Modelling of Phenol Contamination in Wonorejo Estuary, Indonesia

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Abstract. Phenol as a part of marine pollution in Wonorejo estuary has been a concern today. Mass death of clams and decreasing growth of shrimps often occur in this area. The citizens made assumption that source of marine pollution from Sidoarjo mud disaster. This paper investigates the distribution of phenol from modelling with MIKE 21, Eco Lab module. Measurement were done in Wonorejo estuary to get a validation of modelling. Modelling result shows phenol concentration in northern Wonorejo estuary is higher than other areas. Hence, it was concluded that the phenol source is not from Sidoarjo mud disaster.

1. Introduction
Phenol is often sourced from chemicals that are generally derived from industrial waste and from different disinfectant in household cleaning products and products that are consumed like toothpaste and mouthwash. Phenol is also called carbolic acid which is an organic compound with alcohol structure C$_6$H$_5$OH. Phenol can be readily decomposed in the air, but the phenol contaminated water takes longer to be decomposed [1]. Phenolic compound is also a pollutant derived from oil spills or disposal of waste oil into the sea [2]. Phenol concentration that contaminated water became toxic to aquatic life and can cause a bad taste in the meat of fish [3]. Other impacts are decreasing antibody and corrosive to the skin (irritation), and even can cause interference on human health [2]. Clams mass death in Wonorejo estuary made people to assume there are phenol contamination from Lapindo mud disaster waste (oil and gas well blow out) in Sidoarjo.

2. Methods
The research was performed at Wonorejo estuary, Surabaya, East Java province, Indonesia, see figure.

1. Coordinate range of Wonorejo estuary is 7°15'19.60" - 7°17'13.25" S latitude and 112°48’35.69” - 112°48’40.72” E longitude.
Phenol measurement in ten sites as modelling validation was explained in Sakinah, et al. [4] (waiting for publication). Sampling was performed in dry season. A hydrodynamic and water quality model with DHI’s Mike 21 Hydrodynamics and ECO Lab module are used to examine distribution of phenol in Wonorejo river estuary. Hydrodynamics module (HD) as basic computational component to simulate hydrodynamics and ECO Lab module simulates ecological parameter coupled in HD module.

2.1 Modelling methodology
From modelling reference with Mike 21 [5], the water level was prescribed along the open boundary for flow computation i.e. Northern, Southern, and Eastern boundary located in the Madura Strait. The western boundary of the model is the Wonorejo river with water discharge (observed data from Jasa Tirta Surabaya in dry season in the year of 2015 is 0.15 kg/m$^3$) as the boundary condition. Hydrodynamics and ECO Lab modelling was done with the input parameter of modelling consist of hydrodynamics parameters, such as, bathymetry, river flow discharge, tides, wind speed and wind direction, as well as the five boundary conditions, see figure 2. and data of phenol as water quality parameter. Model simulation was carried out for one month (720 hours) with the time step interval = 3600s, number of time steps = 720s, from 23$^{rd}$ August 2015 until 22$^{nd}$ September 2015.
2.2 Model validation
Phenol measurement at site 1, 6, 7, and 10 [4] are used to validate the modeling result. Site 1 represents a western side, site 6 for eastern side, site 7 for northern side, and site 10 for southern side. From the results of modeling and measurement presented in Table 1, which has a relatively small value difference. It could be concluded that the simulation result of phenol distribution in Wonorejo estuary was valid and can be used to predict the source of phenol contamination.

| Location site | Measurement data (mg/L) | Modelling result (mg/L) | Error (%) |
|---------------|-------------------------|-------------------------|-----------|
| 1             | 0.021                   | 0.021                   | 0.92      |
| 6             | 0.086                   | 0.076                   | 11.35     |
| 7             | 0.065                   | 0.053                   | 18.75     |
| 10            | 0.023                   | 0.023                   | 0.09      |

Table 1. Validation results of the phenol from measurement data

The calibration of hydrodynamics model was conducted with examining the water surface elevation from Dishidros-AL (2015) data and the simulation result at site 6, the root mean square error (RMSE) is 0.01 and absolute percentage error is 0.04%. Another calibration of hydrodynamics model was conducted with the sea water current from measurement with acoustic Doppler current propeller (ADCP) and the simulation result at site 6, the root mean square error (RMSE) is 0.015 and absolute percentage error is 27.02%.

3. Result and Discussions
3.1 Hydrodynamics simulation results
Figure 3 show the surface currents distribution during ebb and tide with condition as shown on point (a) and (b) in the upper part of figure 3. The distribution of high tide (figure 3(a)), the current enter the estuarine mouth with the water level 2.53 m and maximum speed of 0.003 m/s occur in the river body and 0.017 in the river mouth for the simulation step of 203. During the ebb current (figure 3 (b)) is with the water level of 0.32 m and maximum speed of 0.017 m/s occur in the river body and 0.02 in the river mouth for the simulation step of 160, the current moving to the downstream direction or toward the river mouth of Wonorejo estuary. At the highest tides, currents in the Wonorejo estuary move toward upstream and at the lowest tide currents moving in the opposite direction.
3.2 The distribution pattern of phenol contamination in Wonorejo estuary based on measurement data and numerical modeling result

The distribution of phenol at the tide condition as shown in figure 4(a), is large enough in the sea and smaller along the river. The minimum value of phenol is \(-7 \times 10^{-6}\) mg/L occurs in river body and the maximum value is 0.89 mg/L in the northern sea. Fig. 4(b) shows the distribution of phenol at ebb condition with the minimum value is \(1 \times 10^{-5}\) mg/L occurs in river body, was marked with the purple colour at the modelling result and the maximum value is 0.88 mg/L occur in the eastern sea. Phenol concentration in the tide condition was higher than ebb condition.

Figure 3. (a) Tide current pattern; (b) Ebb current pattern in the river body of Wonorejo estuary

Figure 4. Phenol distribution pattern (a) during tide condition; (b) during ebb condition
Figure 5 gave the information obtained from the numerical modelling results for the distribution of phenol after one month. The minimum value of phenol is $-1.2 \times 10^{-5}$ mg/L occurs in river body and the maximum value is 0.9 mg/L occur in the northern sea.

![Figure 5. Phenol distribution pattern after one month based on numerical modelling result](image)

The phenol concentration become higher from time to time and the phenol concentration pattern almost same as surface elevation pattern, see figure. 6. The highest concentrations of phenols were at sea while the lowest concentrations are in the area of the river. This is because the sources of pollution are not on the river, but in the environment or from the sea. This phenomenon is reinforced by the concentration on modelling with a negative value. Output appears on modelling using Mike 21 with a negative value means the sources of pollution comes from the environment, negative values also indicate the direction which means the source of the waste water is not towards the environment, but rather away from the environment [6].

![Figure 6. Comparison of phenol distribution between river body, river mouth, and sea in Wonorejo estuary](image)

The last simulation results in figure. 5 showed that phenol contamination in the estuary area becomes higher, it can be seen from the color in modelling result becomes more green, which means the concentration was intense. But for the southern of the sea area, the blue color becomes wider than at
the time of high tide and low tide, see figure. 4. This proves that the assumption of the public about
the contamination of Lapindo mud waste, Sidoarjo cannot be substantiated. Laboratory test results
from Airlangga University also showed the phenol concentration of Lapindo mud waste is still below
the quality standard. This is reinforced by another research [5], which shows the distribution and
concentration parameters of water quality in estuaries Porong, Sidoarjo as a result of the Lapindo mud
waste. The study showed in Porong estuary area relatively close to the source of the sludge are still in
the safe criteria and does not exceed from the quality standard of the Government Regulation Number
82/2001 on the Management of Water Quality and Water Pollution Control. The simulation result
shows the phenol contamination actually comes from the northern sea, the direction of the island of
Madura. This explains the source of phenols derived from Madura strait because of the many ports in
the strait so that there is a possibility of oil spills on ships sailing in the straits of Madura. East
Surabaya seas, including the modelling area are shipping lines that are highly vulnerable by oil
pollution from waste or disposal of the ships in the harbor and across the waters, and mining activities
[7].

4. Conclusions
Numerical modelling with Mike 21 results phenol distribution is higher from time to time and already
exceed from quality standard. The maximum concentration of phenol is 0.89 mg/L occur in northern
sea and the minimum concentration is 7x10^-6 occur in river body. Phenol concentration during tide
condition is higher than ebb condition. All simulation show the highest concentration of phenol
occurs in northern sea. But, Lapindo mud disaster occurs in southern sea. This proves that the
assumption of the public about the contamination of Lapindo mud waste, Sidoarjo cannot be
substantiated.

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