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OIL SPILL RESPONSE PREPAREDNESS MODEL THROUGH COMMUNITY PARTICIPATION IN TELUK PENYU BEACH, CILACAP REGENCY

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Abstract

In Indonesia, oil spill incidents often occur; thus, it has become a matter of national concern. Cilacap Regency is one of the regions in Indonesia that is prone to oil spills, with a history of frequent oil spill incidents during 2000–2018. Oil spill response preparedness needs the integrated effort between government and communities to minimize the environmental impacts of oil spills. A problem usually encountered is the lack of integration of community participation in the oil spill contingency plan because of the limited knowledge of the community regarding oil spill response preparedness. This study aimed to build an oil spill response preparedness model through community participation in Teluk Penyu Beach, Cilacap Regency. This study used the system dynamics modeling method. Results showed that the oil spill volumes in the waters (decay behavior) and on the beach (goalseeking behavior) rapidly decreased after 240 h (10 days). In conclusion, oil spill response preparedness needs the integration between company and community participation by increasing knowledge through community involvement in a combination of oil spill response exercises.

Keywords: Cilacap; model; oil spill; preparedness; response; system dynamics

1. Introduction

Oil spills are the release of hydrocarbons/oils either directly or indirectly to the marine environment (Presidential Regulation of the Republic of Indonesia Number 109 of 2006 concerning the Management of Emergency Oil Spills in the Sea). In Indonesia, oil spill incidents often occur; thus, it has become a matter of national and international concern [\(The](#page-13-0) [Special Task Force for Upstream Oil and Gas Business Activities, 2017\)](#page-13-0). The statistics show that, in 2016, several oil spill incidents occurred, with a total volume of 787,277 barrels in the upstream sector [\(The Directorate General of Oil and Gas, 2017\)](#page-13-1). An international oil spill that had a considerable impact on Indonesia's marine area was the oil spill caused by the Montara offshore oil drilling in 2009, with a spill volume of 27,600 t in the Timor Sea. Furthermore, a recent oil spill incident that occurred in Indonesia is the oil spill in Balikpapan Bay on April 2018 caused by leaks from underwater pipelines cracked by ship anchors [\(The Directorate](#page-13-2) [General of Oil and Gas, 2018\)](#page-13-2). Cilacap Regency is one of the regions in Indonesia that is prone to oil spills. Oil spill incidents have occurred in Cilacap Regency in 2000, 2004, 2007, 2008, 2010, 2015, and 2016 [\(Yulianingsih, 2012;](#page-14-0) [Oil Spill Combat Team Indonesia, 2016\)](#page-13-3). Most of these oil spills originated from tankers involved in shipping activities in Cilacap Regency.

Oil spills have a considerable impact on the environment, as well as on the socioeconomic aspects, of coastal communities [\(International Tanker Owner Pollution](#page-12-0) [Federation, 2014\)](#page-12-0). The oil spill incident that occurred in Cilacap District in 2010 covered the turtle habitat, crane habitat on the Teluk Penyu Beach, and waterbird habitat on the estuary of the Donan River with oil layers [\(Mauludiyah, 2015\)](#page-13-4). Oil spills in the waters also directly affect the social activities of coastal communities [\(International Tanker Owner Pollution](#page-12-0) [Federation, 2014\)](#page-12-0). The oil spill incident in Cilacap Regency disrupted the use of the environment for beach tourism, pier, transportation facilities, and fishing and cultivation areas [\(Mauludiyah, 2015\)](#page-13-4). Moreover, the economic valuation of the oil spill incident in Cilacap Regency in 2010 yielded an economic loss of Rp. 1.9 trillion [\(Mauludiyah, 2015\)](#page-13-4).

The occurrence of oil spills should be avoided by implementing mitigation and preparedness activities involving the participation of companies, governments, and communities in the stages before, during, and after the incident [\(Xiong, Long, Tang, Wan, &](#page-14-1) [Li, 2015;](#page-14-1) [Hyder, Wright, Kirby, & Brant, 2017\)](#page-12-1). Moreover, the impacts of oil spills should be mitigated. Oil spill response in several cases only involved community participation during the occurrence of oil spills. Community participation has not been integrated into the predisaster or oil spill prevention plan of several companies. Teluk Penyu Beach, Cilacap Regency was selected because of its history of frequent oil spills and the involvement of the community in oil spill response in several occurrences. Efforts to minimize the environmental, social, and economic impacts of oil spills include oil spill response preparedness. These efforts should be implemented in an integrated manner by every component, i.e., the polluters, the government, and the community [\(Xiong et al., 2015;](#page-14-1) [Hyder](#page-12-1) [et al., 2017\)](#page-12-1). Several responses to international oil spills have integrated these three components by maximizing community participation to ensure a more effective oil spill cleanup [\(Sargisson, Hunt, Hanlen, Smith, & Hamerton, 2012;](#page-13-5) [Hunt, Smith, Hamerton, &](#page-12-2) Sargisson, 2014; [Hyder et al., 2017\)](#page-12-1). Oil spill response preparedness is an effort to prevent the impacts of oil spills on the environmental, social, and economic aspects [\(Lynch, 1994\)](#page-12-3). Oil spill response preparedness will be effective if supported by contingency planning, policies and regulations, response decision-making, cleanup technologies, and strict implementation [\(Ivanova, 2011;](#page-12-4) [Kurtz, 2013;](#page-12-5) [Smith, Hamerton, Hunt, & Sargisson, 2016;](#page-13-6) [Xiong et al., 2015;](#page-14-1) [Chen, Ye, Zhang, Jing, & Lee, 2018\).](#page-12-6) On the basis of these problems and concerns, this research aims to build an oil spill response preparedness model through community participation in Teluk Penyu Beach, Cilacap Regency.

2. Methods

This research was conducted at Teluk Penyu Beach, Cilacap Selatan District, Cilacap Regency (Figure 1). This location was selected on the basis of its history of frequent oil spill incidents. This research used quantitative and qualitative methods. Qualitative methods (i.e., interviews) were used to determine community participation (e.g., fishermen) in oil spill response at the study site. Modeling is done using the system dynamics method. On the basis of the systems thinking approach, Forrester developed a system dynamics method [\(Assaraf &](#page-12-7) [Orion, 2005\)](#page-12-7). This method was developed to understand the behavior of complex phenomena from the relationships between variables over time (Assaraf & Orion, 2005). System dynamics is defined as a method for learning a complex, dynamic, and nonlinear system by managing feedback [\(Soesilo & Karuniasa, 2014\)](#page-13-7). The system dynamics method aims to predict system performance in the future on the basis of optimal work results [\(Muhammadi,](#page-13-8) [Aminullah, & Soesilo, 2001\)](#page-13-8).

Figure 1. Teluk Penyu Beach, Cilacap Selatan District, Cilacap Regency

The steps of the system dynamics method are shown in Figure 2. The model structures of causal loop diagram (CLD) and stock flow diagram (SFD) are generated using a software called Powersim Studio Version 10, which is described in detail by [Soesilo &](#page-13-9) Karuniasa (2016) and [Soesilo](#page-13-10) (2018). In the modeling process, an assumption is needed to limit the scope of the model. Furthermore, the validity of the simulation results is tested by calculating the absolute mean error (AME) value. The model is declared valid if the AME value is smaller than 30%. Model validation is done by checking the consistency between CLD, SFD, structure validation, and statistical validation. If the model is declared valid, then the model can be simulated with an extension of up to 240 h (i.e., business as usual [BAU]). This duration was selected on the basis of the average time needed to overcome the oil spill in Teluk Penyu Beach, Cilacap Regency. Finally, a simple intervention is needed to optimize the model for the oil spill control efforts.

Figure 2. Steps of the system dynamics method

3. Results and Discussion

Oil spill incidents in Teluk Penyu Beach have environmental, social, and economic impacts. The relationship between environmental, social, and economic subsystems in the oil spill incident in Teluk Penyu Beach, Cilacap Selatan District, Cilacap Regency was analyzed using system dynamics modeling. The results and discussions in this section follow the order of the steps of the system dynamics method described previously.

3.1 Causal Loop Diagram

The causal loop between model variables that comprise the CLD oil spill subsystem is shown in Figure 3. The CLD structure shows the formation of five loops composed of one loop with the feedback loop reinforcing (R) or positive feedback loop $(+)$, which means that the behavior formed is exponential growth or collapse, and four loops with the feedback loop balancing (B) or negative feedback loop (−), which means that the behavior formed is goal seeking or decay. Loop R1 is the main loop formed by 11 variables, i.e., "Oil spill volume in the waters," "The rate of oil spill spread in the waters," "Oil spill area in the waters," "The rate of losing fish catches," "Economic loss of fisheries," "Total economic losses," "GAP economy," "Economic factor," "Community participation," "PTM on the beach," "Oil spill volume on the beach," and back to "Oil spill volume in the waters."

Loop B1 is formed by eight variables, i.e., "Oil spill volume on the beach," "Oil spills along the shoreline," "Economic loss of communities," "Total economic losses," "GAP economy," "Economic factor," "Community participation," "PTM on the beach," and back to "Oil spill volume on the beach." Loop B2 is formed by five variables, i.e., "Oil spill volume on the beach," "Oil spills along the shoreline," "Fishermen affected," "Community participation," "PTM on the beach," and back to "Oil spill volume on the beach." Loop B3 is formed by two variables, i.e., "Oil spill volume on the beach," "Evaporation process on the beach," and back to "Oil spill volume on the beach." Loop B4 is formed by two variables, i.e., "Oil spill volume in the water," "Evaporation process in the waters," and back to "Oil spill volume on the beach."

Figure 3. CLD of the oil spill response preparedness model

3.2 Stock Flow Diagram

The second structure is the SFD shown in Figure 4. The model simulated the oil spill incident in 2015, with an estimated spill source volume of $1,000 \text{ m}^3$. The simulation duration of 120 h (5 days) is in accordance with the response implemented by Pertamina RU IV Cilacap during oil spill incident prevention. Data on $1,000 \text{ m}^3$ oil spill volume and 120 h duration are considered the reference data. The variables in the model are adjusted to the real conditions in this study.

Figure 4. SFD of the oil spill response preparedness model

3.3 Assumption

The constructed models, both in CLD and SFD, certainly have limitations. These limitations are indicated by several model assumptions. The assumptions used are as follows: oil spills occur instantaneously; there are no additional sources of other oil spills in the waters; wind speed and direction are constant; current speed and direction are constant; the oil weathering process involves evaporation and spreading; the oil does not sink to the bottom of the waters; and fish are caught using fishing equipment, such as nets.

3.4 Simulation

The model is simulated to determine the natural conditions of oil spills in the waters without any oil spill prevention effort. The simulation results of oil spill volume in the waters are shown in Figure 5(a). In the first hour, the oil released in the waters is equal to $1,000 \text{ m}^3$. Then, the oil spill volume decreases because of the change in the oil mass through the processes of evaporation and mass transfer of oil to the beach. At 120 h, the oil spill volume in the waters is close to 0 $m³$. Furthermore, the simulation results shown in Figure 5(b) indicate an increase in oil spill volume on the coast, which is caused by the mass transfer of oil spills from the beach to the waters. Model simulation was conducted for 240 h (10 days). This duration was selected on the basis of the average time needed to overcome the oil spill. After 240 h, the oil spill volume in the waters decreases from $1,000 \text{ m}^3$ to 0 m³ (at 0 h to 240 h).

The BAU simulation results of oil spill volume in the waters with the decay behavior are shown in Figure 5(a). Oil spills in the waters will be reduced because of the natural weathering process of oil spills. In this model, the weathering process, which involves evaporation and spreading, is aided by several factors, such as wind and surface currents. The spreading process of oil spills in the waters will cause the oil spill area in the waters to increase, thereby increasing the number of areas in the waters covered by oil and disrupting the activities in these areas. Furthermore, the spreading of oil spills in the waters will reach the coastline because of several driving factors, such as wind and surface currents.

Figure 5. Simulation results of the oil spill volumes (a) in the waters and (b) on the beach

The BAU simulation results of oil spill volume on the beach with the goal-seeking behavior are shown in Figure 5(b). Oil spills on the beach will continue to increase from 0 $m³$ to 900 $m³$ (at 0 h to 240 h). The deployment process does not move all oil particles to the shoreline because the oil will undergo the evaporation process both in the waters and on the coastline. Oil spills along the coastline will have an impact on the environment, i.e., the destruction of mangrove forests along the Nusa Kambangan Coastline, Cilacap Regency. The BAU simulation results of mangrove forest damage with the exponential growth behavior are shown in Figure 6(a). The simulation results show that the extent of mangrove forest damage will increase in the coastline because the oil spills will reach the mangrove ecosystem through the tidal movement of waters; then, the oil will enter the mangrove and sediment root system [\(Mursalin, Nurjaya, & Effendi, 2014\)](#page-13-11). The extent of mangrove forest damage is approximately 13,000 ha. Mangrove forest damage affects the ecosystem. [Mursalin et al.](#page-13-11) (2014) reported that mangrove forest damage can disrupt the function of the forest as a feeding ground, nursery or breeding site, and spawning ground for some marine biota. In addition to the environmental impacts of oil spills on mangroves, capture fisheries activities will be affected. That is, fishing efforts will be reduced because ships and fishing gear are damaged by oil spills and fish in areas affected by oil spills usually die. The economic impact will be in the form of economic losses of fisheries and economic losses of communities from ship compensation costs and fishermen's wages for oil collected. Both of these can increase the total economic losses due to oil spills.

Figure 6. Simulation results of (a) an area of mangrove forest damage and (b) economic losses

The BAU simulation results of total economic losses due to oil spills with the exponential growth behavior are shown in Figure 6(b). The total economic losses for 240 h (10 days) will reach Rp. 600,000,000,000. On the basis of the data, the cost of losses reported by fishermen to the Indonesian Fishermen Association (HNSI) for the 2015 oil spill event was Rp. 40,733,000,000. The cost paid by the company was Rp. 4,250,575,000, which was 10% of the cost submitted. Fishermen will submit the compensation costs consisting of direct and indirect costs through the following mechanism: (1) Fishermen report to the HNSI. (2) The HNSI records and calculates the compensation costs on the basis of the number of fishermen, the number of ships, and the results of fishing. (3) The HNSI reports to related oil and gas processing units, (4) negotiates with stakeholders, (5) provides compensation fees from related oil and gas processing units to fishermen, and (6) distributes the funds to fishermen. This is different from the percentage of willingness of the company to pay the compensation costs of oil spill, which is 11% [\(Kim, 2015\)](#page-12-8). The behavior of the BAU simulation results shows that there is no decrease in the oil spill volume on the beach. Thus, the impact of oil spills on mangrove forest damage and economic losses increase. This finding can be attributed to the interaction between interdependent factors in the system. Contrary to the goal of the sustainability theory, the integrity of the environment can be maintained and guaranteed by minimizing the environmental impacts of oil spills. On the basis of the behavioral discrepancies between the BAU simulation results and these objectives, the researchers conducted several interventions by integrating the environmental, social, and economic aspects.

3.5 Validation

Validation of the simulation results of oil spills in the waters was conducted to test the validity of the simulation results. Validation is done by calculating the AME value from the reference and simulation results data. The AME value of the oil spill volume in the waters is 6.65% (<30%). This value indicates that the simulation conducted on the basis of the structure of the constructed model is valid. The comparison of the reference patterns and the simulation results of the oil spill volume in the waters are shown in Figure 7. The AME value of the oil spill volume on the beach is 19.36% (<30%). This value indicates that the simulation conducted on the basis of the structure of the constructed model is valid. The comparison of the reference data and the simulation results of the oil spill volume in the waters are shown in Figure 7. After determining that the constructed and simulated model is valid, intervention is needed.

Figure 7. Comparison of the oil spill volumes (a) in the waters and (b) on the beach

3.6 Intervention

Interventions are implemented to reduce the oil spill volumes in the waters and on the coast. The intervention scenario of the CLD structure is shown in Figure 8. New variables in the CLD structure after entering the intervention scenario include "PTM in the waters," "Company participation," "Number of PTM equipment," PTM equipment capacity," "PTM equipment effectivity," and "Participation increases effort." The intervention scenario aims to minimize the environmental impacts of oil spills. The intervention involved increasing efforts to prevent oil spills, increasing efforts to overcome mechanical oil spills by companies in the waters, and increasing efforts to deal with manual oil spills by communities on the beach. Oil spill response preparedness in the waters uses oil spill prevention equipment, such as oil booms, oil skimmers, and temporary oil storage tanks, supported by ships. Oil spill response preparedness on the beach increases the participation of fishermen through manual oil spill prevention exercises and schemes. Effective oil spill response preparedness is an effort that involves the participation of all components of the state, be it society or government [\(Xiong et](#page-14-1) [al., 2015;](#page-14-1) [Hyder et al., 2017;](#page-12-1) [Sulistyono, 2017\)](#page-13-12). This effort can work effectively with the increased communication between stakeholders [\(Walker, Pavia, Bostrom, Leschine, &](#page-13-13) [Starbird, 2015\)](#page-13-13). The intervention scenario of the SFD structure is shown in Figure 9.

Figure 8. CLD of the oil spill response preparedness model (intervention scenario)

The results of the intervention scenario show that the oil spill volumes in the waters and on the beach are decreasing rapidly. The results of the intervention scenario of the oil spill volumes in the waters and on the beach are shown in Figures 10(a) and 10(b).

Figure 9. SFD of the oil spill response preparedness model (intervention scenario)

The results show that oil spills in the waters decrease naturally through the processes of evaporation and mass transfer of oil to the beach, which is accelerated by efforts to overcome oil spills. On the basis of the efforts to increase the number of oil spill prevention equipment in the waters by increasing the participation of fishermen on the beach, a decrease in environmental impacts, such as mangrove forest damage, can be observed, as shown in Figure 11(a).

Figure 10. Intervention scenario of oil spill volumes (a) in the waters and (b) on the beach

Figure 11. Intervention scenario of (a) an area of mangrove forest damage and (b) total economic losses

Efforts to mitigate oil spills can reduce the area of oil spills in the waters. Active fishermen provide information about oil spills to the HNSI and conduct field surveys to support the information provided. Some quotes from structured interviews based on the questionnaire support this fact, "If there is an oil spill, the fishermen immediately report to the pillars, together with the head of the pillars of fishermen to the HNSI, then we directly survey the field, see the location, and take samples and photos" (Indonesian Fishermen Association, Cilacap Regency, 2018). Economic losses can also be reduced. The results of the intervention scenario of economic losses are shown in Figure 11(b), in which the original loss of Rp. 600,000,000,000 decreased to Rp. 60,000,000,000. The best intervention scenario of oil spill response preparedness is a combination of increasing the response to oil spills in the waters and on the coast. This result indicates the importance of the integration of oil spill prevention through community participation of both companies and fishermen. [Xiong et al. \(2015\),](#page-14-1)

[Hyder et al. \(2017\),](#page-12-1) and [Sulistyono \(2017\)](#page-13-12) reported that the integration of participation between state components (i.e., governments, companies, and communities) can optimize environmental management and protection. Knowledge related to community oil spills has been relatively high. Thus, efforts have been made not to increase public knowledge but to increase community participation, which could be in the form of community involvement in various forms of activities, such as delivering information, conducting surveys, sampling, and performing oil spill prevention operations.

4. Conclusion

On the basis of the results and discussions, we conclude that oil spill response preparedness through community participation in Teluk Penyu Beach, Cilacap Regency has been effectively simulated by system dynamics modeling. The oil spill response preparedness model is valid, with the AME value of 6.65%, as well as decay and goal-seeking behavior. Oil spill response preparedness needs the integration between company and community participation by increasing knowledge through community involvement in a combination of oil spill response exercises.

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