

Particle Tracking Model Approach for Analyzing Crude Oil Spill (*Palm Fatty Acid Distillate*) in Bayur Bay Based on Navier Stokes Discrete

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Abstract

Oil spilled in the marine ecosystem may be induced by some sources which alter over time and location. Oil leakage from offshore oil drilling, underwater oil pipeline leakage, etc., are the possible source of oil spill pollution. Marine pollution generated by oil spilling occurred in Padang City in 2017. Palm Fatty Acid Distillate (PFAD) spilled within Bayur Bay Harbor due to a leaking storage tank. As much as 50 tons of PFAD overflowed and commenced to pollute Bayur coastal bay. This study aimed to determine the distribution pattern of oil spills throughout the Bayur Bay based on a hydrodynamical model. We employed some oceanographic data and PFAD characteristics obtained directly from survey results. We simulated the particle tracking model for 30 days since the PFAD spilled within the port. The model developed applied the Least Square method to analyze tidal data and a flexible mesh as a model basis, while the governing equation used is Navier Stoke discrete. During a month of simulation, the dominant particles' distribution is still spinning around the Bayur Bay due to the weak current characteristics with the magnitude ranging from 0.02-0.06 m/s. The lighter PFAD particle mass tended to move faster throughout the bay and settled in the coastal area. It will pollute the coastal system even though it is going to be decomposed chemically in the sediment.

Keywords: Particle tracking, PFAD, Bayur Bay, Navier Stokes discrete

INTRODUCTION

Padang City is a coastline city located within West Sumatra Province. The biggest harbor in Padang City is tremendously essential to support goods distribution, marine transportation, and fisheries interest. It tends to be threatened by pollution such as oil spills yielded from port activities in the surrounding port area.

Oil spills in the ocean can result from various sources, namely permanent sources and instantaneous sources that are not always available. Some oil spill may source from oil leakage from offshore oil drilling, underwater oil pipeline leaks (Putri *et al.*, 2017), oil tank leakage, tanker accidents, natural seepage from the seabed (Gemilang *et al.*, 2017), regular operation of tankers and bursts from offshore production and exploration, runoff from land and rivers and also the atmosphere (Mukhtasor, 2007). When oil overflows into the sea, it will be transported by the current and gradually dispersed and degraded by decomposers (Hermana, 2003). Pollution in the

marine environment due to the oil spill in Padang City in 2017 confirmed that palm fatty acid distillate (PFAD) overflowed within Bayur Bay Waters (Figure 1) resulted from a storage tank provenance leaking.

This event happened on September 28th, 2017, which caused oil-logging within the Bayur Bay port area (Figure 2). As much as 50 tons of PAFD were released, directly impacting community activities in the surrounding Bayur Bay. Communities who commonly work as fishers had affected whereby, they could not go fishing because chunks of PFAD covered the sea surface. This state dramatically impacts the community around the coast, which will also endanger the local ecosystem (Ondara *et al.*, 2018).

As Padang City is coterminous by seawater, several marine pollution reports were published, such as in Batang Arau's watershed, the accumulation of garbage with the low dissolved oxygen concentration identified not suitable for biota, had studied by Erliza *et al.* (2019). Putri

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(2010) surveyed the declination of water quality around the Batang Arau estuary. Anggraini and Puryanti (2019) defined the heavy metal contaminations within Bayur Bay Port. In contrast, Oil pollution-related studies have not been reported. One of the best ways to determine the pattern of oil spill pollution is by applying a hydrodynamic simulation to predict and distribute PFAD chunk transported by a tidal current within Bayur Bay. Moreover, it is essential to depict better when a field survey could not cover the Bayur coastal bay's whole area. This research aims to determine the oil spill distribution pattern (PFAD)

for 30 days of simulation using a numerical-based particle tracking model.

MATERIAL AND METHOD

Governing Equation

A complete equation of motion for viscous fluid elements in a gravitational field is the Navier Stokes equation, a differential form of Newton's second law of motion. The Navier Stokes equation states that the change in momentum of fluid particles depends only on the internal viscous force and the viscous external pressure acting on the fluid (Handayani *et al.*, 2016).



Figure 1. Evidence of PFAD chunk settled in the coastal area of Bayur Bay (Source: Site survey, 2017)

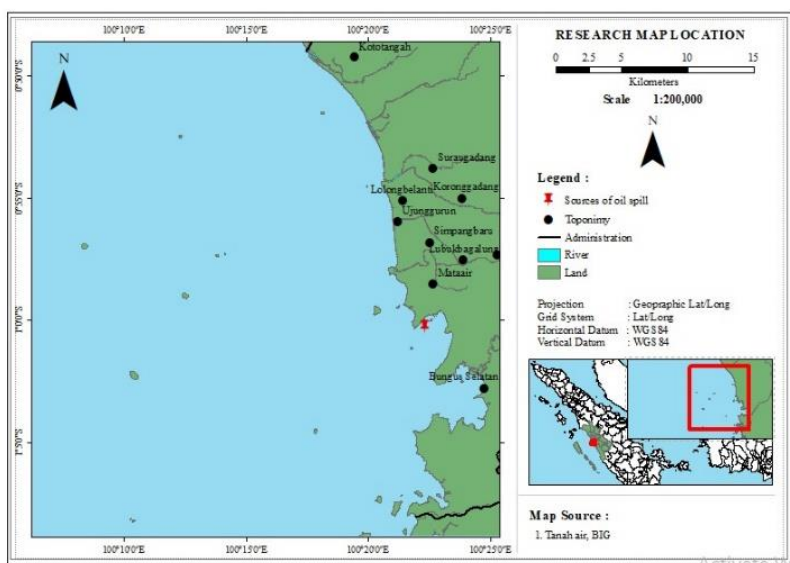


Figure 2. The source of PFAD spill and the study area

Therefore, the Navier Stokes equation explains the equilibrium of the forces acting on the fluid. The Navier-Stokes equation's differentiation is solved by substituting the normal stress, and shear stresses on the forces acting on the fluid element wherein the results are substituted in kinematic continuity and viscosity equations so that the Navier-Stokes equation is obtained for the thickness of the momentum (Rozanova, 2008). Thus, this model consists of continuity and momentum equations. In the two-dimensional cartesian coordinates, the movement of ocean currents can be described as follows:

$$\text{Continuity Equation: } \frac{\partial \zeta}{\partial t} + \frac{\partial(\bar{u}h)}{\partial x} + \frac{\partial(\bar{v}h)}{\partial y} = 0$$

The momentum equation of the x and y directions:

$$x \text{ dir: } \frac{\partial}{\partial t} + \bar{u} \frac{\partial \bar{u}}{\partial x} + \bar{v} \frac{\partial \bar{u}}{\partial y} = -g \frac{\partial \zeta}{\partial x} + \frac{-\tau_{bx}}{\rho h} + A_h \left(\frac{\partial^2 \bar{u}}{\partial x^2} + \frac{\partial^2 \bar{u}}{\partial y^2} \right)$$

$$y \text{ dir: } \frac{\partial \bar{v}}{\partial t} + \bar{u} \frac{\partial \bar{v}}{\partial x} + \bar{v} \frac{\partial \bar{v}}{\partial y} = -g \frac{\partial \zeta}{\partial y} + \frac{-\tau_{by}}{\rho h} + A_h \left(\frac{\partial^2 \bar{v}}{\partial x^2} + \frac{\partial^2 \bar{v}}{\partial y^2} \right)$$

We used those two equations to a developed numerical model associated with MIKE 21 software. MIKE 21 is a professional engineering software that contains a comprehensive modeling system for computer programs for 2D free-surface flow that uses the basic Navier-Stokes Equation. This application can model hydraulic simulations and related phenomena in rivers, lakes, bays, beaches, and seas (Shrestha *et al.*, 2020; Symonds *et al.*, 2017). In this case, we simulated the hydrodynamic flow model first. Then we continued to the particle tracking model, which the results from the flow model will apply as an input in the particle tracking stage.

Hydrodynamic and Particle Tracking Simulation

Before we run a model, it is necessary to build a mesh boundary of the modeled area, consisting of bathymetry data, coastline digitation, and boundary conditions. We used a bathymetry map established by the Indonesian Navy with a correction in 2011. The land boundary applied within the meshing stage is a coastline vector data digitized from Google Earth. Furthermore, we decided only one sea boundary located in the

eastern of the study area. Those data have a role as input materials for hydrodynamic and particle tracking models. The model set-up is shown in Table 1.

Oil spill simulation (particle tracking) modeled for 30 days (28 September 2017 - 28 October 2017). We set only one source at 100,372 BT and 1,005 LS with five particle mass categories (0.01 mg, 10 mg, 10 g, 100 g, and 500 g). we predicted and analyzed tidal data using the Least Square method. Tidal and bathymetry data are the significant parameters for generating a flow model (Kusumawati *et al.*, 2015; Ondara and Husrin, 2018).

Table 1. Input parameter for particle tracking simulation

Parameter	Format data
Area	Projection = longitude/latitude Minimum depth = -0.1 m Datum shift = 0 m
Time	Number of time steps = 744 Time step interval = 3600 s Simulation start date = 28/09/2017 00:00:00 Simulation end date = 28/10/2017 00:00:00
Flood and dry	Drying depth = 0.005 m Wetting depth = 0.05 m
Eddy Viscosity	Eddy type = Smagorinski formulation Format = constant value = 0.28
Bed resistance	Resistance type = Manning number Format = constant Value = 32 m ^{1/3} /s
Wind Forcing	Type = Varying in time, constant in domain Neutral pressure = 1013 hPa Soft start interval = 0 s
Surface elevation	Hight tide = 0.709 m Low tide = -0.5418 m Mean sea level = 0.0053 m
Domain	Format = Varying in time, constant in domain Time series = Long: 100.11013; Lat: -1.01612

RESULTS AND DISCUSSION

Bathymetry and Tidal profile in Padang Waters

The bathymetry profile distribution ranges from 0 - 400 meters (27 km to the sea) (Figure 3). Bordered by the Indian Ocean, it induces bathymetry degradation toward the coastline (Tanto *et al.*, 2016). A water area that faces directly to the open sea will influence the seafloor's irregular relief and the steep slope's shape, resulting in a drastic slope. The coastal area of West Sumatra has a unique topography, consisting of headlands, bays, and several isles (Sugianto and Agus, 2012). The bed morphology will have a role in determining ocean waves' propagation toward the coastal area, which eventually determines longshore current patterns (Wisha *et al.*, 2019).

Model Validation and Particle Tracking Results

During the spring high tidal condition, the sea level rose around 0.709 meters. In contrast, at the time of a spring low tidal condition, the sea level decreased about -0,541 meters. Thus, we can gain a tidal range during the spring phase of 1.25 meters. We compared the surface elevation data from flow model hydrodynamics and BMKG tidal data to validate the simulation results. The Root Mean Square Error (RMSE) value was 2.47. It shows that the model developed can represent the natural characteristics of oceanographic parameters.

Figure 4 illustrates the significant tidal elevation for 30 days tidal data analyzed using a Least Square. We obtained the value of HWS (Highest Water Spring) 0.709 m, MHWS (Mean High Water Spring) 0.621 m, MHWL (Mean High Water Level) 0.352 m, MSL (Mean Sea Level)

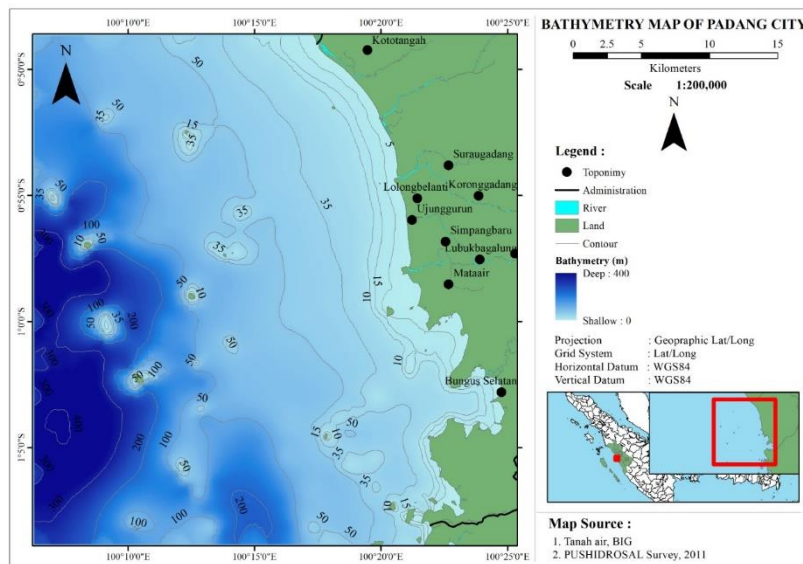


Figure 3. Bathymetry map of Padang City coastal area

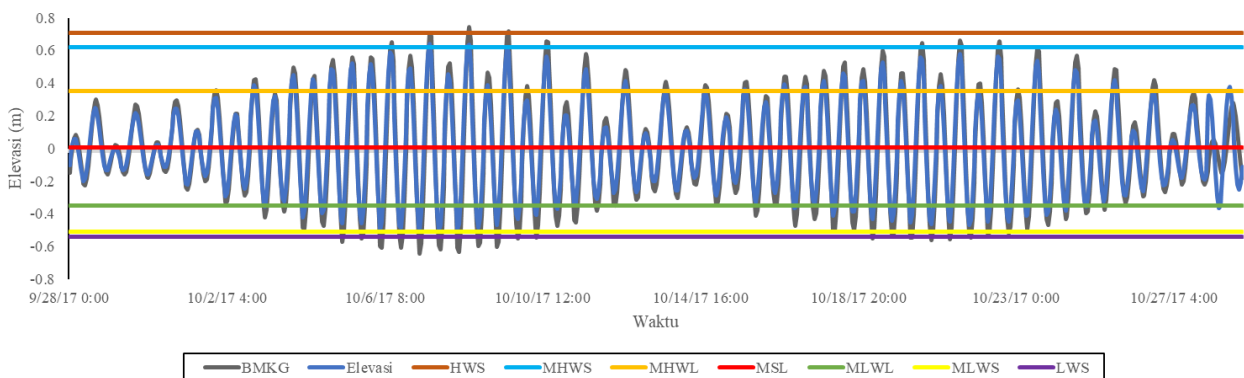


Figure 4. Tidal graphics on September,28 2017 – Oktober,28 2017

0.005 m, MLWL (Mean Low Water Level) -0.347 m, MLWS (Mean Low Water Spring) -0.510 m, LWS (Lowest Water Spring) -0.541 m. From the tidal constituent analysis, we found that the Formzahl number (F) of 0.2875 means that the tidal type of Bayur Bay is mixed tide prevailing semi-diurnal. Several previous studies showed the same result (Sidabutar *et al.*, 2016; Solihuddin, 2011; Sugianto and Agus, 2012). The tidal fluctuation will induce a tidal current pattern in which its magnitude and direction are depending on the tidal conditions. During spring tidal conditions, the current speed will be higher than current features during the neap one (Wisha *et al.*, 2016). Thus, the transport mechanism should be more extensive in the spring phase.

The dynamic movement of oil spill particles on the first day is shown in Figure 5. The

pattern showed sampled from time step on September 28, 2017, at 09.00 until 16.00 Western Indonesian Time. The tidal condition was low spring tide with a maximum current speed of 0.06 m/s. Over 9 hours, chunk particles' distribution pattern was slightly moving, which tend to distribute eastward. The dominant particles moved consecutively toward east and west from their provenance. However, the westerly particles were more diffuse than the easterly ones. This state shows the significant influence of surface currents (Purba *et al.*, 2019).

Figure 6 shows the movement of chunk particles over 16 days of simulation. It sampled from October 12, 2017, at 09.00 WIB (flood tide) and 15.00 WIB (ebb tide). The maximum current speed within the Bayur Bay ranged from 0.02-0.04 m/s. Current velocity tended to be weak toward the

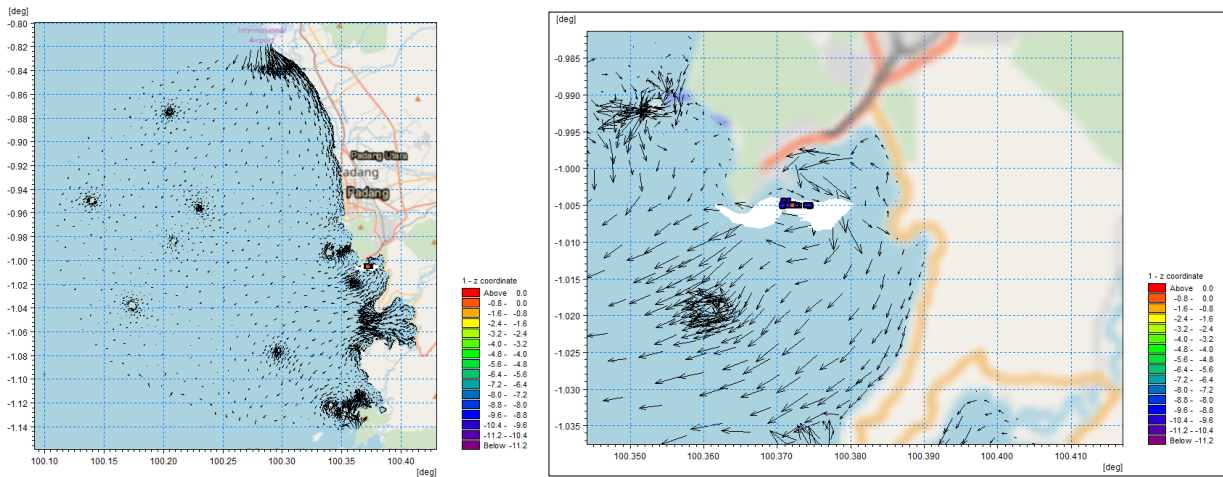


Figure 5. Movement of oil spill particles on September 28th, 2017

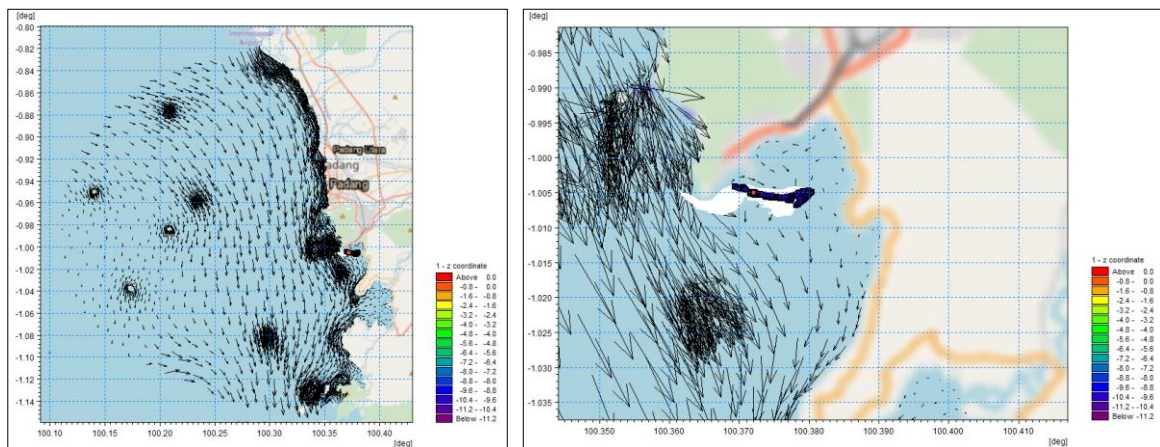


Figure 6. Movement of oil spill particles on October 12th, 2017 (Spring low tidal condition)

land area. The movement of the longshore current was dominant, moving from north to south. The westerly current will turn northward when passing through isles in the surrounding Bayur Bay. The water motions tend to circulate within the bay.

Figure 7 shown after 353 hours since the simulation has started, chunk particles of PFAD tended to move eastward then turned over the southwest. However, the pattern of particles was not significantly different from the first 16-hour simulation. This state creates an assumption that due to the insignificant difference of tidal current pattern. It will cause the chunk particle to circulate its provenance (Ondara *et al.*, 2018). During the spring tidal condition, the northerly current entering the bay moved toward the east and southeast when passing through the headland. It

shows the diffraction effect that will cause oil chunk accumulation behind the headland. The particles tend to follow the current pattern formed within the bay. These accumulations will pollute the coastal area and disrupt the coastal ecosystem nearby (Putra *et al.*, 2020).

Figure 8 shows the pattern of oil chunk particles on October 28, 2017, at 09.00 WIB (flood tide) up to 15.00 WIB (ebb tide). The sea level was ranging from -0.1- 0.2 m during the ebb and flood tide, respectively. The current speed ranged from 0.02-0.1 m/s. The southerly current tended to move landward with low magnitudes. The current speed gradually weakened within the bay. According to Wisha *et al.* (2016), the tidal current that moves toward the land inside the bay will rotate parallelly along the coastline until it moves without the bay.

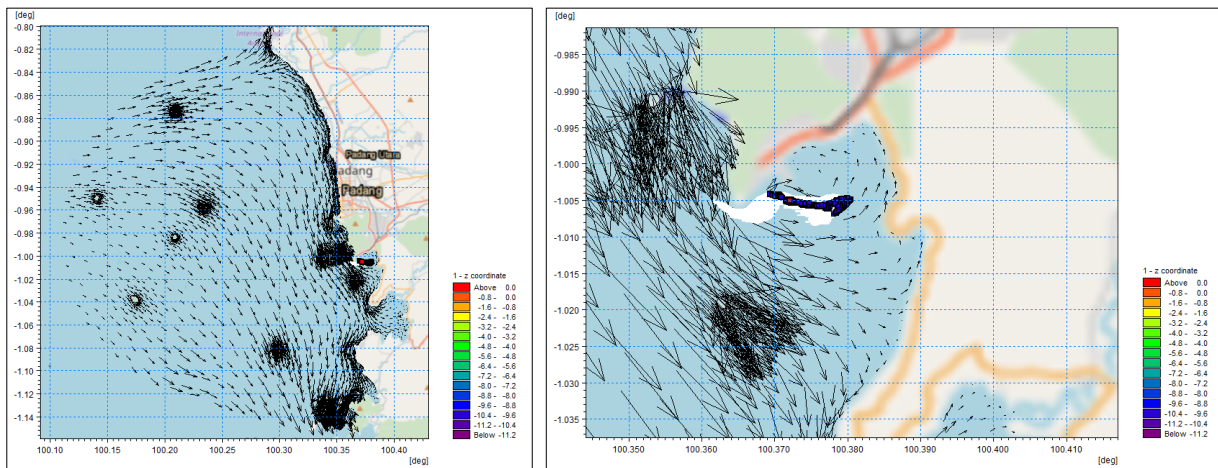


Figure 7. Movement of oil spill particles on October 12th, 2017 (Spring high tidal condition)

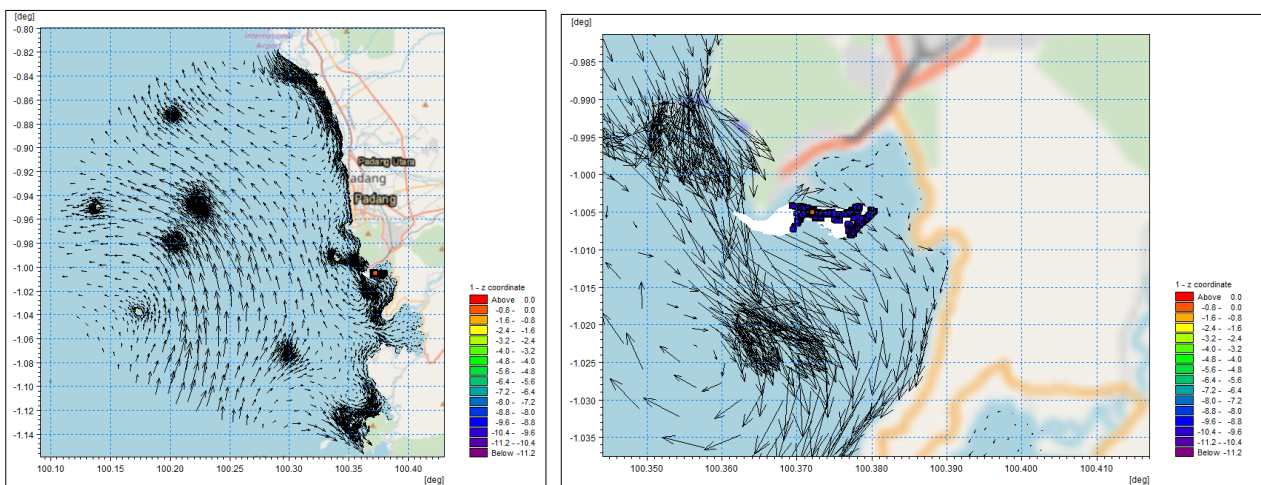


Figure 8. Movement of oil spill particles on October 28th, 2017 (Spring low tidal condition)

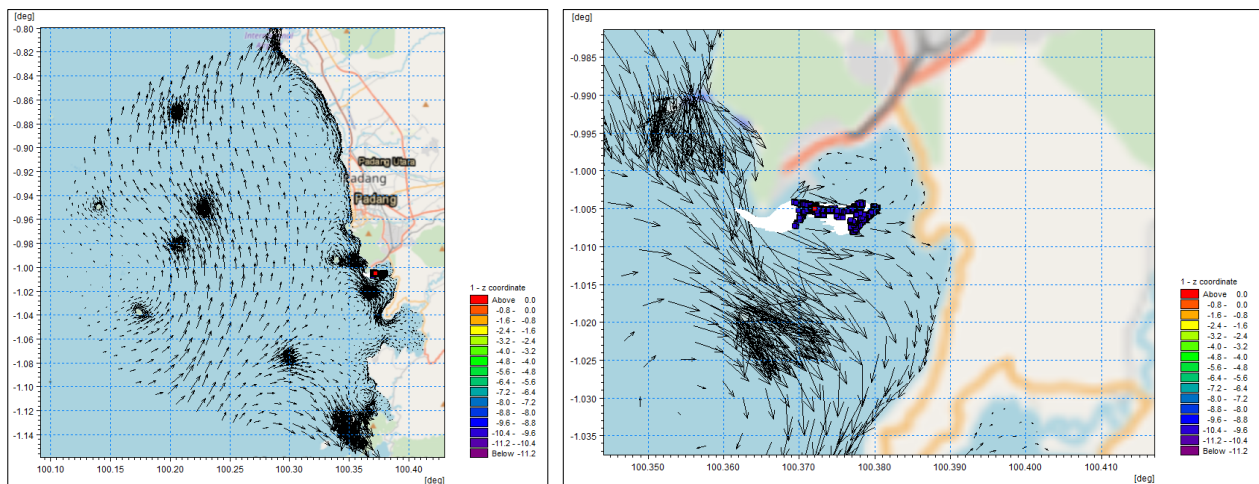


Figure 9. Movement of oil spill particles on October 28th, 2017 (Spring high tidal condition)

Of 7 hours of tidal displacement on 28 October 2017 at 09.00 and 16.00 Western Indonesian Time, we found the more erratic pattern of oil chunk particle movements (Figure 9). However, the dominant direction was still towards the east. Oil chunk particles that move eastward then distributed southwestward and northeastward. Moreover, sometimes, the particles also move toward the west and southwest. The same with the previous state, the pattern of chunk movement was not too significant compared to the last conditions.

CONCLUSIONS

The distribution of Palm Fatty Acid Distillate (PFAD) tends to be spinning around its provenance. During a month of simulation, a particle's movement is not too significant induced a current weakened profile within the semi-enclosed water area. The particles dominantly moved eastward within the bay which the chunk of PFAD also diffracted behind the land and induced a large amount of crude oil chunk accumulation in the coastal area. This condition will disrupt the coastal ecosystem and endanger biota survival ability.

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