Marine Debris Tracking from River Discharge based on Hydrodynamic Simulation on Jakarta Bay

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Abstract. Marine debris pollution is one of the biggest problems that occur in coastal city in Indonesia without exception Jakarta. Those marine debris increase with the addition of the Jakarta population. The main source of marine debris came from 13 rivers that flow into Jakarta Bay. Estimated that around 487 tons/day plastic debris that mismanaged potentially flows into the rivers and ended into the Jakarta Bay. Tidal forcing and current mainly affect the hydrodynamic condition in Jakarta Bay that drive the marine debris spread out from river estuary. The marine debris movement follow the hydrodynamic pattern due to the nature of floating marine debris. The proposed Giant Sea Wall in Jakarta Bay also affected in hydrodynamic condition in Jakarta Bay. As a result, the movement pattern of the marine debris influenced due to complex hydrodynamic condition in Jakarta Bay.

1. Introduction

Plastic is a kind of goods package which are long lasting and hard to be decomposed. Those plastic were massively produced to fulfill the need for any goods package around the world. With the plastic characteristic that is not easy to be decomposes, mostly the unused plastics were become plastic waste that are mismanaged. Based on waste management, plastic waste was differentiated by two types, first is produced plastic waste and other one is mismanaged plastic waste [1]. These plastic wastes mainly are piled down at the temporary waste dump site while the unmanaged plastic wastes were thrown to random place in example river, sea, and other surrounding area.

The existing plastic waste on the ocean was found out firstly in 1970, and in the next 5 years, the plastic wastes were increased about 6.4 million tons around the world [2]. Those mismanaged plastic debris which polluted the oceans are accumulate with the other undecomposed waste such as Styrofoam, metal can, and fishing gears. Based on a research, Indonesia is the second biggest plastic waste producer in the world that contribute to increasing marine debris around 0.48 to 1.29 MMT/year [2]. There are 4
biggest marine debris producer river estuaries in Indonesia (Brantas, Solo, Serayu, and Progo river) that released plastic waste into oceans estimated $6.37 \times 10^4$ tons/year [3]. It is not surprising that all biggest producer marine debris river estuaries located in Java Island while the population in Java Island so dense and Java Island has a lot of rivers that transport the marine debris from the land to the oceans [4].

Jakarta is a capital city of Indonesia that become center of government activity, business, and other activities in Indonesia. With population density around 15,624 people/km2, Jakarta become the densest city in Indonesia [5]. This population density emerging several public problems for example economic prosperity, land use problem, and waste management. Those population density and public problems also affecting the neighbor’s city around Jakarta which are integrated into areas Jakarta Metropolitan City Jakarta-Bogor-Depok-Tangerang-Bekasi (Jabodetabek). With the population around 30 million, Metropolitan city Jakarta produces daily solid waste around 6000-7000 tons [6]. Estimated around 600-700 tons a day or 10% from daily waste total amount were transported into Jakarta Bay [7]. Around 8.32 $\pm$ 2.44 tons plastic debris are reached everyday into Jakarta Bay which is 8-16 times larger than global model estimation [8]. Those marine debris that reached into Jakarta Bay will be spread over due to hydrodynamic condition in Jakarta Bay. The alteration of hydrodynamic condition in Jakarta Bay due to seasonal condition also affecting the marine debris movement in Jakarta Bay. Moreover, the Giant Seawall (GSW) that proposed to protect the Jakarta city from flooding disaster will affect the hydrodynamic circulation in Jakarta Bay.

2. Methods

The hydrodynamic numerical model simulation was developed based on the previous Jakarta Bay hydrodynamic model by Surya et al (2019) [9]. The domain was reduced because the focus is to simulate the marine debris particle movement around 9 rivers discharges in Jakarta Bay.

2.1. Hydrodynamic Condition in Jakarta Bay

Jakarta bay is shallow waters with the bathymetry is less than 50 m. The major hydrodynamic force in the bay is tidal that generates surface current around 0.2 m/s with the highest current speed occurs at the bay mouth and river mouths. During the spring tides, the surface current direction mainly flows from east to west [9]. The ebb current speed had slightly larger than flood current speed due to river discharge. The tidal type in Jakarta Bay is diurnal type by calculating the Formzahl number (3.95) from the tide observation in Kolinlamil Station [9].

The proposed GSW in Jakarta Bay is to overcome the flooding disaster in Jakarta city especially in North Jakarta area. This project is part of National Capital Integrated Coastal Development [10]. The GSW construction project divided into three phases which included sea wall construction and beach protection, land reclamation, and long-term development around the GSW project. The GSW construction plan will majorly affect the hydrodynamic in Jakarta Bay. Figure 1 shows that the water level in Jakarta Bay largely impacted by the GSW.

Figure 1 Water level condition in Jakarta Bay, a) no GSW constructed, b) GSW constructed
2.2. Jakarta Bay Hydrodynamic Model Simulation

Hydrodynamic model simulation is developed using the finite-volume coastal ocean model (FVCOM). The FVCOM model grid is used for unstructured grid that have flexibility to adapt various topography and bathymetry condition. The finite volume and flexible mesh with 3D grid. The river discharge input data for hydrodynamic model simulation are tidal data, wind data, and river discharge data. The tidal data were applied in open boundary condition, while the wind data were applied in all model grid. The tidal data were applied in open boundary condition, while the wind data were applied in all model grid. The river discharge was applied in the specific river mouth location.

The model simulates the Jakarta Bay hydrodynamic condition start from 3-19 July 2015. First three days of simulation used for spinning up model and the rest day is the model result. The hydrodynamic model result used as generating for in marine debris particle tracking model.
2.3. Marine Debris Particle Tracking

The particle tracking numerical simulation also utilize the FVCOM module. Basic numerical particle module in FVCOM is Lagrangian particle tracking scheme in nonlinear system based on ordinary differential equation (ODE). The particle tracking equation (9) written in:

\[
\frac{dx}{dt} = V(x(t), t)
\]

(9)

Where \( x \) is the particle position at a time; \( \frac{dx}{dt} \) is rate of change of the particle position in time and \( V \) is velocity generated from the model.

3. Results and Discussion

The hydrodynamic model in Jakarta Bay was verified by comparing tidal field observation data in Kolinlamil Station with the water elevation from model. The tidal verification starts from 6th June 2015 until 19th June 2015. From the Figure 2 shows the water elevation model indicates the resemble pattern with the tidal observation. The root mean square error (RMSE) is 0.08 m. The skill value which introduced by Ma et al. indicates the disparity between simulation and observation result [13]. Skill value 1 indicates the perfect compliance between model and observation. The skill value in this verification result is 0.97. This value means, the tidal model shows fine similarity with the tidal observation.

**Figure 2** Data comparison result between tidal field observation and model result

Hydrodynamic model in Jakarta Bay shown in Figure 3. The water level during flood tide almost has similar height in all part of Jakarta Bay with the water height about 0.26 m. During the ebb tide, the water level in the eastern side of Jakarta Bay were higher than the western part with the height difference about 0.15 m. This tide model pattern shown similar result with the previous study which propagates westward in Java Sea [9].

The effect of GSW to the tidal pattern in Jakarta Bay shown in Figure 3 in the bottom figure. From the visual comparison with the hydrodynamic result without the existing of GSW shows that tidal pattern in Jakarta Bay highly affected by the GSW. The water basin inside the eagle island almost completely closed and only have a small gap to connect the basin to the outside sea. As a result, the water level inside the eagle island shows different tidal phase comparing with outside eagle island.

During the flood tide, the water level inside the eagle island significantly higher than water level outside the basin. The water level outside the eagle island has similar height with the normal water level condition without GSW. While the ebb tide occurs, the GSW amplify the water level outside the eagle area, especially on the eastern side near the Tanjung Priok port area. The water level become higher compares with the normal condition due to existing of artificial island. Inside the eagle island, the water level is lower comparing with the outside area. This phenomenon prevail due to the basin inside the eagle island is closed and only have small gap to connect the outside sea. So that, the tidal phase inside the eagle island was delayed compare outer side area.
Hydrodynamic model in Jakarta Bay also produced ocean current direction in the surface. The current direction during flood and ebb has uniform direction which moving from east to west. The differences only in the magnitude of the surface current. During the flood, the ocean current has higher magnitude (0.3 m/s) while in ebb the current magnitude about (0.15 m/s). The uniform current direction in Jakarta Bay mainly due to east monsoon which occurs during June-August.

Figure 3 Hydrodynamic condition in Jakarta Bay on the tidal spring condition. (Upper left) flood tide without GSW; (Upper right) ebb tide without GSW; (Bottom left) flood tide with GSW; (Bottom right) ebb tide with GSW.

Figure 4 Current direction and current magnitude on tidal spring condition. (Upper left) flood tide without GSW; (Upper right) ebb tide without GSW; (Bottom left) flood tide with GSW; (Bottom right) ebb tide with GSW.
The effect of GSW significantly impacted the current direction in Jakarta Bay. Similar with the tidal condition disruption, the current condition in Jakarta Bay is changed to the GSW. While the current magnitude is high during flood and ebb, the current magnitude inside the basin is unaffected by hydrodynamic condition outside of the basin. The closed basin inside the eagle island is the main reason the current magnitude inside the basin is unaffected by hydrodynamic condition outside the basin. The current fluctuation appears close to the gap on the eastern side of basin area which affected the current magnitude near the gap area.

Marine debris trajectory simulation also done using FVCOM particle tracking module. The simulation also took similar time frame with the hydrodynamic condition. The result of particle tracking simulation shown in Figure 5. The particle was released from 9 river mouth which disembody in Jakarta Bay. From the upper picture in Figure 5 shows the particle tracking simulation without GSW spread out to the offshore of Jakarta Bay. The particle tracking in eastern side able to move out from the coastal area while on the western side still accumulate around coastal area.

The particle tracking simulation with existing of GSW show remarkably distinctive result with the simulation without GSW. The existing of basin inside of eagle island and outside area differentiate the marine debris distribution base on particle tracking model result. With the existing GSW, the marine debris able to move further away from coastal area after 2 weeks simulation on the eastern side of Jakarta Bay. Several marine debris was trapped in the front of artificial island and stranded of. On the basin area inside of eagle island, the marine debris able to move up into the inside of the basin area. Several marine debris was blocked by artificial island which the island is exist in the front of the river mouth. As a result, the marine debris unable to move further away and accumulate around the river mouth area.

Figure 5 Marine debris trajectory simulation result from 9 main river mouth in Jakarta Bay (Upper left) Initial condition without GSW; (Upper right) End condition without GSW; (Bottom left) Initial condition with GSW; (Bottom right) End condition with GSW.
4. Conclusion

The hydrodynamic condition in Jakarta Bay is highly affected by the monsoon season in Indonesia which affected the tidal and current condition in Jakarta Bay. Those hydrodynamic condition explained by the model simulation result during the east monsoon season. The existence of Giant Sea Wall (GSW) will dramatically change the hydrodynamic pattern in Jakarta Bay. The hydrodynamic alteration could be change in current direction, current magnitude, as well as water level condition. GSW will divided Jakarta Bay into two different hydrodynamic condition which is inside the basin of eagle island and outside area of eagle island.

Particle tracking simulation in Jakarta Bay shows that the marine debris movement follows the hydrodynamic condition, especially tidal condition which mainly move the marine debris to northern direction. GSW will affect the marine debris movement in Jakarta Bay, such as the accumulation and stranded place of marine debris and spreading into farther distance from the coastal area. In the future, the existence of GSW may result the problem of sedimentation near the coastal area.

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