Spatial Distribution of Pollutant Distribution in Jakarta Bay from Hydrodynamic-2D Transport Coupled Model

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Abstract: Being a center of marine activities such as shipping and fishing which are accompanied by massive development and industrial, Jakarta Bay is susceptible to the environmental degradation from the pollutants. Observation was conducted in Jakarta Bay during the southeast monsoon (Juli-Agustus) 2015 to collect physical properties data such as sea surface temperature and heavy metal component. Pollutants distribution such as Pb, Ni, Zn, Polychlorinated biphenyl (PCB), Polycyclic aromatic hydrocarbons (PAH) and Dichloro-diphenyl- trocholoroethane (DDT) are simulated using Horizontal 2D hydrodynamic model from Princeton Ocean Model (POM) with the Arakawa-C grid system. The model domain consists of 400 x 260 grid and 110x110m grid resolution. With the high accuracy rate (92%) for the tidal validation and mean sea level residual 0.074 m, the simulation shows that pollutant distribution is mainly influenced by ocean current condition. Observed eddies in the simulation, which are triggered by significant difference of bathymetry and shear current velocity, indicate that the pollutants from Jakarta Bay are not easily transported by tidal current into the Java Sea.

1 INTRODUCTION

Jakarta Bay is one of the most heavily used semi-enclosed coastal waters in the world. Along with the massive development and industrial activities on the coast, water pollution caused by the dumping of industrial and domestic wastewater had been a serious ecological problem for coral reef (Kunzmann et al., 2018) as well as fisheries (Irianto et al., 2017). Research of metal concentration in Sediments in Jakarta Bay by Arifin (2008) revealed that its concentration experiences a rapid increased in the last 20 year.

Water quality monitoring by **BPLHD-DKI** in 2013 found that heavy metals concentration in Jakarta Bay such as Pb, Ni and Zn has exceeded the specified quality standard threshold by **MenLH**. Furthermore, Susanna and Yanagi (2002) argued that the sources of pollutants are coming from major river that flows into the Jakarta Bay.. As consequence, the study to get information of pollutant distribution are very essential to obtain the better understanding about water quality in the Jakarta Bay.

Several studies have been done to assess the pollution in Jakarta Bay including methods that involving biota (Soemodihardjo and Kastoro, 1977; Rees et al., 1999), sediment geochemistry (Sindern et al., 2016) as well as using a numerical ocean model simulation (Koropitan et al., 2009; van der Wulp et al., 2016).

The lack of pollutant dynamics study in the Jakarta Bay motivated the investigation that is presented in this paper. This paper aims to simulate the spatial pattern of pollutant distribution using hydrodynamic and Horizontal 2D transport coupled model. This study could give the useful information about heavy metal concentration in all regions of Jakarta Bay.

2 METHODS

2.1 Model Design

The coupled Hydrodynamic-Horizontal 2D transport model are simulated in forty-five (45) days from 1 July until 15 August 2015 with the time step of 2

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second. The domain of this study lies on 106.633ºE – 107.033ºE and 5.868ºS – 6.118ºS (see Figure 1).

To simulate the pollutant distribution, horizontal 2D hydrodynamic model from Princeton Ocean Model (POM) is employed with the additional numerical solution from 2D transport equation. The model is built by Arakawa-C grid system, consisting of 400x260 grid with the resolution 110x110m.

The type of pollutant in this research are Pb, Ni, Zn, Polychlorinated biphenyl (PCB), polycyclic aromatic hydrocarbons (PAH) and Dichloro-diphenyl-trocholoroethane (DDT) with the consideration of advection and diffusion of these pollutants.

2.2 Model Input

The several primary data such as bathymetry, coastline, tide, sea temperature, salinity, river debit rate are used as model input. While the temperature and salinity are measured from observation with thirty two (32) measurement station (see figure 1), the bathymetry is obtained from Indonesian Navy (DISHIDROS TNI AL). It is interpolated spatially into the specified grid size of this study (see figure 1). Then, the temperature and salinity data are employed to gain the density reference value in the Bay. The tidal data for the main force in west, north and east part of domain come from Tide Model Driver (TMD) (see figure 1). Besides, the debit rate from five major rivers and wind velocity are also used as the main force. Referring the Courant-Friedrichs-Lewy (CFL), the main forcing data are interpolated into 2 second.

For the initial value of the model (see figure 2), this study assumes that the sea is calm ($u = 0$, $v = 0$, and $\eta = 0$) and the initial value for pollutant concentration in the domain model is spatial interpolation with the Kriging method from field measurement, conducted by Research Center for Oceanography, Indonesian Institute of Sciences (LIPI) on July-August 2015.

The results of the distribution of pollutant distribution in Jakarta Bay are verified using data from field measurements including tidal elevation and sea current velocity. The information regarding the data for model validation is written in Table 1.

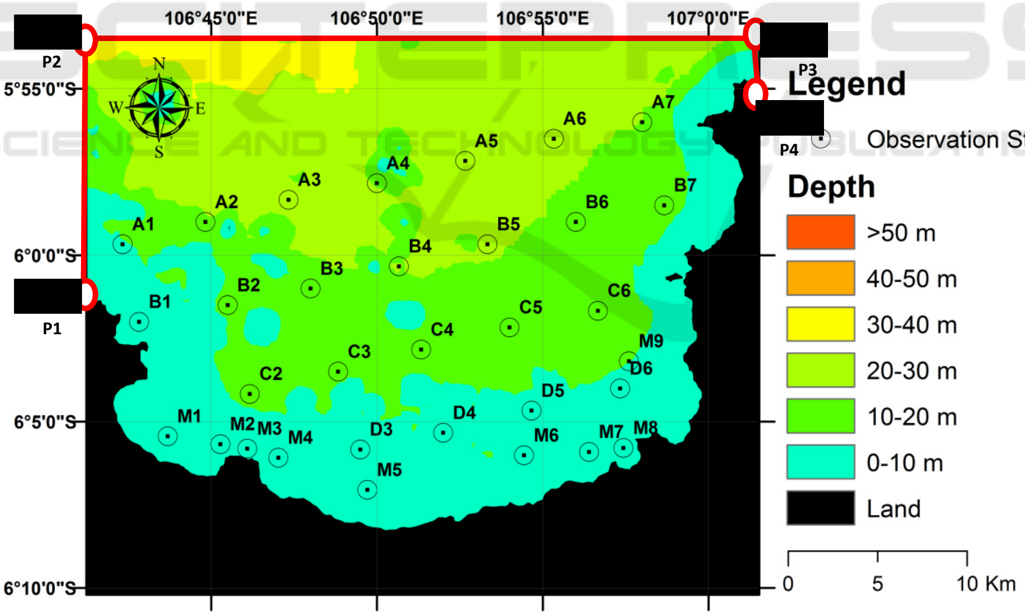

Figure 1: Bathymetry map with the thirty two (32) measurement stations with the open boundary of domain (red line) and spot for tidal data (red circle – P1, P2, P3 and P4).

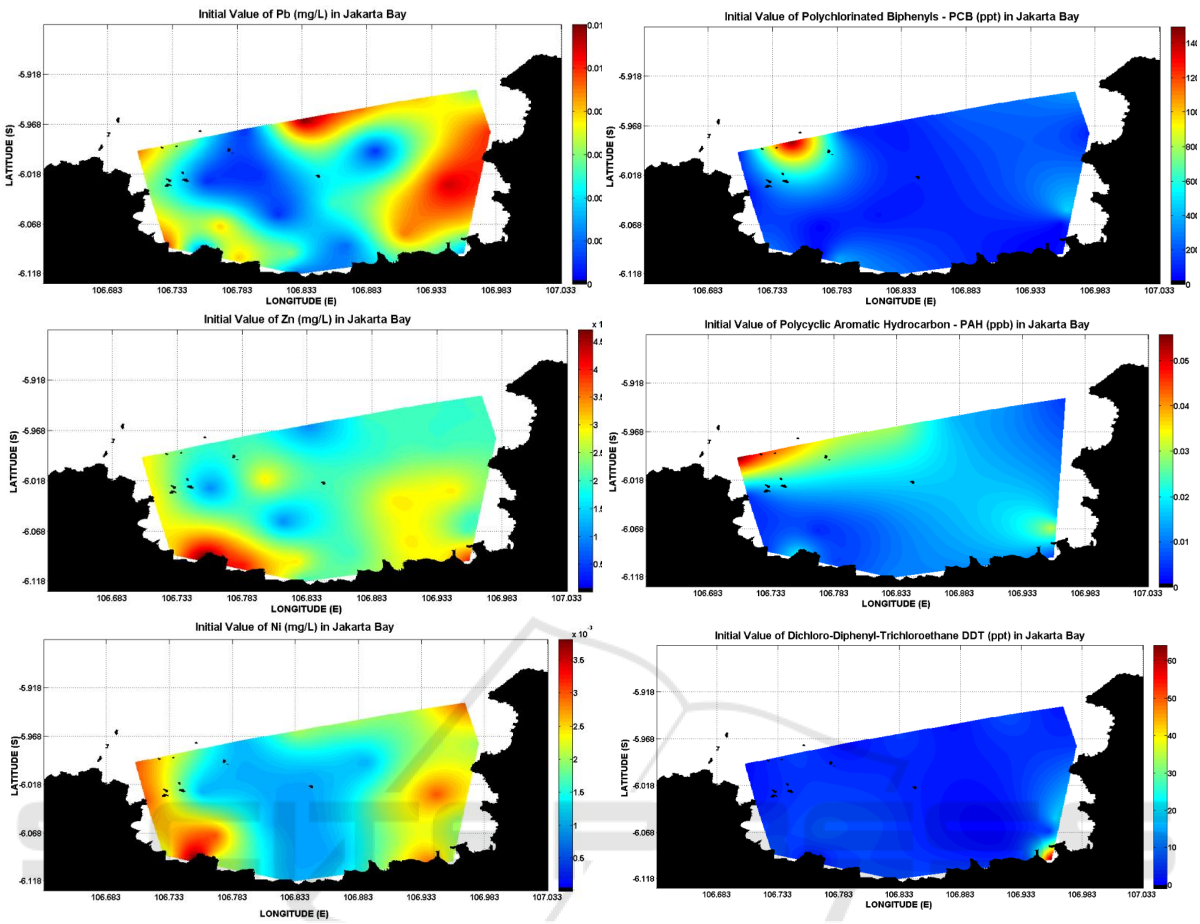

Figure 2: The initial value of heavy metal concentration; Pb (mg/L), Zn (mg/L0, Ni (mg/L) (left panel) and organic pollutant; PCB (ppt), PAH (ppb), DDT (ppt) (left panel) based on the field measurement July-August 2015.

Table 1: Data for Model Validation.

No	Data	Source	Location	Period (dd/mm/yy)	Interval
1.	Tidal Elevation	Agency of Geospatial Information (BIG)	*Kolinlamil* statiun, Jakarta	01/07/15 – 31/08/15	5 minute
2.	Current Velocity	Observation	a. St.B2 (-6.025°S and 106.758°E)	29/07/15 - 30/07/15	10 minute
			b. St.B6 (-5.975°S and 106.978°E)	30/07/15 - 31/07/15	10 minute

2.3 Model Equation

The governing equation for hydrodynamic and transport coupled model consists of continuity equation (1.1), momentum equation in x-y axis (1.2a and 1.2b) (Mellor, 2004) and transport equation in x-y axis (1.6a and 1.6b) (Putri and Mihardja, 1999). On this equation, there is assumption and simplification which are only consider to advection and diffusion, the source and sink of heavy metals from chemical reaction and other factors are not taken into account. The transport simulation on this study is conducted only based on the initial value from observation. In the absence of other supporting data, the input pollutants during the simulation period are not reviewed.

Then, this research produces a distribution pattern and pollutant flushing processes in the Jakarta Bay.

$$\frac{\partial \eta}{\partial t}+\frac{\partial \bar{U}D}{\partial x}+\frac{\partial \bar{V}D}{\partial x}=0 \tag{1}$$

$$\frac{\partial \bar{U}D}{\partial t}+\frac{\partial \bar{U}^2D}{\partial x}+\frac{\partial \bar{U}\bar{V}D}{\partial y}-\tilde{F}_x-f\bar{V}D+gD\frac{\partial \eta}{\partial x}=-\langle wu(0)\rangle+\langle wu(-1)\rangle+ G_x-\frac{gD}{\rho_0}\int_{-1}^{0}\int_{\sigma}^{0}\left[D\frac{\partial \rho'}{\partial x}-\frac{\partial D}{\partial x}\sigma'\frac{\partial \rho'}{\partial \sigma}\right]d\sigma' d\sigma \tag{2a}$$

$$\frac{\partial \bar{V}D}{\partial t}+\frac{\partial \bar{U}\bar{V}D}{\partial x}+\frac{\partial \bar{V}^2D}{\partial y}-\tilde{F}_y+f\bar{U}D+gD\frac{\partial \eta}{\partial y}=-\langle wv(0)\rangle+\langle wv(-1)\rangle+ G_y-\frac{gD}{\rho_0}\int_{-1}^{0}\int_{\sigma}^{0}\left[D\frac{\partial \rho'}{\partial y}-\frac{\partial D}{\partial y}\sigma'\frac{\partial \rho'}{\partial \sigma}\right]d\sigma' d\sigma \tag{2b}$$

where,

$$\bar{U}\equiv\int_{-1}^{0}U d\sigma \qquad dan \qquad \bar{V}\equiv\int_{-1}^{0}V d\sigma \tag{3}$$

$$\tilde{F}_x=\frac{\partial}{\partial x}\left[H2\bar{A}_M\frac{\partial \bar{U}}{\partial x}\right]+\frac{\partial}{\partial y}\left[H\bar{A}_M\left(\frac{\partial \bar{U}}{\partial y}+\frac{\partial \bar{V}}{\partial x}\right)\right] \tag{4a}$$

$$\tilde{F}_y=\frac{\partial}{\partial y}\left[H2\bar{A}_M\frac{\partial \bar{V}}{\partial y}\right]+\frac{\partial}{\partial x}\left[H\bar{A}_M\left(\frac{\partial \bar{U}}{\partial y}+\frac{\partial \bar{V}}{\partial x}\right)\right] \tag{4b}$$

$$G_x=\frac{\partial \bar{U}^2D}{\partial x}+\frac{\partial \bar{U}\bar{V}D}{\partial y}-\tilde{F}_x-\frac{\partial \bar{U}^2D}{\partial x}-\frac{\partial \bar{U}\bar{V}D}{\partial y}+\bar{F}_x \tag{5a}$$

$$G_x=\frac{\partial \bar{U}\bar{V}D}{\partial x}+\frac{\partial \bar{V}^2D}{\partial y}-\tilde{F}_y-\frac{\partial \bar{U}\bar{V}D}{\partial x}-\frac{\partial \bar{V}^2D}{\partial y}+\bar{F}_y \tag{5b}$$

Generally, 2D transport equation can be written as (Putri dan Mihardja, 1999):

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=K_x\frac{\partial^2 C}{\partial x^2}+K_y\frac{\partial^2 C}{\partial y^2}+S+R \tag{6}$$

where C is , S and R are for source and reaction respectively. On this study, we ignore the S and R due to the absence of supporting data. Then, Kx and Ky are the horizontal diffusion coefficient in x-y which is different for each parameter. We use 9.45 x 10^{-6} cm^2/s [Pb^{2+}], 6.79 x 10^{-6} cm^2/s [Ni^{2+}], 7.15 x x 10^{-6} cm^2/s [Zn^{2+}] (Li and Gregory, 1974), 3.16 x 10^{-11} m^2/s [PCB], 2.51 x 10^{-11} m^2/s [PAH] (Rusina et al., 2010) and 6.86 x 10^{-12} m^2/s [DDT] (Dueri et al., 2005).

3 RESULTS AND DISCUSSION

3.1 Model Validation

The model results are validated using two main parameters; sea level elevation and ocean current. The sea level elevation is verified by observation data, which are obtained from the Agency of Geospatial Information (BIG) located at Kolinlamil station, Jakarta. The validation is carried out for 15 days on 10 July 2015 – 25 July 2015 (see Figure 3) showing the high accuracy of 92% with an average residual sea level elevation of 0.074 m.

The observational ocean current data from 24 hours measurement at B2 and B6 stations are also utilized to verify the model result. The measurement was conducted at 5 m depth in 28-29 July [station B2] and 29-30 July [station B6] with the interval of 10 minute. The results in station B2 showed that the accuracy of the zonal and meridional current are 54% and 55%, respectively. Station B6 has the accuracy rate of 50% and 73% easting and northing current correspondingly. Some components show an accuracy value which is not accordance with the field data. That conditions are potentially due to the lack of matching drag coefficient values for surface wind speed. Based on the wind speed during the simulation period, the wind is large enough to generate ocean currents. Therefore, the model results are underestimated during that condition.

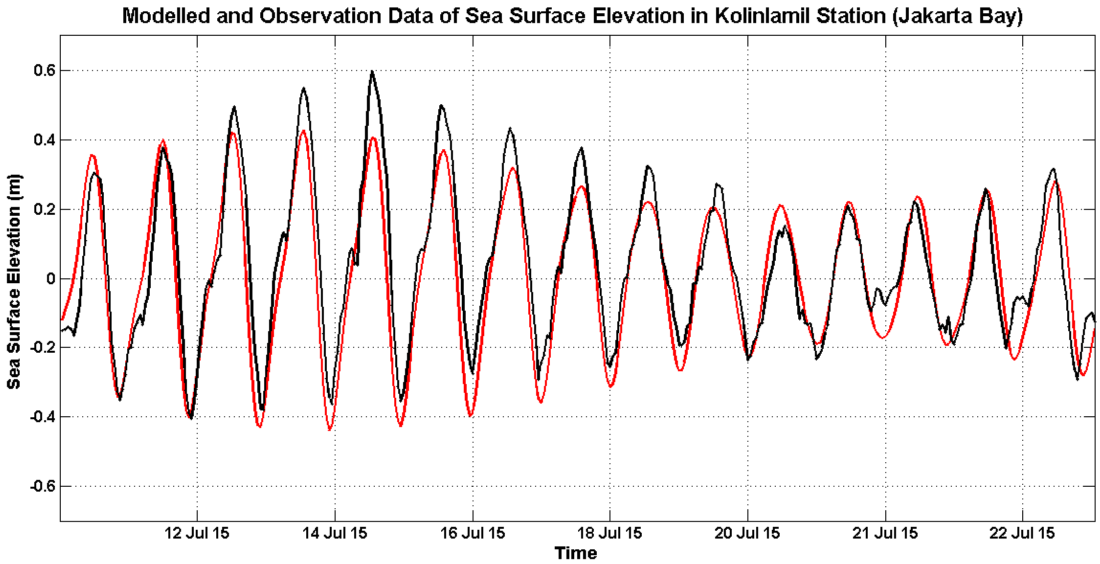

Figure 3: Model Validation between model result (red line) and observation (black line) on 10 – 25 July 2015, located on Kolinlamil Station, Jakarta.

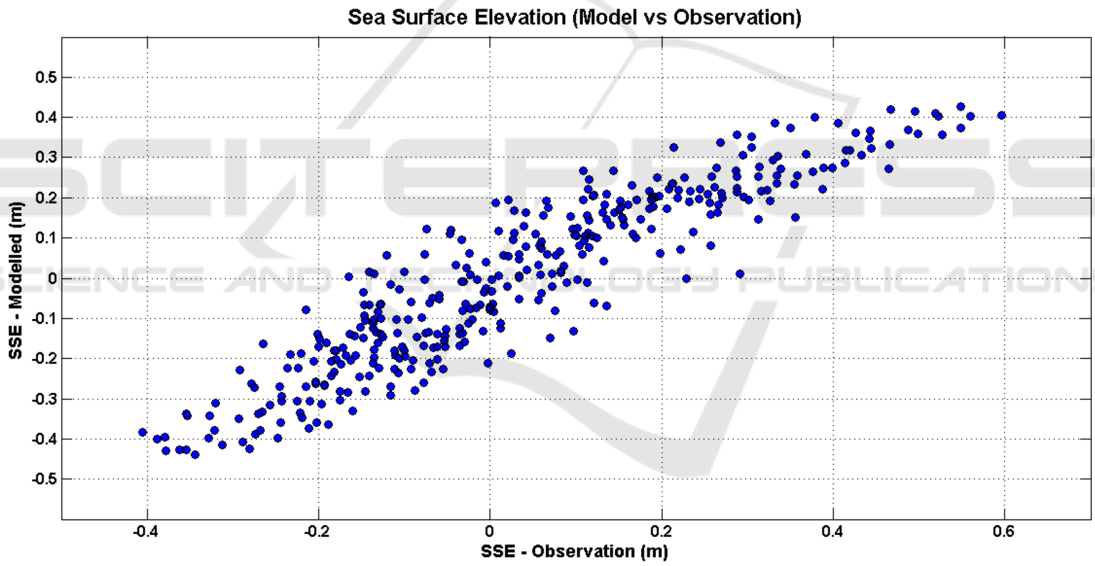

Figure 4: Model Validation between model result (red line) and observation (black line) on 10 – 25 July 2015, located on Kolinlamil Station, Jakarta.

3.2 Jakarta Bay Dynamics

Generally, the type of tide in the Jakarta Bay is mix tide with the flood and ebb tide occur just once in a day. Furthermore, ocean current patterns in the Jakarta Bay vary, depending on tides and monsoons. In some cases, where the wind blows so strong in the southeast monsoon, the ocean currents move north-eastward. During the ebb tide phase, the current flows into the open sea while there are southward currents in the eastern part of the Bay (Fig 5; upper panel), while the ocean current dominantly moves into the mainland when the flood tide (Fig 5; lower panel). These results are consistent with Putri and Mihardja (1999) and Sanusi et al (2005). The magnitude of ocean current varies from 0 until 0.20 m/s. These conditions also indicate that the pollutant distribution is more influenced by ocean current than the diffusion rate of each pollutant.

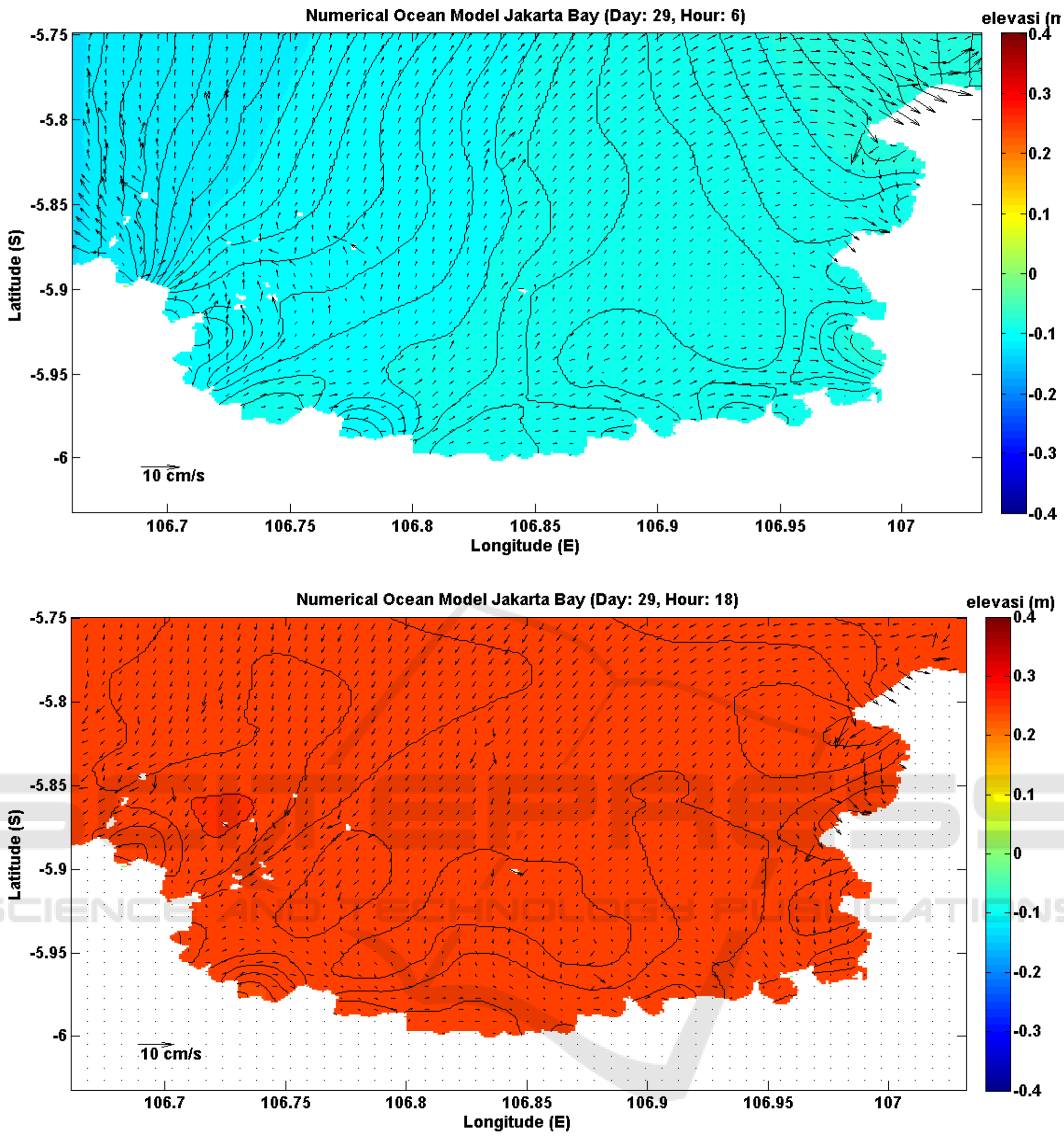

Figure 5: Model Validation between model result (red line) and observation (black line) on 10 – 25 July 2015, located on Kolinlamil Station, Jakarta.

3.3 Pollutant Distribution

Overall, the model results show the distribution of pollutant which is mainly influenced by the ocean current pattern (Figure 6 – 11). The variation of bathymetry and the shape of the coastline in Jakarta Bay contributed to eddies current in the several places along the Jakarta Bay. For the example, the observed eddy current in the eastern part of Bay is triggered by shear current velocity. In some areas, the eddy current are also found due to the significant difference of bathymetry. The formation of eddies causes the particle movement that rotate around the centre of eddies. As a result, the pollutants from Jakarta Bay are not easily transported by tidal current into the Java Sea. In addition, the monsoonal cycle also has an important role to transport the pollutant by moving the ocean current. It can be indicated from the simulation result. The pollutant distribution has the dominant direction into the west while the southeast monsoon triggers the ocean current to move southwestward.

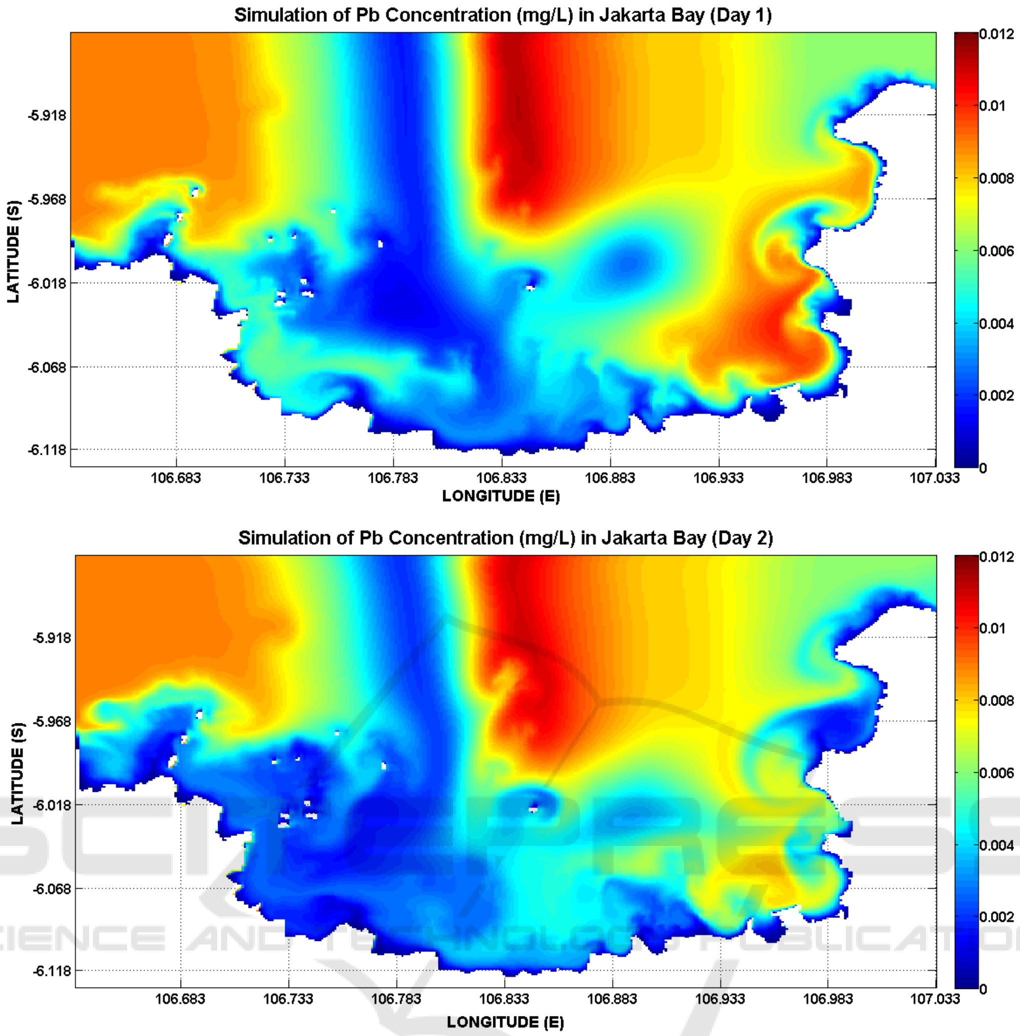

Figure 6: Simulation result of Pb concentration in Jakarta Bay.

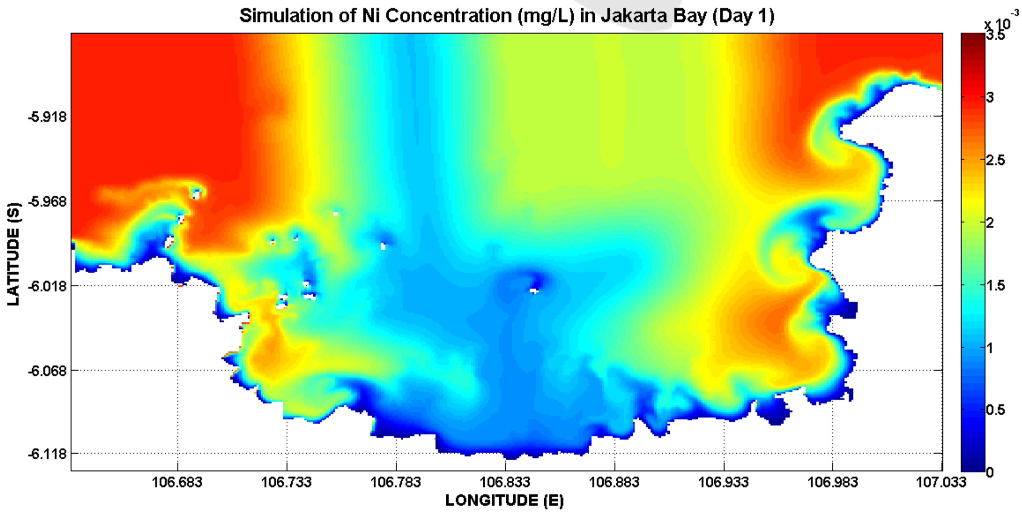

Figure 7: Simulation result of Ni concentration in Jakarta Bay.

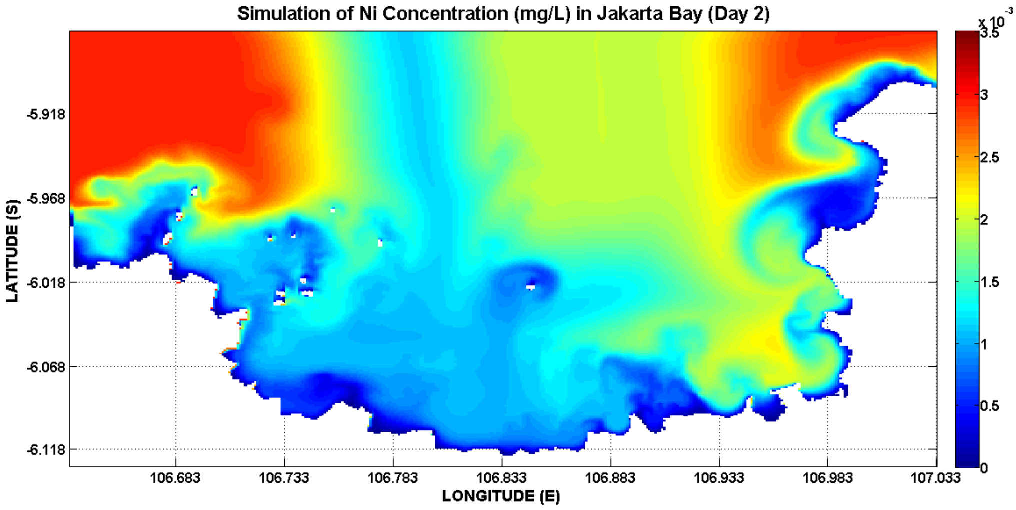

Figure 7: Simulation result of Ni concentration in Jakarta Bay (cont.).

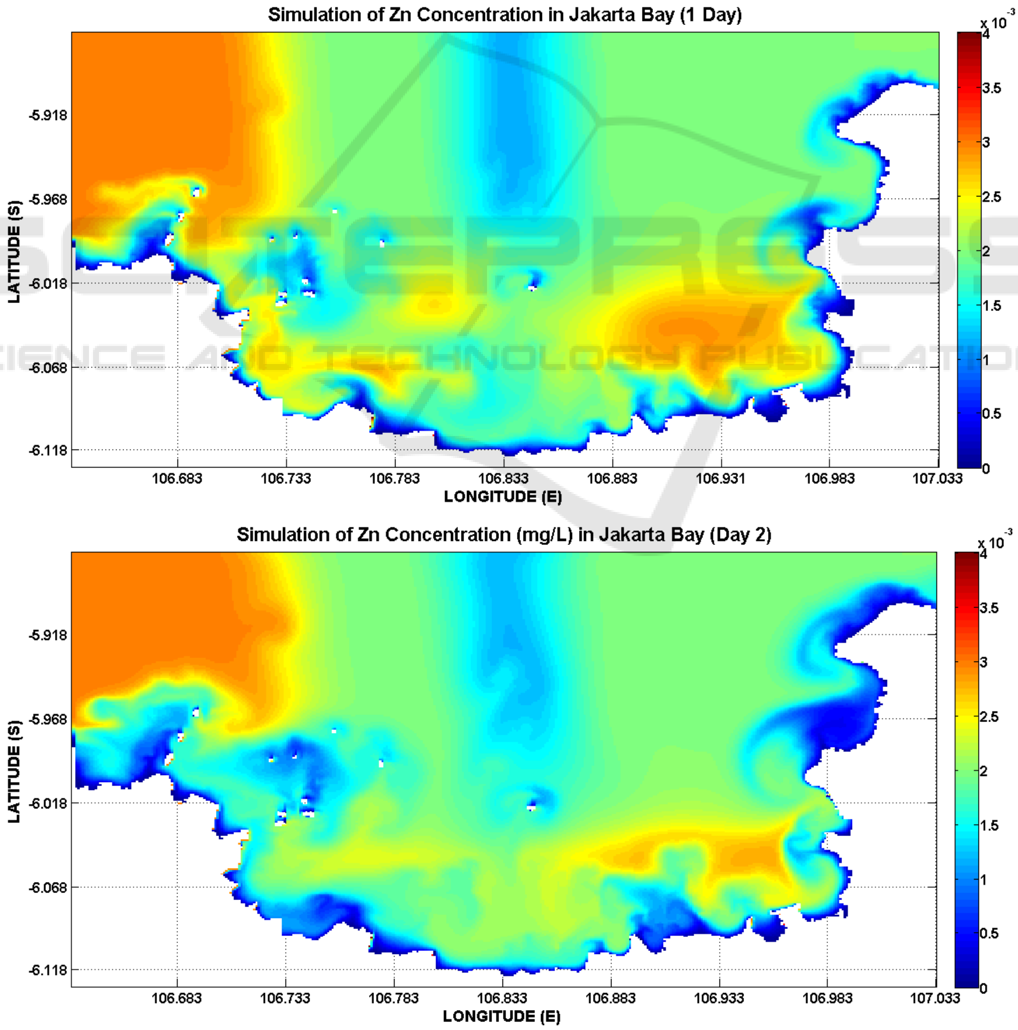

Figure 8: Simulation result of Zn concentration in Jakarta Bay.

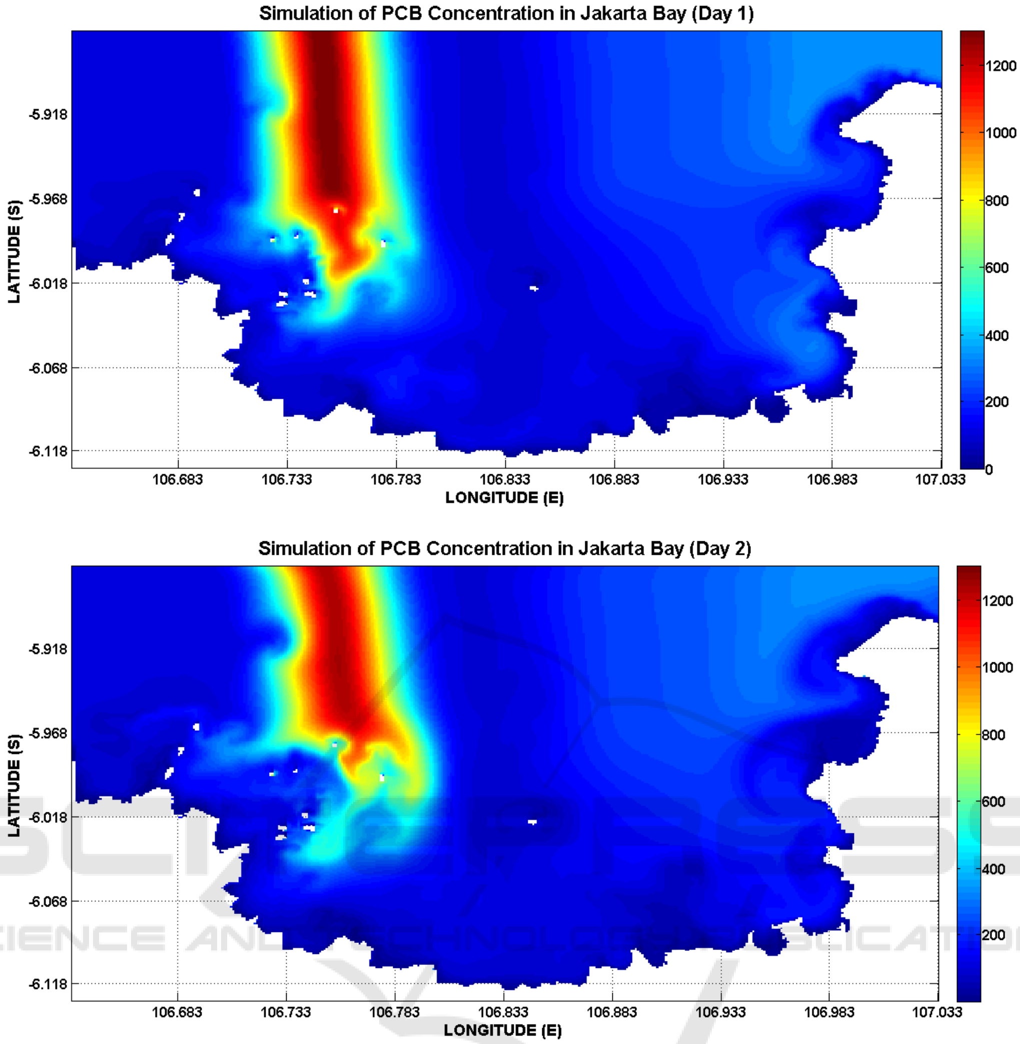

Figure 9: Simulation result of PCB concentration in Jakarta Bay.

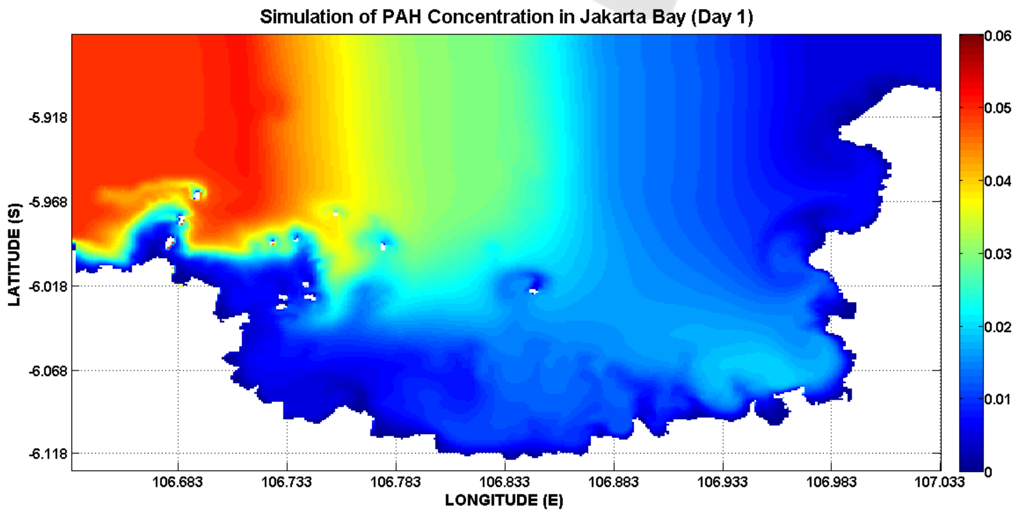

Figure 10: Simulation result of PAH concentration in Jakarta Bay.

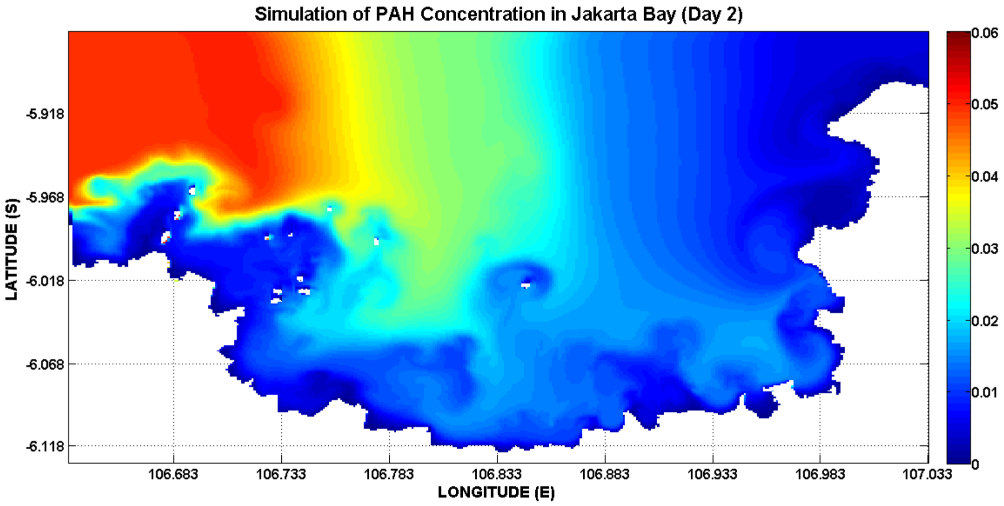

Figure 10: Simulation result of PAH concentration in Jakarta Bay (cont.).

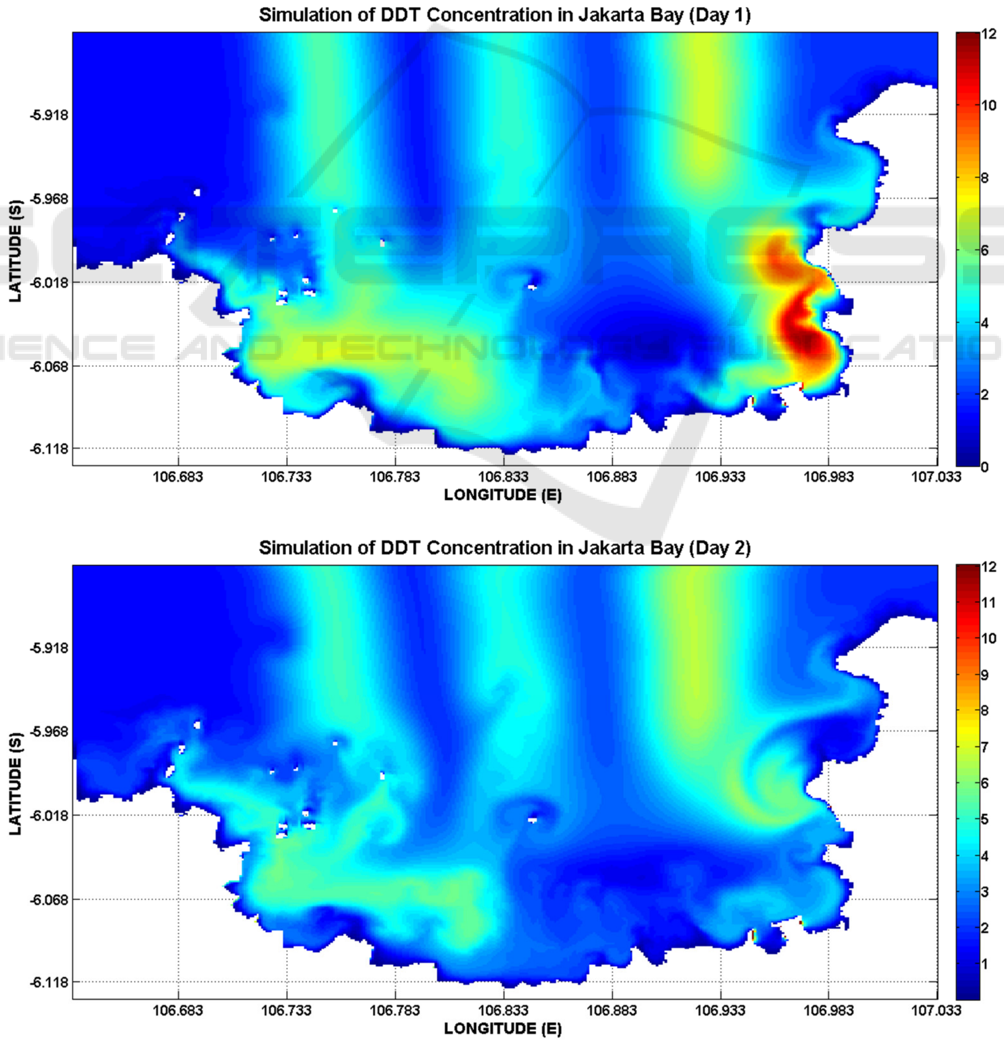

Figure 11: Simulation result of DDTconcentration in Jakarta Bay.

4 CONCLUSION

From the simulation of pollutants distribution using coupled hydrodynamics-2D transport model, we conclude that the water movement in Jakarta mainly driven by tidal condition, debit of river and wind velocity.

Those ocean-atmospheric factors contributed to the spatial variation of the pollutant in the Jakarta Bay. The pollutants from Jakarta Bay are not easily transported by tidal current into the Java Sea due the formation of eddy currents.

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