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Physical Control on Marine Debris Spreading Around Muara Gembong, Jakarta Bay

Ibnu Faizal[1,2*], Noir Primadona Purba[1,2], Marine Kenzie Martasuganda[2], Amarif Abimanyu[2], Muhammad Royhand Akbar[3], Erik Sugianto[4]

[1] Department of Marine, Faculty of Fishery and Marine Science, Universitas Padjadjaran, Jl. Raya Bandung-Sumedang Km. 21, Jatinangor 45363, Indonesia

[2] Movement for the Ocean (MOCEAN) Foundation, Jl. Batununggal Indah Raya no. 199 Batununggal, Bandung 40267, Indonesia

[3] KOMITMEN Research Group, Universitas Padjadjaran, Jl. Raya Bandung-Sumedang Km. 21, Jatinangor 45363, Indonesia

[4] Department of Systems and Naval Mechatronic Engineering, National Cheng Kung University, Dasyue Rd, East District, Tainan City, 701, Taiwan

* Corresponding author’s e-mail: ibnu.faizal@unpad.ac.id

ABSTRACT

The Citarum River flows through different characteristic of terrestrials with 297 km length and become one of the largest rivers in West Java. It potentially transfers debris from land into the sea. This research aimed to define the Marine Debris (MD) trajectories based on seasonal monsoon. The method used was numerical analysis combined with artificial debris pathways. The simulation controlled by ocean currents, tide, wind pattern, and bathymetry conditions. The MD observations were conducted in four mouth of estuaries across the Muara Gembong areas. These simulations with specific time during two main monsoons (the northwest and southeast Monsoon) period. The results showed that the debris trajectory patterns vary in the two monsoons. The macro debris trajectory showed the waste patterns similar to oceanographic condition, especially the ocean currents pattern. The trajectories of waste from two estuaries flow towards the south and southwest follow the coastal contours. Specifically, in Northwest Monsoon, MD spread to the south and was stranded in the surrounding coast areas. In Southeast Monsoon, MD was forced to the central of Jakarta bay and surrounding islands in the western and southern side of the estuaries. Compared to the Bendera estuary, the MD that comes from Jaya estuary affects the surrounding areas, including in the northern side and southern side.

Keywords: Lagrangian analysis, ocean currents, marine litter, plastics, artificial debris.

INTRODUCTION

Marine debris, also known as marine waste or ocean garbage, is known as a global issue (Noir Purba et al., 2019). The debris that ended up in Indonesia seas does not only come from its territory, it is also originates from other surrounding countries (Purba et al., 2020). Furthermore, based on previous research, Indonesia had tripled in import tonnages of internationally traded waste (Hurley et al., 2020). Another fact stated that 80% of marine waste are generated from human activities on land, and only 20% comes from marine activities (Ondara & Dhiauddin, 2020). This case is expected to cause harmful effects for a system known for mismanagement of domestically produced solid waste (Lestari and Trihadiningrum, 2019). Indonesia’s vast coastline, large population, and a high proportion of unmanaged waste are the leading causes of large amounts of waste originating from land to the ocean (Cordova and Nurhati, 2019).

In Indonesia, the waste input sources mainly include rivers with several categorized in the rankings of polluted rivers (Lebreton et al., 2017).

This research focused on the one of the unique and complex rivers in Java island, near the capital of Indonesia. Muara Gembong, as its name, the estuary of the Citarum River is belong to Jakarta Bay and was known as a source of pollutant (Cavelle, 2013; Jasmin et al., 2019). Previous sampling stated that there were damages to the habitats that were destroyed by residential inorganic waste. This waste disposal affects biodiversity and causes changes in habitats for associated coastal and marine biota. The waste disposal distribution relies heavily on ocean currents, winds, object size, mangrove density, and the distance between the island to the nearest land (Ivonie et al., 2020).

The impact caused by marine debris is very complex, and due to the lack of data, it needs to be monitored. Several approaches through models have been used to predict the distribution direction (Eriksen et al., 2013; Purba et al., 2020) or source of marine debris (Handyman et al., 2019a; Van Sebille et al., 2012). This research focused on simulation of debris trajectory influenced by oceanographic parameters, such as ocean current and wind patterns. This model will carry out trajectory modelling to determine the sources and potential patterns of waste movement. The distribution of waste influences the estuary ecosystem, especially the mangroves in Muara Gembong.

MATERIAL AND METHODS

Data collecting

The Oceanographic data was collected from several sources, including wind, depth, ocean currents, tides, and coastline, which will be used to model the waste data with a modifiable weight (Table 1). From these data input, the waste distribution pattern is obtained by modeling. Furthermore, model validation also used tracking with Artificial Debris (Seaghost II), and it is carried out to obtain on-field waste distribution data in the water column (Kubota, 1994).

This research used an approach that considers oceanographic factors, i.e. wind movement patterns and ocean current direction, which are the main movement factors of marine debris. Oceanographic condition significantly influences the particle movement, including marine debris (Purba et al., 2021). The wind is a vector quantity that has a direction and a value. The same applies to ocean currents, and in this study, the authors focused on surface ocean currents that are directly in contact with the wind that becomes the driving force for the surface ocean currents.

Marine debris trajectory

This simulation used Particle Tracking (PT) modul to determine the movement particles in the marine environment. This technique uses the Lagrange discretionary method. The primary method behind particle trajectory is to transport particles based on the moving particles and add dispersion using a random run time. There are four Starting Points (SP) in the trajectory observation (Figure 1), i.e. 1 point in the north station, 2 points in the south and another one in the CBL River, which is based on the community's perception that one of the pollution sources comes from the river. The simulation of particle trajectories depends on the number of particles in the domain. In this case, MD is assumed float in the waters and forced from surface wind and tides as the main external physical forced.

The modeling was used to figure out the distribution direction and speed of the debris. The data required is U and V data of wind, tide, and ocean current, representing the three oceanographic factors divided into two seasons: Northwest Monsoon (February-March-April 2021) and Southeast Monsoon (June-July-August 2020). The model analysis includes the waste trajectory movement at the Four Starting Points (SP) in 4 water conditions, i.e. when the water is approaching high tide, during high tide, when water

Table 1. Data collection for debris trajectory

No.	Data	Data Range	Remarks
1.	Wind	Daily	ECMWF Copernicus Climate Data (https://cds.climate.copernicus.eu/)
2.	Ocean currents	Daily	CMEMS Copernicus Resources Marine (https://resources.marine.copernicus.eu/)
3.	Shorelines	Long/Lat	Indonesia Geospatial Agency (BIG)
4.	Land use	.shp	Indonesia Geospatial Agency (BIG)
5.	Sentinel 2-A raster image	.shp/.jpg	Europe Space Agency Copernicus (https://scihub.copernicus.eu/)

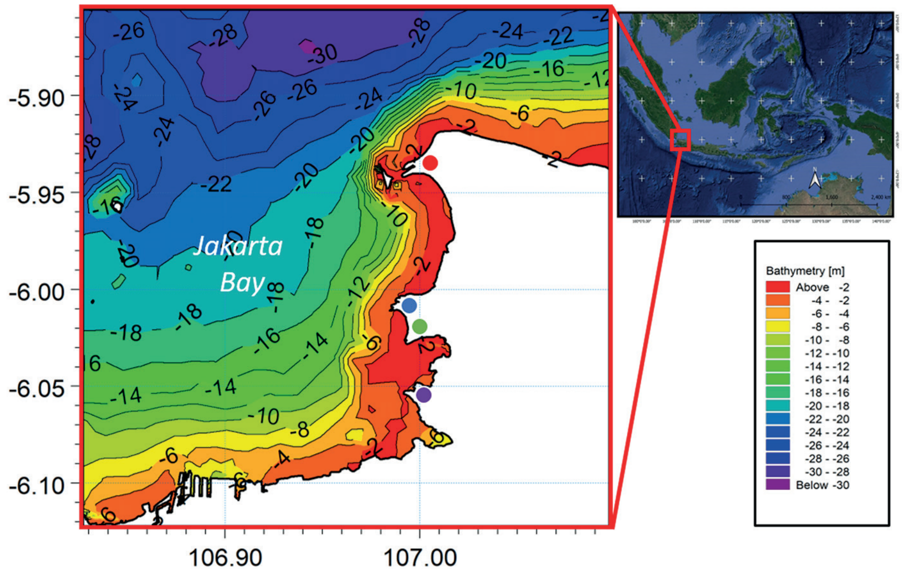

Figure 1. Marine Debris modelling area overlaid with bathymetry contour. Four dots represent the starting point of marine debris modeling, consisting of Bendera Estuary (Red), Kuntul Estuary (Blue), Jaya Estuary (Green), and CBL River (Purple)

is approaching low tide and during low tide. The trajectory results will be compared with the point of release from the FAD to determine the direction where the debris will move.

For model settings, the simulation using triangle mesh consists of 4,819 elements with 3,068 nodes. Time step using 3600 s interval with several settings using default mode, namely eddy viscosity (Smargorinsky formulation 0.28 m2s), No Coriolis force, No wave radiation, and standard flood and dry for shore. Verification of this simulation controlled by bed resistance was performed using various Chezy numbers (30, 32, 36, 44, and 50 m1/2/s).

Calibration was carried out to obtain the model results following the actual conditions. It was done by comparing the tide data (Mean Sea Level – MSL) from the simulation results of the Hydrodynamic model with the field observation data. The 7-day field observation data were compared with the model result data at the exact coordinates to see the error difference. Table 1 shows the comparison of the results of the water level validation and field observation data. The equation to obtain the error value is:

$$\text{Error} = \frac{1}{N}\left[\sum_{i=1}^{N}\left|\frac{\dot{X}_i - x_i}{\text{MSL}}\right|\right] * 100\% \qquad (1)$$

where: N – time step,
$\dot{X}_i$ – modeling data,
X_i – observation data,
MSL – mean sea level (observation).

The model setting used limiting factors in the north, west and east of the model area in the form of tidal data, followed by adding the wind factor in the same period as the tides. Another employed limiting factor was the river discharge from each estuary that entered the modeling area. Four estuaries had discharge values with the appropriate period. For debris particle, the model using 12.975 gr as minimum particle mass with maximum particle age by 1 year according to the previous study which has been done beforehand.

RESULTS

The simulation model was carried out for three months during the Southeast Monsoon and Northwest Monsoon cycles. The Southeast Monsoon period used was June-July-August (JJA) in 2020 and the Northwest Monsoon in February-March-April (FMA) of 2021. The purpose of selecting these two different seasons was to obtain a complete picture of the macro debris movement patterns around Muara Gembong.

Hydrodynamic conditions

From the validation results, it was found that the slightest error value is the model using the Chezy number 44, an error value of 4.356%. Therefore, for the hydrodynamic model, the Chezy number used is 44. Figure 2 shows the water level comparison from field observations to the simulation results with different Chezy Numbers.

The three-month ocean currents simulation in the research areas showed that the ocean currents pattern was dominated by tidal currents and the reversing currents due to its contours. On the basis of the hydrodynamic simulation results, it was also discovered that the type of tide in the research area was mixed tide with prevailing diurnal.

Figure 3 shows the ocean current pattern against elevation when approaching high tide. The velocity in each season ranged from 0.02–0.2 m/s with varying ocean current directions. The most dominant one was from the north to the south. The sea level elevation in this condition ranged 0.31 m from the Mean Sea Level (MSL).

The ocean currents velocity of the area around Muara Gembong during the maximum tide period ranged from 0.07–0.25 m/s, with direction still dominant from the north to the south. In the northernmost part of Muara Gembong, the ocean current direction was split to the east, influenced by land morphological factors. The sea level elevation in this condition equaled 0.33 m from the Mean Sea Level. This characteristic was formed by sea-level and wind, where the wind force could affect the direction of surface currents propagation. This condition was the phase where the ocean currents would reverse in the opposite direction depends on the type of tides.

The ocean currents pattern against elevation when heading for low tide showed that the velocity was around 0.03–0.25 m/s; the most dominant direction was from the south to the north. The sea level elevation under these conditions ranged from -0.20 to -0.23 m. There was a slight difference in ocean currents velocity in the two seasons where during the Southeast Monsoon, the ocean currents velocity in this area was higher. Figure 4 shows the ocean current pattern against elevation at low tide. The current velocity was around 0.19–0.25 m/s with the most dominant direction from the south to the north. The sea level elevation in this condition was -0.34 m. The current velocity in this area tends to be higher during the low tide than the high tide period in the two seasons.

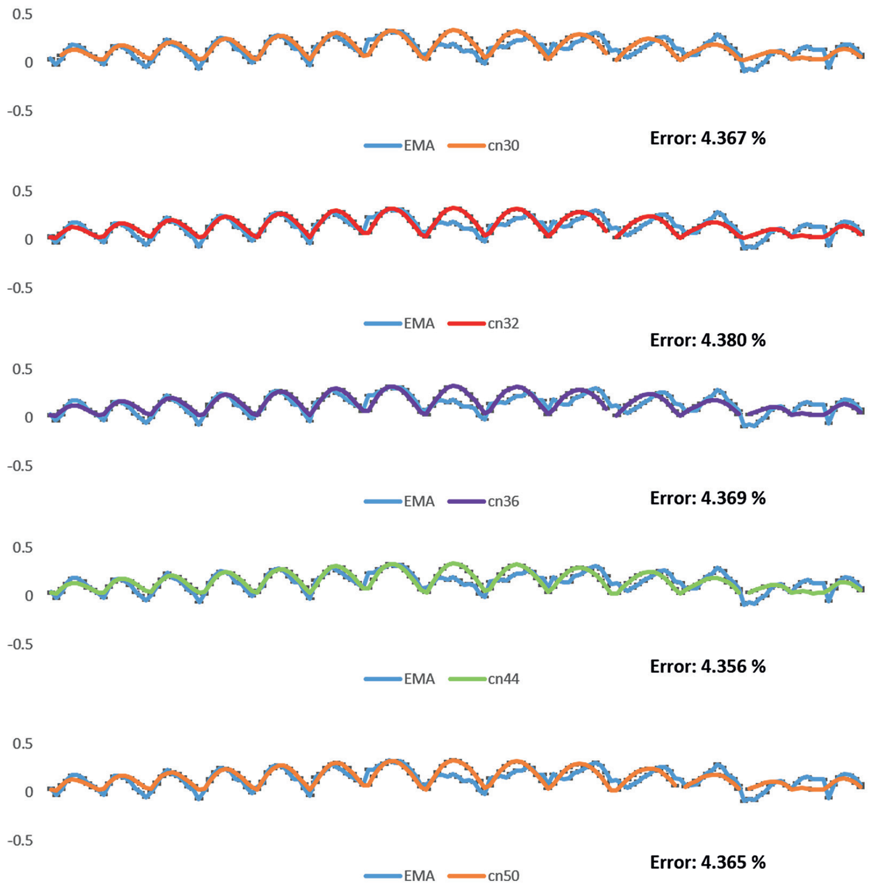

Figure 2. Comparison chart of tidal calibration with model results using different bed resistance (Chezy number) values

On the basis of the analysis of ocean currents patterns on sea level elevation under various conditions, it can be deduced in the Java Sea is a reversing current. The effect of tides on the ocean currents pattern around the Muara Gembong waters is quite significant, but the wind factors also affect them, because wind drag can change sea level elevation and affect the direction of ocean currents.

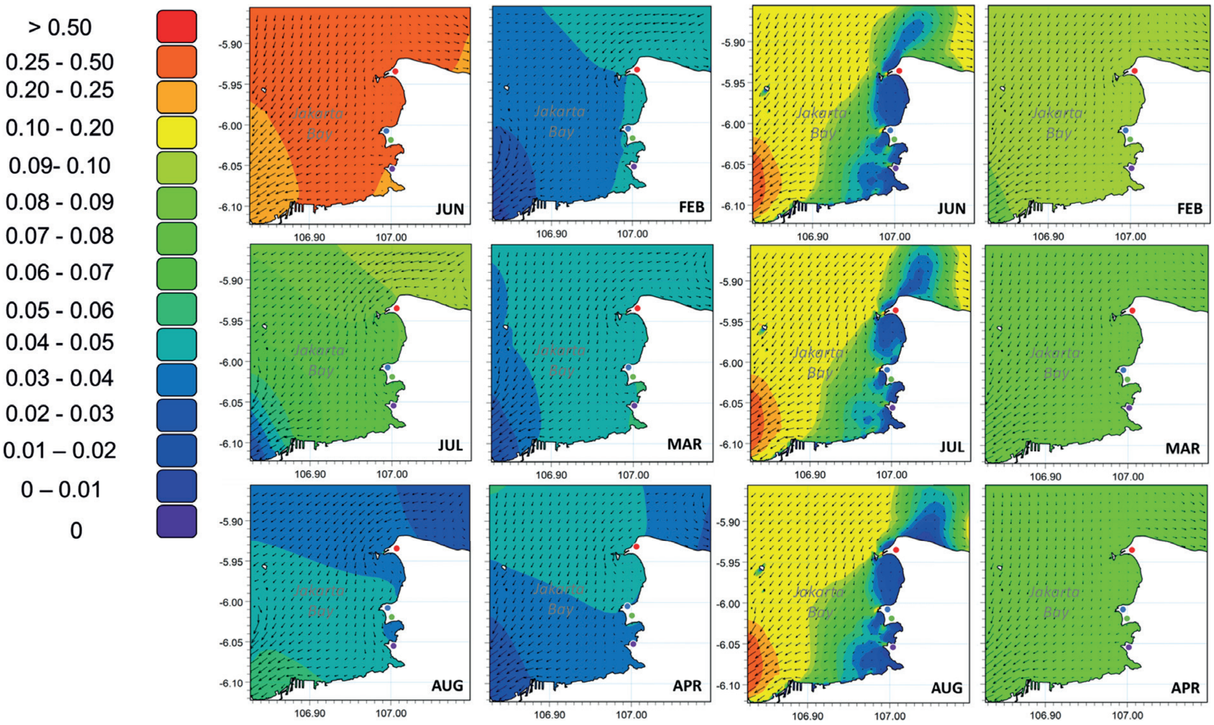

Figure 3. The conditions approaching tide (left) and high tide (right) in the Muara Gembong waters in the Southeast Monsoon (JJA) sand Northwest Monsoon (FMA) period

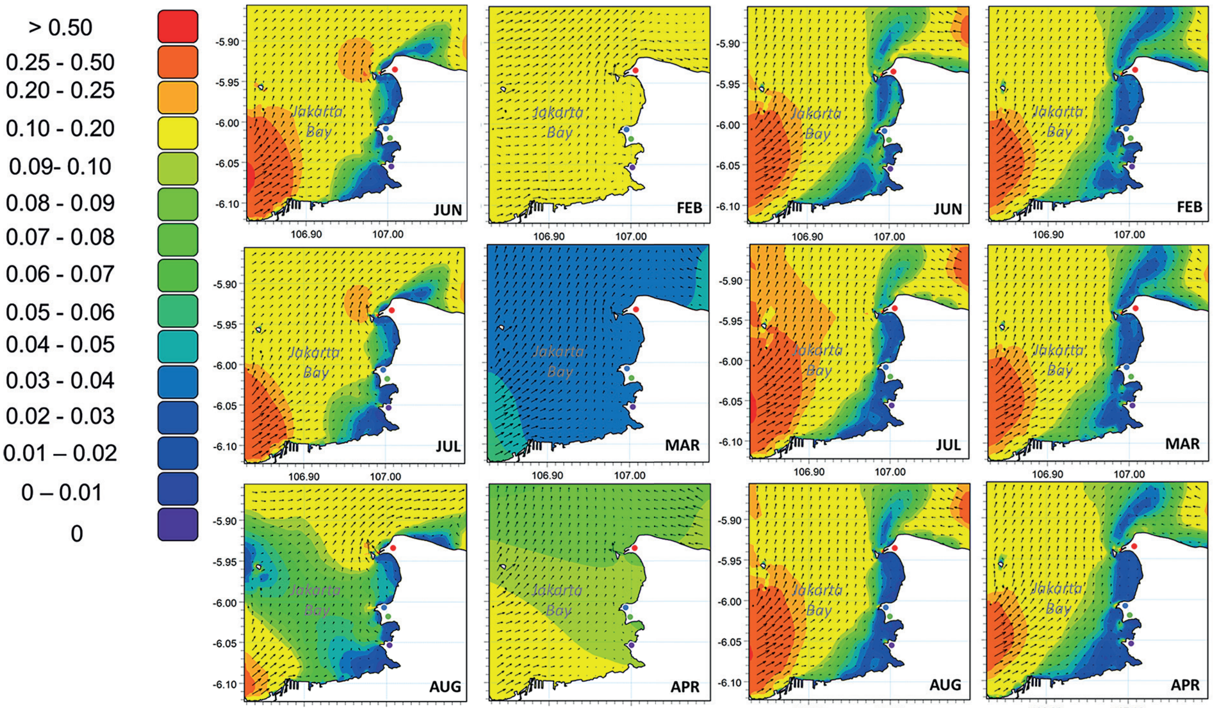

Figure 4. The conditions approaching low tide (left) and low tide (right) in the Muara Gembong waters in the Southeast Monsoon (JJA) and Northwest Monsoon (FMA) periods

Trajectory modeling

In this research, the method used to determine the macro debris movement was the Particle Tracking (PT) simulation. PT simulation was carried out for 30 days with the source scenario (Starting Point/SP). There were four Starting Points (SPs) consisting of the tip of the estuary in Muara Gembong Waters, i.e. Muara Bendera in the North, Muara Kuntul and Muara Jaya in the South, and the CBL River, which is located in the southernmost part of the other SPs. Another assumption used in this model was the degradation of macro debris through the marine oceanographic factors that intersect the Muara Gembong coast so that the trajectory modeling can be obtained, either coming from or going to the river towards the direction along the cycle and surface ocean currents movement of marine macro debris (Handyman et al., 2019b; Purba et al., 2018).

On the basis of the trajectory simulation results (Figure 5), the 30-day macro debris movement was influenced by alternating ocean currents movement in the Java Sea. The distance traveled by the particle differed from the particle displacement. The particle had moved away from the source but still returned to the point of origin.

In the Southeast Monsoon (JJA) Period, the position of the dominant particles moved to the west. This is presumably due to the influence of wind which strengthened the ocean currents to the west. On day 1, the macro debris moved away from the source towards the west. The macro debris then moved back and forth on the 7th day, when it had reached the central water column of Jakarta Bay, where tidal factors were dominant in the area. On the 15th and 30th day of the model, the macro debris movement had reached the coastal area of Jakarta Bay. This condition would continue to move westwards, following the dominant direction of ocean currents and winds where the macro debris would be 'trapped' around the Jakarta Bay.

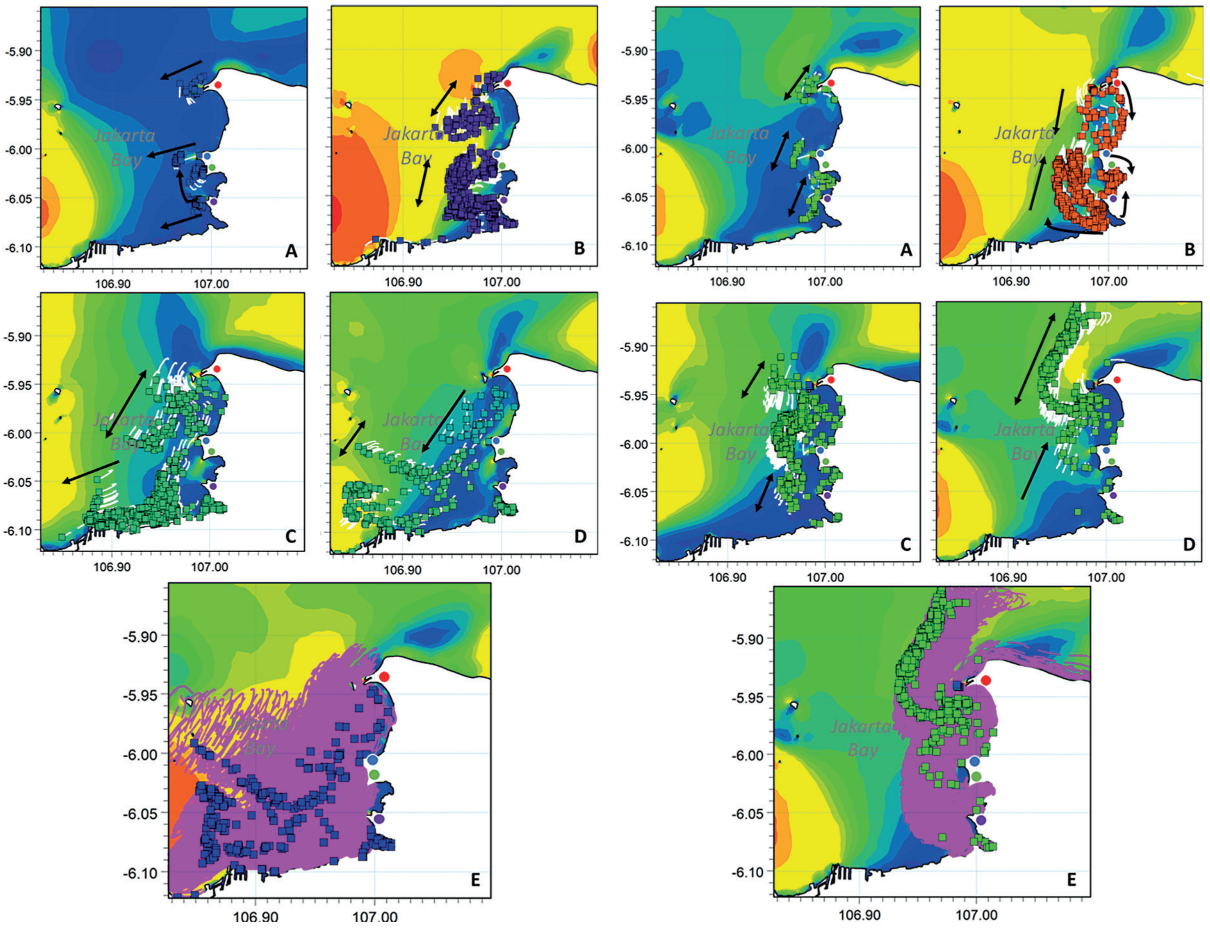

Figure 5. The condition of the macro debris movement in the Southeast Monsoon (JJA) Period (left) and Northwest Monsoon (FMA) period (right). (A) One day, (B) 7 days, (C) 15 days, (D) 30 days, and (E) Overall area of macro debris coverage

In the Northwest Monsoon Period (FMA), the position of the dominant particles moved to the North and East of the research area. On day 1, the macro debris moved away from the source to the east. There was a variation in a movement where the macro debris source from the north of SP1 moved to the south. While the macro debris source from the north of SP2, 3, 4 moved to the north. Therefore, there was an accumulation in the coastal part of Muara Gembong. On the 15th and 30th day of the model, the macro debris also moved back and forth, following the tidal movement pattern. This alternating movement would continue to move outward from the bay to the east by the dominant direction of ocean currents and winds where some of the macro debris would reach the coastal areas in the north but be more dominantly concentrated in the west coast part of Muara Gembong.

Model verification was done by comparing the motion pattern of the macro debris from the modeling results with the motion of the Sea-Ghost II, which was released at the same time. There was a typical movement pattern from the model results with the instruments shown in Figure 6.

The distance and coverage area of the macro debris displacement could be discovered from the model simulation results. In this research, the calculated distance was the source point and the point on day 1 of the model. Afterwards, the coverage area of the macro debris distribution from the modeling results of Table 2 was calculated. It shows the macro debris displacement in the model.

The waste collected around the area included the waste sent from other rivers along the way from upstream in Bandung and the waste sent from the direction of Jakarta via the sea. The results of the model show the macro debris movement in the Northwest Monsoon Period (February-March-April), which was indicated as the dominant waste movement towards the north, whereas in the Southeast Monsoon period (June-July-August), it was predominantly moving towards the west (Figure 3). The tidal conditions around the estuary were alternating currents; at high tide, the direction of the dominant current went to the south, while at low tide, the direction of the dominant ocean current went to the north (Figure 4). Furthermore, in previous studies, it was stated that due to the shift in land use for mangrove ecosystems in the coastal area of Muara Gembong, abrasion and floods often occur. The floods, in this case, were caused mainly by the tidal waves from the Citarum River.

The results of the macro debris trajectory showed waste patterns that were carried by the

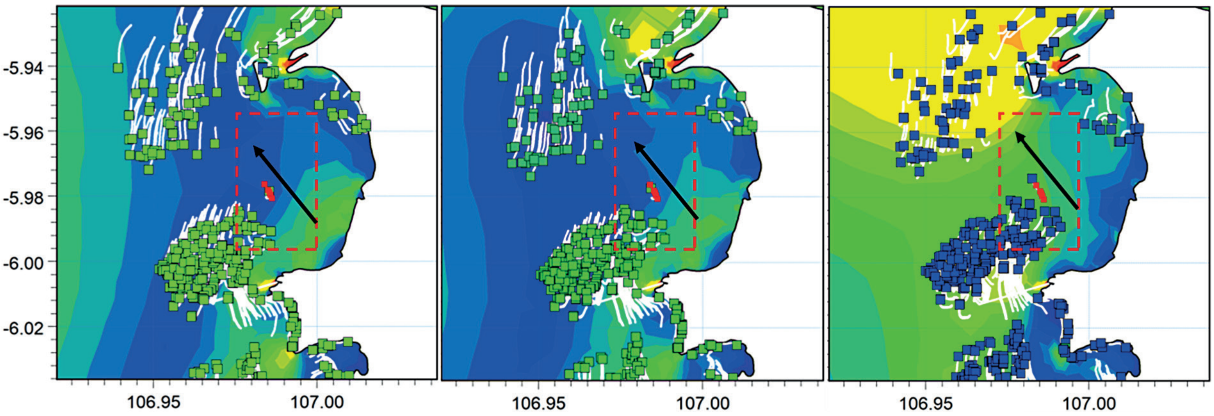

Figure 6. Macro debris modeling verification using Sea-Ghost II. The red dot is the coordinate of Sea-Ghost II, which is overlaid with the macro debris movement model results

Table 2. The results of macro debris particle displacement model

SP	Start Point		Distance (km)		Coverage area (km^2)	
	Longitude	Latitude	East Monsoon (JJA)	West Monsoon (FMA)	East Monsoon (JJA)	West Monsoon (FMA)
1	106.98894	-5.940952	8.23	5.27	251.7	187
2	106.987611	-6.006402	8.36	7.16		
3	106.991807	-6.027044	5.01	3.05		
4	106.991852	-6.051582	5.63	2.41		

ocean currents at the research location. This is related to the waste transport route around the Muara Gembong area. In addition, it could also be seen how garbage moves along the coastline. The model results showed that the macro debris would be stranded along the coastline which it passes, with the possibility to return to the water column, following the tidal pattern of seawater if it is not stuck on the coast/ land. This determining factor is related to the weight characteristics of the waste particle model and the morphology of the shoreline (Purba et al., 2021).

CONCLUSIONS

The identification of particle movements using a model, assuming that the waste in Muara Gembong was from river accumulations and shipped from Jakarta, was proven to be correct. The dominant particle movement pattern headed towards the north in the Northwest Monsoon and towards the west in the Southeast Monsoon. This shows that there is a possibility that the waste from the coast of Jakarta and its surroundings in Jakarta Bay move northward and become trapped in the mangrove area of Muara Gembong.

It should be noted that the accumulation of waste carried by each river has a significant effect on the waste stranded at the estuary. Further research is needed regarding the mass water transport route from upstream to downstream, followed by the research about the number and what treatments are carried out in the rivers along the way. There is also a need for research on the characteristics and types of vertical waste. Moreover, surveys and interviews are needed to the communities around the estuary, especially scavengers, about how they respond if there is an action to reduce waste at each branch of the river.

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