Oil Spill Simulation for Analysis of Environmental Mitigation in Cilacap Coastal Areas

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Abstract: The frequency of oil spills in Cilacap coastal area is high enough to cause ecological and economic consequences. Based on data from various sources, during the period 1989-2015, there were 17 cases of oil spills occurred in Cilacap coastal area, 12 were due to tanker accidents and 5 cases due to leaked pipes. Oil spills often result in both environmental damage and social and economic losses. The main objective of this work is to do simulation of an oil spill in Cilacap area under different environmental conditions to facilitate the mitigation for oil spill emergencies at sea by local authorities. To estimate the distribution of oil, referring to the King Fisher case which occurred on 1 April 2000 in Cilacap area, a spill with 2,500 ton of crude oil was simulated by MoTum from January to December. The model approach was done by taking into account the effects of wind, tide, bottom friction, and turbulence. The simulation results reveal that the trajectory of the oil depends on hydrodynamic forces and highly depends on meteorological conditions, such as wind. The simulation results also show that Teluk Penyu area, the eastern part of Nusakambangan Island, and Donan River estuary are area with a high probability of pollution. The mitigation associated with accidental spills can use one or several approaches, i.e., technology, socio-cultural-economic and institutional and stakeholder approaches.

1 INTRODUCTION

Accidental large oil spills are one of the disasters and become important problems that occur in marine and coastal areas. Accumulatively, an oil spill usually has a huge impact on marine and coastal environment. This will directly or indirectly affects fisheries productivity which is very dependent on environmental quality. The economic losses will be greater if the oil spills occur in areas that have high fisheries production, such as Cilacap coastal areas. It will mainly impact fishermen who depend on marine and coastal resources.

Based on data compiled from various sources, during the period of 1989-2015, there were 17 oil spill cases that occurred in Cilacap coastal areas, with 12 cases were caused by ship accidents and 5 cases were due to pipe leakage. Some of the oil spills that have occurred have shown that Cilacap coastal areas are vulnerable to oil pollution. Moreover, the traffic intensity of tankers carrying crude oil as well as oil refinery produced by Pertamina Refinery Unit IV Cilacap to Tanjung Intan Port is quite high, with an average of 70 ships per month.

Oil spills that often occur in Cilacap coastal areas will have an impact on the marine and coastal resources. In addition, oil spill will also affect the economic life of the community which depends on the location around the occurrence of oil spills. The Ministry of Environment stated that economic losses due to the King Fisher ship accident in Cilacap coastal areas in 2000 reached 272 billion rupiah (Jayawardana, 2006). For this reason, an environmental mitigation effort is needed related to the risk of oil spills in the Cilacap coastal area.

In general, environmental mitigation is an effort to prevent negative impacts that are expected to occur or have occurred due to the planning of an activity. Environmental mitigation can also mean efforts to overcome the negative impacts that arise as a result of an activity. According to Law of The Republic of Indonesia Number 24 of 2007, mitigation is defined as a series of efforts to reduce disaster risk, both through physical development and awareness and capacity building to face disaster threats.

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Mitigation is done to minimize or to reduce the possible impacts of a disaster. Therefore, mitigation can reduce and/or eliminate victims and losses that may arise. Mitigation must be carried out for all types of disasters, both those included in natural and man-made disaster, including oil spills.

In order to prevent and mitigate the risk of oil spills in the Cilacap coastal area, this study aims to simulate an oil spill under different environmental conditions that will provide predictive distribution of oil when spilled in the Cilacap coastal areas. The results of the analysis are expected to minimize the impact, both environmental and socio-economic impact, that will be caused by oil spill.

2 METHODS

2.1 Simulation Model

In order to estimate the distribution of oil spills in Cilacap coastal areas, MoTuM (Modul Tumpahan Minyak) developed by Muin was used. This software is used to simulate hydrodynamics and the movement of oil spilled in open seas, straits, bays, or estuaries. The software generates a series of outputs after the simulation: the hydrodynamic model, the spread of oil particles and thickness/oil concentration (fates and trajectory model), the probability of the stochastic model, and the probability of the location of oil pollution sources (receptors model).

MoTuM uses the methodology of combining the Three-Dimensional Model of Non-Orthogonal Hydrodinamic Curvilinear Coordinat Technique and the Oil Spill Model. Hydrodynamics model is based on tides, current and wind databases. This model is able to simulate the pattern of three-dimensional ocean currents due to tides, wind, density, and influence of rivers. Model applications have been carried out in several locations such as Fundy Bay (Canada), Narraganset Bay and Savannah River (United States), and Ajkwa (PT Freeport Indonesia).

2.2 Model Input Parameters

Data input used in the hydrodynamic model is bathymetric map, tides, wind speed and direction, eddy viscosity value, and seabed roughness coefficient. Bathymetry data from the study area were obtained from the Pushidrosal (Hydrography and Oceanography Center, Indonesian Navy). Tidal data used in this study are the tidal constituent at the Cilacap Tidal Station from Geospatial Information Agency with Formzahl number 0.3436, which indicates that mixed tides, prevailing semidiurnal, are predominant in the Cilacap coastal areas. Wind data, in the form of direction and speed, used were 2010 wind data that were obtained from Meteorological, Climatological, and Geophysical Agency.

In this study, it was assumed that eddy viscosity was considered constant, 1 m2/s and 0.001 m2/s for horizontal and vertical direction, respectively. This parameter is not a fluid property but flow property so that the value is very dependent on the current and roughness of the seabed (Muin, 2005). The average value of seabed roughness coefficient, which is commonly used in the application of marine hydrodynamic models, ranges from 0.001 to 0.005. Therefore, the value of 0.002 was adapted in this study.

Furthermore, the oil spill model requires a series of parameters of different kind. Some of the spill parameters required are geographical coordinates of the spill, type and quantity of the spill. In addition, environmental parameters are also included, i.e., eddy diffusivity, temperature of the sea and air, and sediment concentration.

The location of the oil spill is 109˚02'57.9" and 07˚45'09" in longitude and latitude, respectively, referring to the location of the King Fisher oil spill that occurred in the Cilacap coastal area in 2000 (Figure 1). The simulation was done with a volume of 2,500 tonnes of crude oil in 12-month period, from January to December. The value of 2,500 tonnes was chosen based on the average volume data of oil spills that occurred in Indonesia.

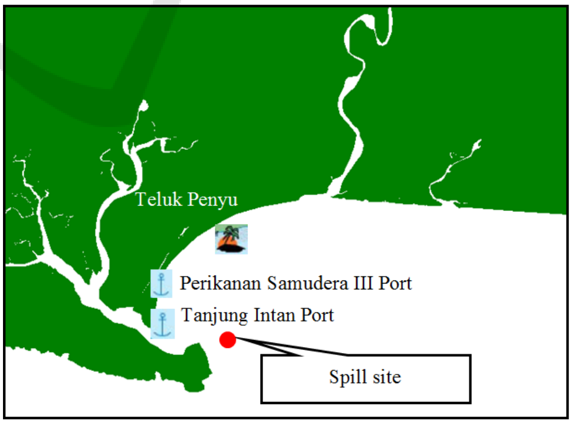

Figure 1. The location of the King Fisher spill

In this study, eddy diffusivity value is determined at 100 m2/s which is the value of the diffusion coefficient for the open bay (Joseph, et al., 1998 in Butyliastri, 2009). Sea water temperature in the simulation was 27˚C (BAPPEDA Cilacap &

Diponegoro University, 2001). The air right above the water was assumed to have the same temperature as the water surface. The sediment concentration in this study was assumed to be 5 ppm. According to Hartami (2008), suspended sediments concentration ranging from 5 to 25 ppm is considered to be good in marine aquaculture ecosystems and Cilacap coastal areas were well known for their marine fishery production.

2.3 Model Evaluation

Before being used to model the distribution of oil spills in Cilacap coastal areas, the model was first evaluated with field case. The field case used in this evaluation is the oil spill data from the MT King Fisher, which occurred on April 1, 2000 at 16.00 in Cilacap coastal areas. MT King Fisher, the Maltese-flagged tanker, ran aground after crashing into the reefs in 3 and 5 buoys of the Port of Tanjung Intan Cilacap in the eastern tip of Nusakambangan Island, Cilacap. The location of the King Fisher oil spills is given in Figure 2.

The simulation began at 16.00 with a volume of 4000 barrels of crude oil. When the King Fisher oil spill occurred on April 1, 2000, Meteorological, Climatological, and Geophysical Agency informed that the wind blowing from the south with velocity of 10 knots. Figure 2 shows the trajectory of the oil spill that occurred after 1 hour. The oil spill began to move northward. This movement was influenced by the direction of the wind that blew from the south. Figure 3 shows the oil spill has reached the coast after 6 hours and 40 minutes of simulation. After 24 hours, the area of the oil spill gets larger and the distance of the oil spill is also further away, as shown in Figure 4.

MoTum simulation results show that the length of the coastline affected by the oil spill is 9567 m (Figure 4). Meanwhile, the news related to the King Fisher oil spill informed that the oil spill was spread over 10 kilometers from Area 70 (Cilacap Village), Teluk Penyu coast, Nusakambangan Fishing Port, to Tegal Katilayu and Lengkong coast. This result showed a reasonable agreement between simulation result and field case.

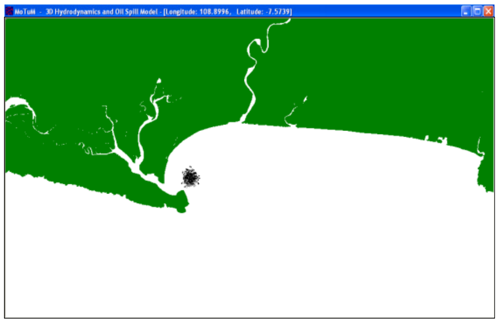

Figure 2. King Fisher spill position after 1 hour.

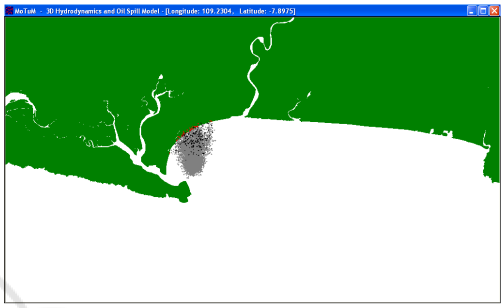

Figure 3. King Fisher spill has reached the coast.

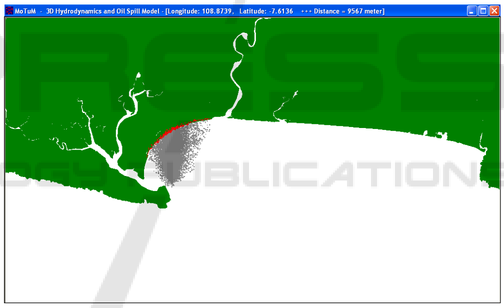

Figure 4. King Fisher spill position after 24 hours.

3 APPLICATIONS AND RESULTS

The first objective of this work is to do a series of simulation of crude oil of Cilacap coastal area, of which geographical coordinates belong to a latitude of 07˚45'09" and a longitude of 109˚02'57.9", referring to the King Fisher case. Simulations are done with 2500 tonnes for crude oil. Twelve simulations were done considering the hypothetical cases explained above.

As it can be observed, the model shows the most probable trajectory of the spill depends on the current and wind pattern as the oceanographic and meteorological conditions. From the simulation results, it was found that the contribution of surface wind to the distribution of oil spills was quite large.

Consequently, it is possible to know if the spill reached the coast and, in this case, when and where it would impact the coast.

Simulation results showed that in January, oil spills spread to the southeast (Figure 5). In February and March, oil spills spread eastward (Figures 6 and 7). In April, oil spills spread to the northwest (Figure 8). In May and June, oil spills spread to the west and the south (Figures 9 and 10). Oil spills spread westward in July, August, September, and October (Figures 11-14). Whereas in November and December, oil spills spread to the southeast (Figures 15 and 16).

The simulation results also show that the coastal area of Teluk Penyu, the eastern end of Nusakambangan Island and the estuary of the Donan River are the area that have the highest polluted probability level. In addition, Widarapayung Beach and Ketapang Indah Beach also have risk of being contaminated by oil spills. It can be known from simulation results in the March scenario, as shown in Figure 7.

These areas have high biodiversity and are tourist destination in Cilacap Regency so that if the area is contaminated by oil, the potential for economic losses will be very high. The areas that have the probability of oil contamination are shown in Figure 17.


Figure 5 and 6. Simulation results in January and February, respectively.

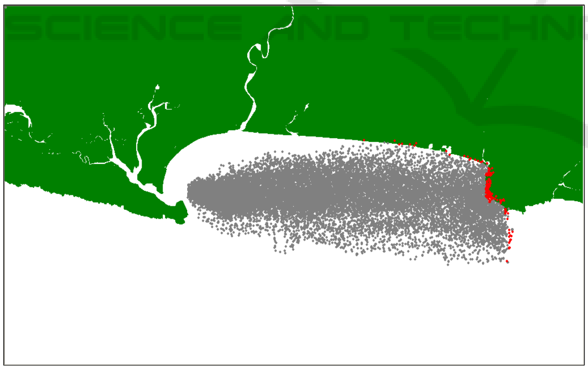


Figure 7 and 8. Simulation results in March and April, respectively.

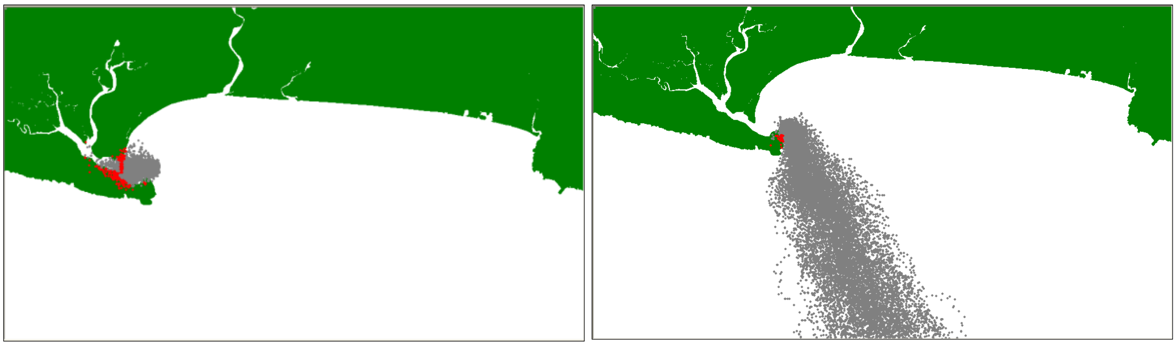

Figure 9 and 10. Simulation results in May and June, respectively.

Figure 11 and 12. Simulation results in July and August, respectively.

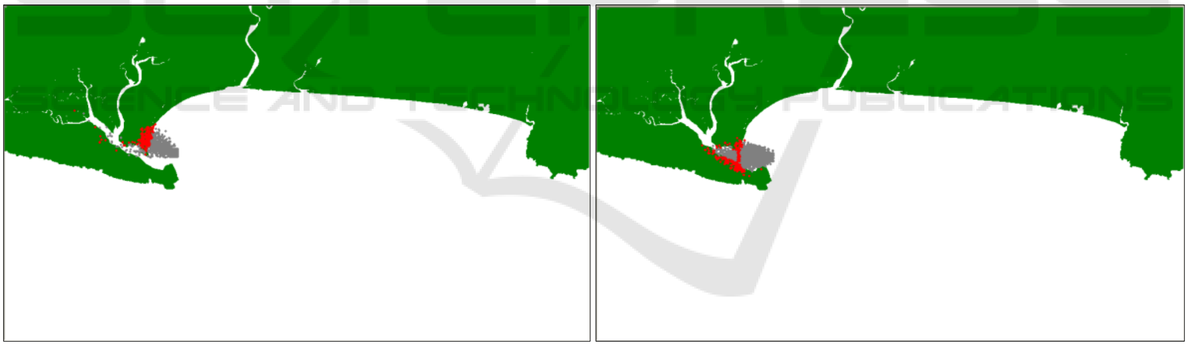

Figure 13 and 14. Simulation results in September and October, respectively.

Figure 15 and 16. Simulation results in November and December, respectively.

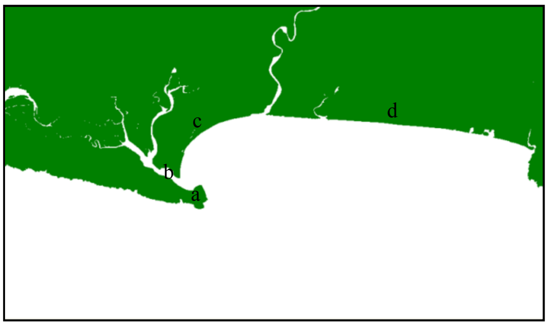

Figure 17. The most polluted area: a) The eastern end of Nusakambangan, b) Teluk Penyu beach area, c) Donan River estuary, and d) Widarapayung and Ketapang Indah Beach

The impact of the oil spill on the Donan River estuary, which is a mudflat with high biodiversity, will be different from the impact of the oil spill on the coastal area in Cilacap, which is a sandy coastal plain. Productive areas, such as estuary areas, when it is exposed to an oil spill, will experience a long-term impact. On the other hand, the sandy beach area also has a high economic value because it is used, among others, for beach tourism, docks, and building materials/mineral resources/mining materials. In addition, sandy beach area is a habitat for various flora and fauna. Likewise, the clean-up of oil spills in estuary areas will be different from it is in sandy coastal plains.

For this reason, in the context of preventing or reducing the risk of oil spill while minimizing the impact caused by oil spill, oil spill mitigation can use one or several approaches, i.e., technology, socio-economic culture, institutions, and stakeholders.

As an example, in technology approach, one of the mitigation efforts can be carried out by widening and dredging the shipping channel periodically to reduce the potential for the tanker to be docked. In addition, the application of technological instruments to this mitigation effort can also take the form of applying double hull requirements for oil tankers to minimize the risk of accidental oil spills.

In addition, mitigation through a technology approach also means using technology to minimize the impact caused by oil spills. The application of the right method in tackling oil spills will be very effective in reducing oil in the environment, be it the physical method of using a boom, absorbent, skimmer, use of dispersants (chemical methods), bioremediation (biological method), or burning. The method to deal with oil spills can be used in one method or in a combination of several methods, according to the location of the incident, the type of oil spilled, and the volume of oil spills.

4 CONCLUSIONS

The simulation of the oil spills based on the 3D model of non-orthogonal hydrodynamic curvilinear coordinate technique and the oil spill model of Cilacap coastal areas was investigated. It can be concluded that the Teluk Penyu beach area, the eastern end of Nusakambangan Island, and the Donan River estuary under the present study are the areas with the highest probability of contamination in regard to oil spills risk. This research finding may be able to be utilized for preventing and mitigating the risk of oil spills in Cilacap coastal area.

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