Potential Source Analysis of Macrobeadbris in Untung Java Island by Using Trajectory Particle Modelling

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Abstract. Untung Java is one of the small islands in Thousand islands. One of the most highlighted problems on this island is the accumulation of macrdebris that occurs in the coastal and mangrove ecosystems. The purpose of this study is to determine the most potential source point for distributing debris to Untung Java Island by using a hydrodynamic model and particle trajectory model of MIKE 21. The scenario of the simulation is using pre-reclamation condition in 1999 and 2019. The estuary in Jakarta Bay is illustrated as the starting point for debris transport. Five other estuaries as potential source assumption are selected, namely Cisadane, Citarum, Muara Angke, Ciliwung and Cikeas. The validation data model used tidal data from Intergovernmental Oceanographic Commission (IOC) Sea Level Monitoring by utilizing Root Mean Square Error (RMSE) method. The RMSE is calculated up to 0.49-12.78%. The tidal current of Jakarta Bay is simulated up to 0.015-0.375 m/s. The Cisadane estuary is the most potential source as a supplier of macrdebris to Untung Java Island due to its debris movement pattern and the nearest distance to the island.

Keywords: Untung Java Island, Macrdebris, Potential Source, Estuaries, Trajectory Particle Modelling

1. Introduction
Marine debris is material from the production or processing process that can no longer be used and enters the marine environment [1]. In general, based on the size marine debris is divided into 5 types, namely megadebris, macrdebris, mesodebris, microdebris and nanodebris. Macrdebris is debris with a size of > 2.5 – 1 m [2]. Macrdebris can sink to the bottom and float on the sea surface. The floating debris will be carried away by currents and winds, then accumulate on the coast [3]. Macrdebris has a positive correlation with population, where the higher the population in an area, the higher the amount of debris. However, at this time the problem of debris also appears on the coast of small islands with a relatively low population density.

Untung Java Island is one of the small islands located in the north part of Jakarta Bay. This island has a relatively low population of around 2547 people in 2020 [4]. Despite of this low population, the amount of debris in Untung Java Island is relatively high. Hence, macrdebris is one of the main problems in Untung Java Island [5]. Its location in the north part of Jakarta Bay causes the island of Untung Java to receive shipping debris from the mainland of Java [6]. Jakarta Bay is known as a coastal area that has a relatively high population density. The amount of debris produced every day reaches 5000 tons in Jakarta Bay [7]. As much as 10% of the debris generated will end up in the waters through the river. There are 13 estuaries that empties into Jakarta Bay. The Cisadane, Ciliwung, Angke, Cikeas and Citarum rivers are watershed areas with a high population density, making them asf the dirtiest estuaries in Jakarta Bay [9]. The estuary is the source point for the entry of debris into the waters of Jakarta Bay. There were 14 m³/day that entered Jakarta Bay from the river [8].

Research on the analysis potential sources of macrdebris is very important for overcoming the problem of debris in Untung Java Island. Moreover, Untung Java is famous as a place for tourism since it is relatively near Jakarta Bay compared to other islands in Thousand Island. Thus, the aim of this research is to analysis potential source point of macrdebris production from estuaries in contributing...
macrobeads in Untung Java Island by addressing oceanographic parameters. Optimistically, this research could prepare recommendation of mitigation action to reduce macrodebris in Untung Java Island.

2. Material and Method
The location of Untung Java Island and five estuaries (Cisadane, Muara Angke, Ciliwung, Cikeas, Citarum) is illustrated in Figure 1. The method used in this research is model simulations by using hydrodynamic and trajectory particles models DHI MIKE ZERO 21 software [10]. The particle trajectory model used is the Lagrarian method. Bathymetry data were taken from DIHIDROS 2012, tidal model data were selected from Prediction of Tidal Height (PTH) in DHI MIKE, winds data were collected from the European Center for Medium-Range Weather Forecasts (ECMWF) with resolution of 0.125°x 0.125°, and the streamflow data were picked from Balai Besar Wilayah Sungai (BBWS) [11]. The weight of macrodebris used is 4450 gram for material input.

![Research Map](image)

**Figure 1. Research Map**

Hydrodynamic modelling is performed to determine the direction and speed of currents in the domain area of Jakarta Bay. Trajectory particle modeling is carried out to determine potential sources of macrodebris. As mentioned above, five estuaries are selected as sources of macrodebris, namely the
Cisadane, Angke, Ciliwung, Cikeas and Citarum estuaries. The estuaries will be the first grid of the macrodebris movement model simulation. This model simulation considers only a pre-reclamation scenario in Jakarta Bay. Actually reclamation in Jakarta Bay started in April, 2019. But in this case, Simulation model in 1999 and 2019 using pre-reclamation condition before 2019, Simulation model of macrodebris tracking use Lagrarian method, simulation of macrodebris movement is carried out every month for one year. The simulation use continue point source for one year. Simulations were carried out in 1999 and 2019 in order to determine the differences in the movement patterns of macrodebris in Jakarta Bay after two decades.

The verification data of simulation output is using tidal data from Intergovernmental Oceanographic Commission IOC Sea Level Monitoring in Jakarta Kolinamil station of 2019, downloaded from http://ioc-sealevelmonitoring.org. The verification data is analysed by using Root Mean Square Error (RMSE) method to obtain the error value in tidal calibration using the following equation [12]:

\[
Error = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left| \frac{X_i' - X_i}{TP} \right|} \times 100
\]

Where Xi' is the data model, Xi is the field data, TP is value of tidal range, N is the amount of data.

3. Result and Discussion

3.1 Wind
Figure 2a. shows the average wind velocity and direction in Jakarta Bay during 1999. The average wind velocity ranges from 0.3 – 2.7 m/s. In 1999, the wind blew from various directions, with the dominant direction is from the northeast and southwest with a larger tendency than the other directions. The maximum wind speed is up to 2.7 m/s moves from the northeast.

Figure 2b exhibit the average wind velocity and direction in Jakarta Bay after two decades (2019). The average wind velocity ranges from 0.3-2.4 m/s. In 2019 the wind blows from all directions with major direction from the west and the most dominant direction from the southwest. The maximum wind speed is up to 2.4 m/s moves from the northeast.

![Figure 2. Wind Rose of Jakarta Bay in (a) 1999 (b) 2019](image-url)
The decreasing of wind speed in 2019 is most likely due to changes in construction and topography in Jakarta. Reclamation and housing settlement in Jakarta Bay has been developing up to 2019. This could have an impact on the wind velocity in the area [13].

3.2 Tidal
The tidal patterns in 1999 and 2019 display the similar results. Jakarta Bay has a single regular daily tide (diurnal) with a formzahl value of 3.5. This in line with the previous research with a formzahl range of 3.2 - 4.85 [14]. This type of tide means that there is one flood tide and one ebb tide in one day. Graphic 1 shown graphic tidal in 1999 and 2019. January tidal data represent the tides of the western season. July tidal data represent the tides of the east season.

![Graphic 1. Tidal of Jakarta Bay in (a) 1999 (b) 2019](image)

The seasonal tidal patterns in 1999 and 2019 indicate the west season the flood tide occurs at 12.00 – 03.00 or noon to morning. Meanwhile, the ebb occurs at 06.00 – 12.00. During the east season, the flood tide occurs starting from midday until the afternoon at 00.00 – 18.00. While ebb tide occurs from afternoon to morning at 18.00 – 06.00.

Tidal patterns are one of factors that affect the amount and distribution of makro debris in the ocean [15]. In flood tide conditions, marine debris will tend to accumulate on the coast, land and coastal ecosystems. Meanwhile, at ebb tide, marine debris will move away from the coast and land [16] to the middle of the ocean. So based on the tidal pattern of Jakarta Bay, it is diurnal. Then there will be a condition where the debris moves away from the beach and is distributed to the middle of the ocean, at ebb tide. And one time the debris came back closer to the mainland during flood tide conditions

3.3 Validation Data
Hydrodynamic and particle trajectory simulation input were run using some primary data such as bathymetry, shoreline, wind and tide from the mentioned above source data. Primary data validation is an important stage before conducting a simulation. In this simulation, tidal data validation will be carried out. Bathymetry and shoreline data are obtained from PUSHIDROSAL by a direct measurement. Thus,
no further validation is needed because it has been validated [17]. Wind model data from ECMWF has good accuracy, especially in the tropics [18]. Jakarta bay is located in Indonesia which is tropics region. The wind data interval used is 6 hours/day. Verification of the tidal model (PTH) data was carried out by using the calculation of RMSE. The tidal dynamic components used are K1, O1, M2 and S2. The tide data simulated was compared with field data from IOC Sea Level Monitoring at Kolinamil-2 Jakarta station with coordinates 106.89083 and -6.10667 in 2019. The RMSE is summarized in Table 1.

Table 1. RMSE Value of Tidal Data in 2019

| Month    | Error (%) |
|----------|-----------|
| January  | 12.78     |
| February | 1.08      |
| March    | 0.96      |
| April    | 0.96      |
| May      | 1.68      |
| June     | 1.08      |
| July     | 0.49      |
| August   | 1.16      |
| September| 0.79      |
| October  | 1.02      |
| November | 1.08      |
| December | 1.73      |

Table 1 shows the error values from January-December 2019. The error value ranges from 0.49 – 12.78% illustrates that the accuracy of the model can still be trusted. The highest error value is in January (12.78%) and the lowest error value is in July (0.49%). The RMSE value in January is the highest error value, this is probably because the IOC level monitoring tidal data in January is not very complete compared to other months. The hourly tide data during January is incomplete, so there are many fill gap which cause the error value to be higher. This value represents the error rate of the tidal model data with Kolinamil-2 is very low (average: 2.07%) and the accuracy level reaches 99.51%. The smaller the error value, the higher the level of accuracy [19]. When RMSE value closer to 0, the prediction result will be more accurate [20].

3.4 Ocean Current
Based on the results of the hydrodynamic simulation of DHI MIKE, ocean currents in Jakarta Bay are influenced by wind and tides. However, tides have the most dominant influence on ocean current patterns in Jakarta Bay, So Jakarta Bay has a tidal current pattern [21]. Tidal current is dominant current of bay [22]. This type of current shows a current that moves back and forth, meaning that the ebb tide current will have the opposite direction to the flood tide current. This confirms by [23] where Jakarta Bay as area of Java Sea exist with a tidal current pattern.

Figures 3 and 4 depicts the Jakarta Bay ocean current pattern in 1999 and 2019, respectively. During ebb tide, the ocean current moves to the east coast of Jakarta Bay (Figure 3a and 4a). Meanwhile, during flood tide, the ocean current moves to the west coast of Jakarta Bay (Figure 3b and 4b).
Moreover, Figure 3 confirms the average of ocean current velocity in Jakarta Bay ranging from 0.015 – 0.375 m/s in 1999. At high tide, the current velocity ranges from 0.025 – 0.375 m/s, while at ebb tide current ranges from 0.015-0.225 m/s. The maximum current velocity occurs when flood tide conditions in the western part of the Jakarta bay reach of 0.375 m/s. Flood tide currents have a higher average velocity compared to the low ebb tide currents. This is associated to the maximum wind velocity from northeast (Figure 2a). Hence, the wind increases the velocity of the ocean current during flood tide. In Figure 2a, for one year the wind from northeast has the highest wind speed. Because the direction of wind has same direction with flood tide current. So the wind friction will increase flood tide current.

Figure 3. Ocean Current in 1999 during (a) Flood tide (b) Ebb tide. Shade colour shows magnitude (m/s) and arrow shows direction.
In 2019 the ocean current velocity in Jakarta Bay is ranging between 0.025 – 0.325 m/s. This is align to the finding of [24] where the current velocity along Jakarta Bay was up to 0.2 – 0.3 m/s. At flood tide, the ocean current velocity ranges from 0.025 – 0.325 m/s, while at ebb tide the ocean current velocity ranges from 0.045-0.165 m/s. The maximum ocean current velocity is captured when flood tide conditions in the western part of the bay at about 0.325 m/s. A year simulation shows the ocean current is higher in the western and eastern parts of the bay compared to the other area during flood tide. This is due to the western and eastern most part of the bay location is nearby to one of the biggest estuaries, Cisadane and Citarum Estuary, respectively. It is known that Citarum estuary is a river with the highest water discharge in Jakarta Bay at 64.2 m$^3$/s [25]. This results in the flow of water close to the mouth of the river is higher than other areas.

In comparison, annual average ocean current velocity in 1999 was higher than in 2019. The maximum current in 1999 was up to 0.375 m/s, while in 2019 it was only at 0.325 m/s. As mentioned before, the decrease was due to the influence of the wind (Figure 2) where there was a decrease of wind velocity in
2019 compared to 1999. However, the pattern of ocean current during flood tide and ebb tide in 1999 and 2019 is remainin

3.5 Potential Source Analysis

![Figure 5](image_url)

**Figure 5.** Trajectory Particle of Macrobebris in (a) 1999 (b) 2019. Shaded colours shown average current speed Dot colours shown macro debris movement, Box colours shown potential accumulated area of macro debris.
Figure 5 affirms the movement of macrodebris particles during one year in 1999 and 2019 with macrodebris weight is 4450 gram. Simulation of macro debris movement is monthly for one years, with using countinue point source simulation. The macrodebris track in 1999 looks more complicated and longer than in 2019 (Figure 5a). The movement of debris from the source point to the last point looks robust. Whereas in 2019 the movement of debris is minor, where the debris tends to move only near point source. In 1999, debris originating from the Citarum estuary moves farthest with a displacement of 4779 m. Macrodebris from the Citarum estuary moves to the south of the bay, then accumulates on the south coast of the estuary (yellow box area). Macrodebris from the Cikeas estuary moves along 1918 m with the direction of movement to the south and then to the southeast, due to type of topography in the southeast is in the form of a basin, the debris is easily accumulated on the coast (brown box area). Most likely the movement of the debris slow and stuck in that area. The movement of macrodebris from the Cikeas estuary is the shortest movement compared to other estuaries. This is associated to the water discharge of the Cikeas estuary is smaller than the others (27.3 m3/s) [26]. Macrodebris from Ciliwung estuary moves to the northwest as far as 2247 m. Existence of a port in the western part of the Ciliwung result in the coastal topography in the western part is elongated. Thus, the movement of macrodebris from the Ciliwung estuary is blocked by the pier and accumulate the debris around the pier. The movement of the macrodebris will be hampered by the presence of a pier. Macrodebris from Angke moves to the northwest for 3521 m. Macrodebris from this estuary has a movement pattern towards northwest of the bay to the north and generate a high probability as a supplier of macrodebris in Untung Java Island. Macrodebris from the Cisadane estuary moves as far as 2220 m with a movement pattern towards north of the bay. As seen in Figure 5, annual pattern of debris movement in Cisadane estuary is in the form of a zigzag towards northwest and northeast direction. Since Cisadane estuary is the closest to Untung Java Island, it is determined as a potential source of debris suppliers in Untung Java Island. This is due to pattern of debris movement that continues to the north and contribute to the distribution of macrodebris to the coast of Untung Java Island.

In 2019 the average movement of debris at each source decrease compared to the previous decade with only 1983-4571 m the farthest. This is due to the factor of decreasing wind velocity and currents compared to two decades ago. The pattern of alternating currents in the Jakarta Bay contributes to the distribution of debris. A weaker ocean current result in a slower movement of debris by considering the debris could be trapped in the source area. Additionally, ebb tide currents are currents that carry debris away from the source. In 2019, the ebb tide current velocity around the estuary is only 0.015-0.060 m/s. This is weaker compared to ebb tide currents velocity around the estuary up to 0.075 to 0.210 m/s, in 1999. However, the pattern of debris movement at each stand almost similar in 1999 and 2019. In 2019, the movement of debris from the Citarum and Cikeas estuaries remains to the south, Angke estuaries to the northwest, and Cisadane estuaries to the north, except in Ciliwung estuary which moves eastward. The distance of debris movement can be seen in Table 2.
Table 2. Particle Moving

| Year | Source          | Start Point | Endpoint | Displacement (m) |
|------|-----------------|-------------|----------|------------------|
|      |                 | Longitude   | Latitude | Longitude | Latitude |         |
| 1999 | Cisadane Estuary| 106.676 E   | -6.011 S | 106.677 E | -5.991 S | 2220 m   |
|      | Angke Estuary   | 106.765 E   | -6.101 S | 106.740 E | -6.082 S | 3521 m   |
|      | Ciliwung Estuary| 106.827 E   | -6.117 S | 106.812 E | -6.103 S | 2274 m   |
|      | Cikeas Estuary  | 106.973 E   | -6.054 S | 106.981 E | -6.069 S | 2918 m   |
|      | Citarum Estuary | 107.014 E   | -5.966 S | 106.994 E | -6.004 S | 4779 m   |
| 2019 | Cisadane Estuary| 106.676 E   | -6.011 S | 106.680 E | -5.991 S | 2310 m   |
|      | Angke Estuary   | 106.765 E   | -6.101 S | 106.740 E | -6.083 S | 3540 m   |
|      | Ciliwung Estuary| 106.827 E   | -6.117 S | 106.844 E | -6.120 S | 1983 m   |
|      | Cikeas Estuary  | 106.973 E   | -6.054 S | 106.972 E | -6.083 S | 3164 m   |
|      | Citarum Estuary | 107.014 E   | -5.966 S | 106.977 E | -6.003 S | 4571 m   |

4. Conclusion
Tidal current in Jakarta Bay has an average velocity of 0.015 – 0.375 m/s in 1999 and 0.025-0.325 in 2019. This tidal current plays a role in contributing macrodebris movement in Jakarta Bay along to the water discharge from five estuaries of Cisadane, Angke, Ciliwung, Cikeas, and Citarum. Macrodebris in 1999 moved with a displacement of 1918 – 4479 m. While the movement of macrodebris in 2019 is between 345-898 m. Likewise, tidal is a major factor in determining the movement of macrodebris to Untung Java Island along to tidal current. The finding exhibits that Ciliwung and Cisadane are potential sources of debris supply to Untung Java Island. However, by judging from the result, Cisadane estuary is the most potential source as a supplier of macrodebris to Untung Java Island due to its debris movement pattern and the nearest distance to the island.

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