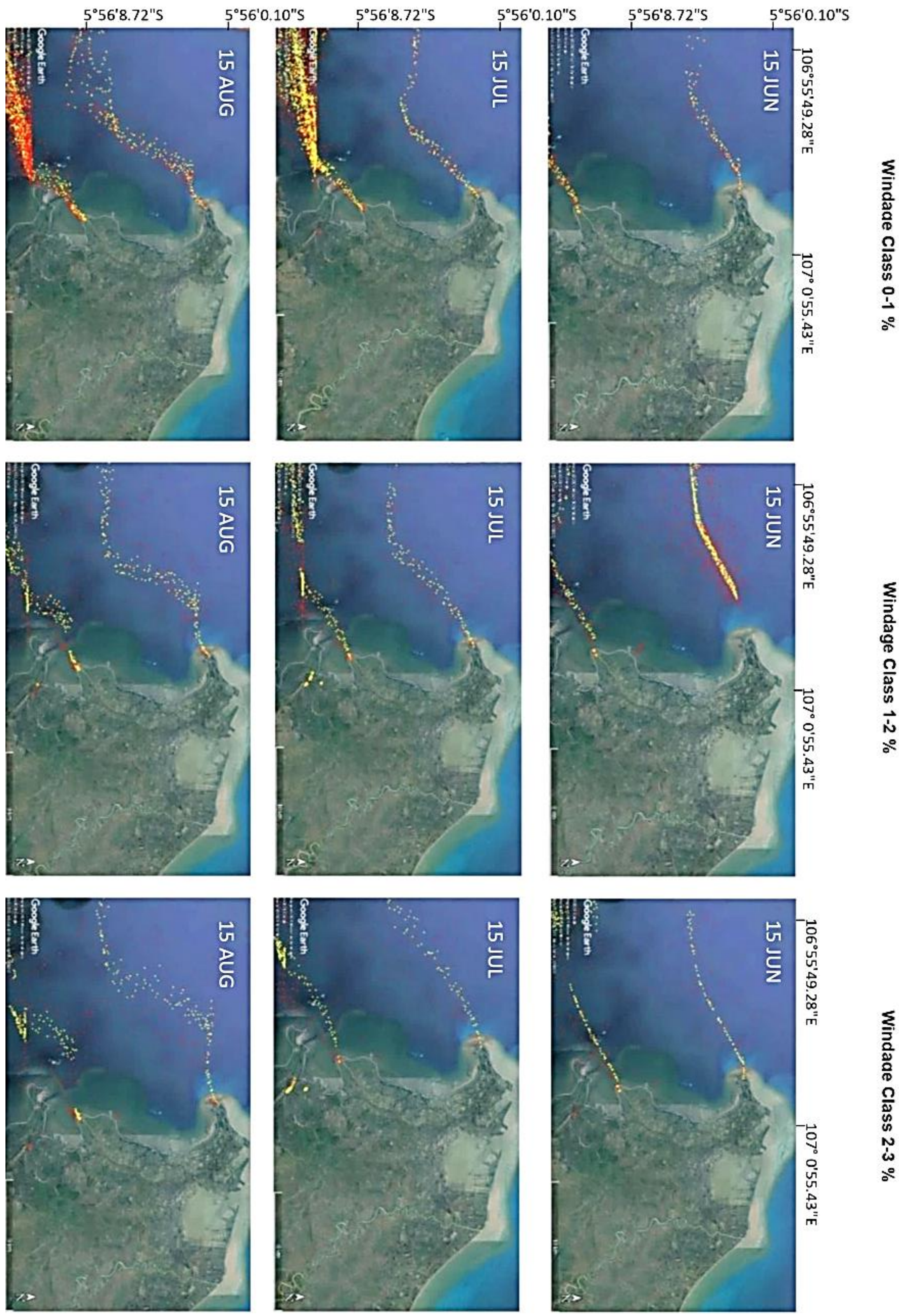

Figure 6. Debris patch during southeast monsoon. (red dot) best guest model, (red-cross) stranded marine debris, (green) debris' monthly movement

In December, waste was being washed up on the beach. GNOME predicted that all the MDs are stranded on the beach adjacent to the estuaries. No higher density of waste could be seen in the sea.

This situation is due to the tidal system in the waters of Jakarta Bay follows the contour of the land, which causes MD to flow along the beach. The same results were also obtained from previous studies, which stated that waste from the estuary of Jakarta Bay would move north and south according to the land contours [10]. In January, the waste moved further to the southern area, which caused a higher waste density compare to the January condition. In February, they moved further towards the Jakarta waters. It can be seen on the water surface near Jaya estuary.

The waste movement patterns for the three classes in SEM show something different from NWM. Generally, they moved towards the southwest. A small portion of the waste headed northwards, especially in the Jaya estuary (Fig. 6).

In windage class 0-1%, there is a difference in waste density in the waters between June and August. In June, waste from the two estuaries headed southwest. There was no visible difference in the amount of waste originating from Jaya estuary and Bendera estuary. However, debris from the southern estuary also moved to the DKI Jakarta province. In July, MD from Bendera estuary was more dispersed compared to the ones from Jaya estuary. The best guest analysis of the GNOME software also showed that most of them floated on water surfaces. Furthermore, in August, the waste distribution was similar to July but with an enormous amount in Muara Jaya than the previous month.

In windage class, 1-2%, the direction of the waste distribution looks the same as the 0-1% windage, moving towards the southwest. However, compared to the same month with lower windage, the waste distribution from Muara Jaya was greater. The same thing happened when compared to the waste from Bendera estuary. In July, there was less waste from the two estuaries compared to the previous month. There was a small amount of waste near the southern part of Muara Jaya. The same thing was obtained when compared to the previous class. In August, waste continued to flow towards the southwest with less density.

For windage class, 2-3%, MD (which consisted of heavier types) had the same pattern as the previous class. In June, waste from both estuaries headed southwest. In July and August, a small amount of debris was found in the southern part of Muara Jaya.

When compared to June and July, the MD movement in August was a little more curved. This can be seen more clearly in the 1-2% and 2-3% windage for waste originating from Jaya estuary. It happened due to the weakening of the eastern monsoon, where the wind turned around in the opposite direction. It also changed the direction of sea currents along with the coastal areas in Jakarta Bay.

4. CONCLUSION

This research has succeeded in mapping the MD trajectories that exit the estuaries. Some of the waste found in the estuary waters were intact, whereas others were not. They were generally found in boundaries between the estuary and the beach, the river and the mangrove ecosystem, and the sediments of the mangrove ecosystem. The oceanographic conditions that mainly influence the MD distribution in these waters are tides and winds. MD from both estuaries affects other waters, especially in Jakarta city. To better understand the spread of waste in Jakarta Bay, modelling with a more extended period is required to discover their patterns, especially during other monsoons.

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