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GIS AND OIL SPILL TRACKING MODEL IN FORECASTING POTENTIAL OIL SPILL-AFFECTED AREAS ALONG TERENGGANU AND PAHANG COASTAL AREA

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Abstract

Oil contamination can occur accidentally or incidentally in the environment as long as petroleum or shipping activities exist. There is a need to take appropriate preventive measures to reduce the negative impact by carefully monitoring the sprinkles and dispersion particles due to the oil spill movement. An expected oil spill originating from the Resak platform is positioned at 49.1 nautical miles from the Kuala Terengganu shoreline. The Dulang platform, positioned at 69.8 nautical miles from the Kuala Terengganu, can pollute the coastline of the Terengganu and Pahang ecosystems. This study aims; (i) make predictions from the direction of oil particle dispersion and; (ii) engage the ecosystem to determine the effect of an oil spill on a platform around the coastal area. The combination of the Geographic Information System (GIS) and the Oil Spill Trajectory Model (OSTM) has been used to establish the appropriate response to locate the dense area of the slick. The result from the model running show in Northeast (NE) monsoon season, Terengganu and Pahang, have a high potential to affect. It is highly likely to reach the Terengganu coast area, especially in Dungun. It was predicted that 466 barrels of oil would arrive within four days of the December incident. Moreover, Kemaman and Pekan districts in Pahang also have the highest risk of being exposed to oil pollution during the Northeast Monsoon. This is due to the wind factors, which blow from South to North along the East coast of Malaysia Peninsular with a speed maximum of 13 ms-1 and indirectly carry the oil particles to coastal areas in Terengganu and Pahang.

Keywords: GIS, Oil Spill Tracking Model (OSTM), Monsoon Season

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INTRODUCTION

Oil spills are one of the significant sources of pollution in the environment. These unfortunate events could cause severe damage to the environment, especially to the sea ecosystem and tourism. Oil spills in the sea would take several months to get vanished. It can be lethal if it remains for an extended period on the sea surface, as it can spread over a vast area within a few hours in an open ocean due to the wind and waves (Jha, 2008). There are a minimum of 135011 platforms in the South China Sea (SCS), and 74% offshore installations in the SCS for Indonesia, Malaysia and Thailand (Twomey, 2010).

The South China Sea (SCS) covers a maritime area of 3.5 million square kilometres, with more than 70.78 billion barrels of oil reserves. It also is a part of the shipping route connecting the Pacific and Indian Oceans (Metelitsa, 2014). Malaysia has an estimated 615,100 km2 of acreage available for oil and gas exploration, which that area is almost the size of Myanmar (Khan et al., 2013). An enormous amount of oil was released from a barge found around the SCS on March 14, 2014 (Bernama, 2014). Oil drilling and mining activities are harmful. To the extent that they not only affect the ocean ecosystem due to the oil spill but also increase the risk of chemical material pollution, such as ferum, sulphur, and mercury, that has adverse effects on human health and ecosystems (Ohimain, 2002).

Moreover, Terengganu and Pahang states are exposed to the seasonal monsoon, influenced by Northeasterly (Nov, Dec, Jan, Feb and Mar) and Southwesterly wind (Jun, July, Aug). The Northeast (NE) monsoon winds that cross the SCS and Siamese Bay bring heavy rain to both areas (Suhaila et al., 2010). When the NE monsoon wind groups cross the equator and enter the southern hemisphere, the direction is refracted to the left by the Coriolis force and later becomes the northwest monsoon wind (Loo et al., 2015). The difference in the direction and the strength of the winds in these states will affect the movement and the direction of the pollution on the sea surface and the ability to tackle an issue, especially in case the pollution occurs in an open sea area.

Therefore, proper monitoring of oil spill movement directions can be carried out through a remote sensing image by obtaining the reports of a location which have been affected due to an oil spill. The cause of the problems and the solutions have been analysed and identified based on the possible incidents. Geographic information systems (GIS) and OSTM from National Oceanic and Atmospheric Administration (NOAA) are valuable tools for oil spill disaster management. Integration between these techniques produced a simulation model for monitoring areas likely to be contaminated. The results provided by OSTM the analysis can be stored in ArcGIS for making the oil spill model that can show the virtual simulation of the spreading pattern and the pollution effect on any potential area that is experiencing the pollution (Jordi et al., 2006).

STUDY AREA

Terengganu and Pahang are situated at the East Malaysia Peninsular, surrounded by beautiful beaches that have always been a source of tourist attraction. However, the focus area of this research is the mainland Terengganu and Pahang because the sources of oil pollution are caused by the platforms located close to Terengganu and Pahang shoreline. Terengganu has various kinds of islands, such as Redang Island, Lang Tengah Island, Wan Island, Bidong Island, Tenggol Island, Kapas Island and Perhentian Island, that are visited by many local as well as international tourists (Figure 1).

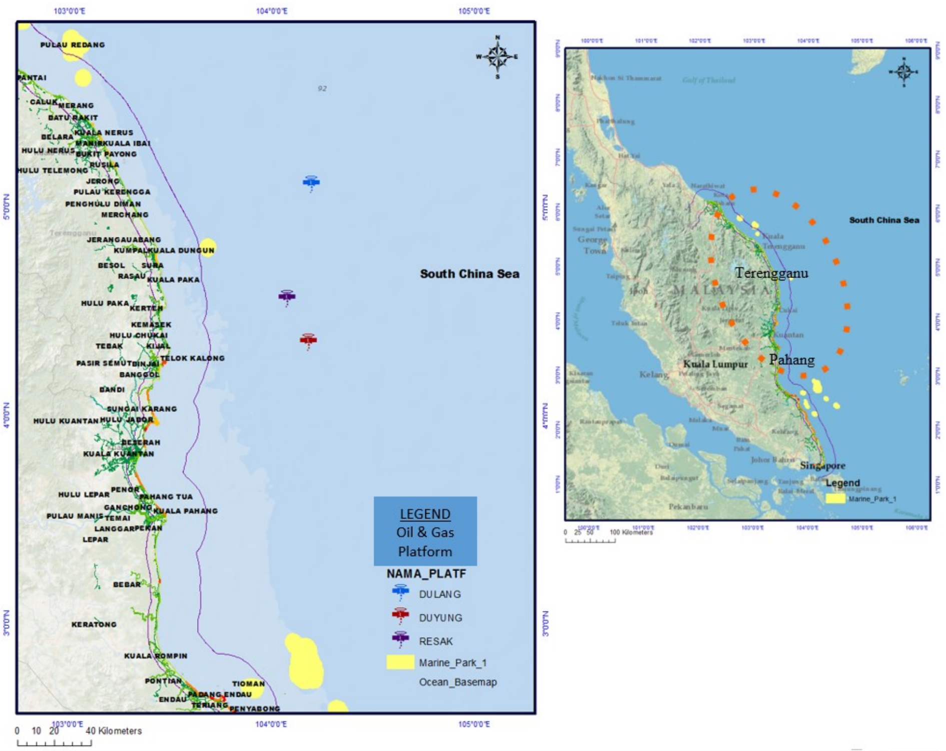

Figure 1: Research Area- Terengganu and Pahang Coast.

While in Pahang state, Kuantan is the capital of Pahang state and is one of the East Coast Economic Region (ECER). Most of the beach area at Pahang is a tourist attraction area. Specifically, Cherating has several international-class hotels, including Club Med Cherating, which high-end travellers visit. Apart from the tourist attractions in Cherating, the coastal area along Sg. Ular is also a famous tourist attraction and a location for grouper farming, where it is becoming one of the significant economic resources to the locals in the region. Meanwhile, based on the wind system, Terengganu and Pahang are exposed to the NE monsoon, where the wind regularly blows from the northeast in November and ends in the middle of March (Akhir, 2014).

The majority of the mining platform for oil and gas are found in relative structures along the country's coast, such as the Resak platform is positioned 91 km from the Kuala Terengganu shoreline, and the Dulang platform, located 130 km from Kuala Terengganu, excluded the other platform around. Consequently, the risk of an oil spill in the Terengganu and Pahang shoreline is high, especially when the NE monsoons, where the northeasterly wind indirectly will force the oil particle from SCS to move to the coastal area.

METHODOLOGY

Material & Method

Two platforms offshore are chosen as a source of oil pollution point latitude 5.1836°N, longitude 104.3253°E, which is the location for the Dulang platform and 5.7975°N, 103.9281°E for the Resak platform. The research areas are facing the SCS and are bounded by the coordinates 102.601°E, 6.403°N, 104.787°E and 2.367°N. The wind blowing strongly through the areas situated in this winding path will experience the cold effect. This leads to temperature fluctuations in Southeast Asia due to the monsoon climate and equator being over-exposed to the monsoon wind with rough sea conditions, which indirectly influence the oil spill on a coast.

The OSTM integrates Oil Spill Trajectory from NOAA and GIS techniques. The OSTM can conduct sensitivity analyses to understand how a spill's environmental parameters can affect a spill's spread and fate (Al-Azab et al., 2005). ArcGIS is the primary tool for producing a map of the environmentally sensitive area for oil spill management. ArcGIS mapping with several layers of land use and classifying the land cover map for research area according to the sensitivity to oil pollution based on the socio-economy and habitat types. ArcGIS will import an image from OSTM to observe the oil spill trajectory. Satellite image from the LANDSAT 8 ETM+ images on April 15, 2013, was used to produce the land use map and the shoreline map using the Image classification (supervised) technique. The views on the satellite images that show various types of landscape and colour tones can help to identify land use in the study area. Determining the kind of land use helps determine the areas with high value and a contributor to the economy.

The combination band technique was used to determine the land use type more clearly. This includes the combination of band middle-infrared (7), thermal infrared (6) and near-infrared (4) to classify the utilised land in the study area. Combination Band 432 provides more precise water boundaries and distinguishes apparent different types of vegetation. This band was also used for forecasting vegetation (Apan, 1996). Usually, band 432 is used to view the vegetation more accurately and make differences with the other vegetation area. Image composite 432 executes to interpret images matches with functional, vegetation mapping, identification, reflection chlorophyll, and differences in the species of vegetation (Dat & Yoshino, 2011).

Moreover, the image classification technique (Supervised) was used to classify the vegetative beaches, sandy beaches and much more (Clinton et al., 2010). While digitising, the baseline was done using the shoreline buffer with the pre-existing baseline. The buffer technique with a distance range of 50m was used to divide the distance between water surfaces with land to produce images of the coastline area. The buffer technique was used after the classification technique. It specifies the length of all other shorelines' landward and seaward positions.

Observing the incident scenario depends on the type and status condition of the pollution or fate of oil spilt floating, beached, or evaporated. In this observation, wind speed data will be used. The data taken from the ECNWF (European Centre for Medium-Range Weather Forecast) web is open, and the process by MATLAB software for plotting to produce a map for wind direction and wind speed in ms^{-1}. The wind data and wind direction were taken from November 1 to March 31, 2013, every 6 hours and started from 00.00, 06.00, 12.00, 18.00 and 23.00 at 6 hours intervals so that oil spill modelling and oil spill movement can observe for NE monsoon season.

Model Run

The model is operated for about 168 hours for the first week, representing the oil spill at 168, 360, 672 hours and 720 hours for one month in finding the dispersion direction-classified based on the yearly wind blows. Therefore, the monitoring was done from 0:00 a.m. to 24:00 p.m. throughout the year commencing from January until December 2013, where the oil spill model operated with an estimated total spill of 1000 barrels with a medium crude oil with API (heavy oil type) gravity values 0.91 and the rates of an oil spill of 1000 barrels from Resak and Dulang platforms.

The year 2013 divided into four scenarios according to the monsoon seasons presented in this research was, from November 2012 to the end of March 2013, to forecast the fate of an oil spill in the NE Monsoon season. The period from April to the end of June and September to the end of October were identified as the monsoon transition seasons to see the risk of oil spills during the monsoon. Moreover, to forecast the Southwest monsoon season, the period from the whole month of June till the end of August was selected to see the risk and fate trajectories of oil spills. To estimate the fate of the oil spill, specifically the movers, the model has been constructed by an equation as below;

$$\Delta x = \frac{\frac{u}{111{,}120.00024} * \Delta t}{dx}, \Delta y = \frac{v}{111{,}120.00024} * \Delta t, and \Delta z = 0$$

Where,

Δx, Δy = 2-D longitude and latitude displacement Δz = Held at zero

$\Delta t = t - t_1$ (Time elapsed between the time steps)

y = Latitude in a radian.

111,120.00024 = A number of meters per degree of latitude,

δx, δy = 2-d is long and flat displacement, respectively, at a given depth of a layer z

(GNOME, 2012).

The leading causes of pollutants' movement are the winds, currents and diffusion. To gain all the oil particle moves, a v (north-south) with u (east-west) components from diffusion, wind and currents and all types of other movers are added to each time step by the Euler Scheme in the equation above (1). It is divided into two types, the attached map movers and the universal movers.

A simple random walk makes diffusion with a square unit probability. The diffusion value is basic to a random walk; during the incidents, its value is calculated based on overflight data. The random walk, based on the diffusion value-*D*, represents the horizontal eddy diffusivity in the water. A low value would be 1,000 $cm^2\ s^{-1}$, and a high value would be between 100,000 to 1,000,000 $cm^2\ s^{-1}$. The model default is 100,000 $cm^2\ s^{-1}$. The diffusion result is given by following the formulas;

$\frac{\partial C}{\partial t} = D\nabla^2 C$, and below are the coordinates of a Cartesian. *C* is the concentration of a material.

$\frac{\partial C}{\partial t} = D_x * \frac{\partial^2 C}{\partial x^2} + D_y * \frac{\partial^2 c}{\partial y^2}$; Where *D* is a scalar diffusion coefficient in the x and y direction

Where Diffusion coefficient is; $D_x = \frac{1}{2} * \frac{\sigma_x^2}{\Delta t}$; (3)

While a variant of a distribution is $\sigma\frac{2}{x} = \int_{-\Delta x}^{\Delta x} \frac{x^2}{2*\Delta x} dx = \frac{\Delta x^2}{3}$ (4)

Moreover, for the $\Delta x = \frac{dx*\frac{\sqrt{6*\frac{D}{10{,}000}*\Delta t}}{111{,}120.00024}}{\cos(y)}, \Delta y = dy * \frac{\sqrt{6*\frac{D}{10{,}000}*\Delta t}}{111{,}120.00024}$ (5)

Where,

t, t₁ = Time elapse (age in hours) at time steps.

y = Latitude in radians.

While the evaporation result was calculated using the equation

$$x_{prob} = \frac{P_1*\left(\frac{-t_i}{2H_1} - 2^{\frac{t_i-1-2*t_i}{H_1}}\right) + P_2*\left(\frac{-t_i}{2H_2} - 2^{\frac{t_i-1-2*t_i}{H_2}}\right) + P_3*\left(\frac{-t_i}{2H_3} - 2^{\frac{t_i-1-2*t_i}{H_3}}\right)}{P_1*\frac{-t_i}{2H_1} + P_2*\frac{-t_i}{2H_2} + P_3*\frac{-t_i}{2H_3}}$$; (6)

Where,

H = Half-lives of each constituent (in an hour) for a pollution while.

P = Percentage of each constituent (as decimals).

RESULT AND DISCUSSION

During the Northeast Monsoon

About 473 barrels in January came from Resak, reached the Kemaman district shoreline, and contaminated the Marang area to Kuala Paka. These are based on the forecast analysis of OSTM, according to which 20 barrels of oil spill particles were in the second week have taken place in November (Figure 2). However, the December results from the Resak platform reveal that the spreading radius is much smaller. The spreading radius is only from the Marang district shoreline to the Dungun district shoreline. However, in Dungun, it was predicted that 466 barrels of oil would arrive within four days after the incident in December. In contrast, the spread of oil particles from the Dulang platform is wider, where the particles have been spread to almost 223 km from Kemasik to the Bebar area at Pekan, Pahang.

In January, 473 barrels of oil spilt came from Resak. They reach the shoreline at Kemaman district, contaminating the Marang area to Kuala Paka, thus affecting the shores, mangroves, epifauna and infauna, wildlife and the socio-economic area along the coast of the Kemaman district up to the Kuantan district in Pahang. The Resak platform is closer to the Kuala Terengganu shorelines. Therefore, the wind cannot spread the oil particles to a broader area.

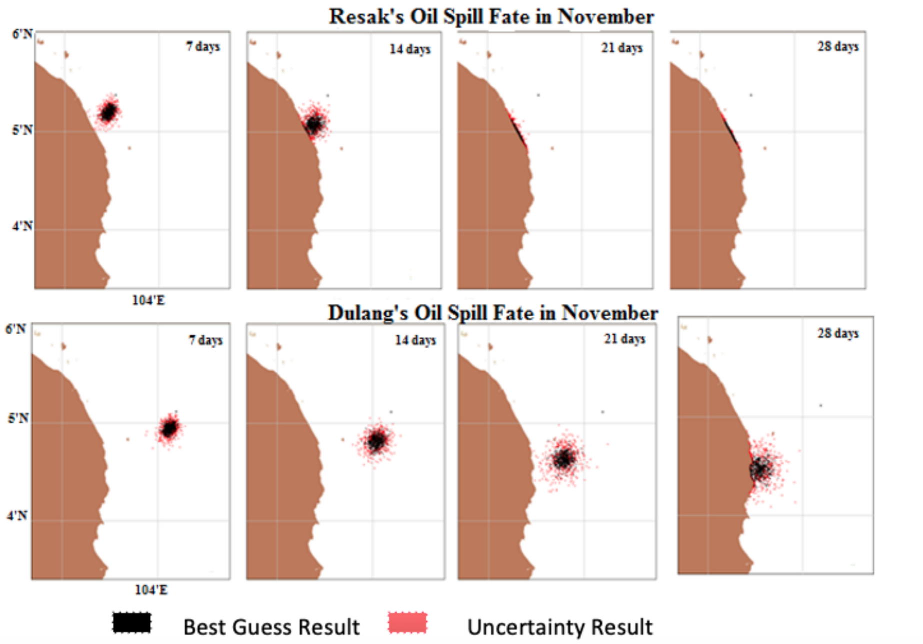

Figure 2: Oil particle movement during the Northeast monsoon in November.

Moreover, in February, there were 43 barrels of particles found in February, risking the pollution in the shoreline at Merchang. Likewise, in March, almost 217 barrels of particles were found to be threatening the pollution at the Pulau Kerengga beaches by the first week. In March, the forecasting analysis also shows that contaminated particles have a significant prospect of reaching the shoreline on December 14. Compared to December, February and March, the forecasting results show that oil particles from the Resak platform are at high risk of reaching the shore of Pulau Kerengga to Merchang by the fourth day. Moreover, the model also indicates that the wind speed in December is stronger as compared to November and that it takes just a short period to carry all the contaminated materials to the land along the coast of Marang, Kuala Paka, Dungun beaches up to the area of Pekan and Pahang from Dulang platform with a wider radius.

During Southeast Monsoon

The scenario is different during the southwest monsoons in which, even after a month, 50.9% of the raw materials still floating on the sea and did not disperse to the beach by June from both platforms (Figure 3).

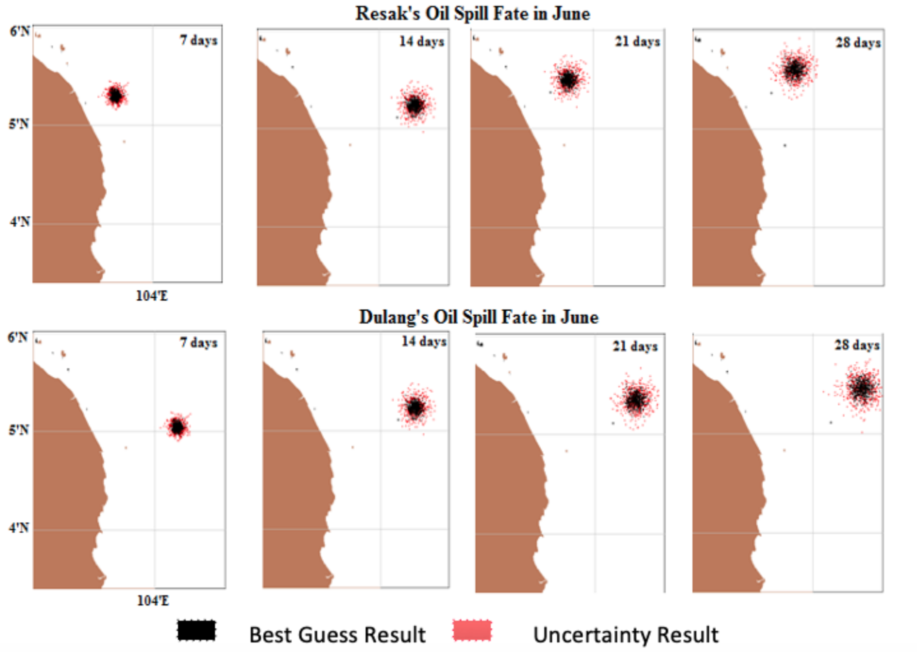

Figure 3: Oil particles movement during Southwest Monsoon in June

Moreover, modelling showed that the spilt material in this season was moving away from the Dulang and Resak platforms, and the onshore spill was heading towards the sea in the direction of the southwest monsoon winds.

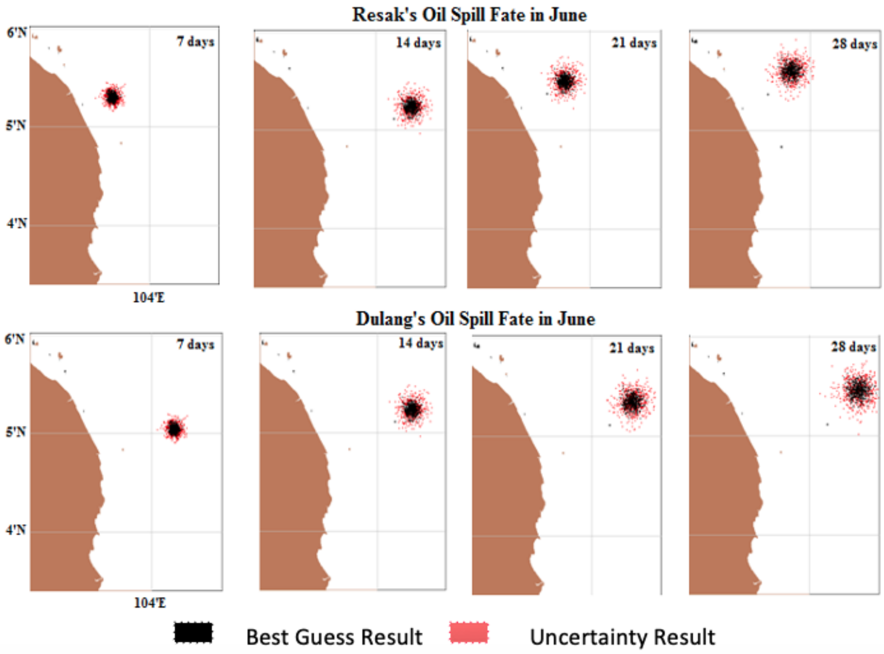

Figure 4: Oil particles movement during Southwest Monsoon in August

However, it was different in July and August during the monsoon season for the Resak platform because, based on the analysis, about 18 barrels of contamination could reach the shoreline or the islands in the North (figure 4).

During Transmission Monsoon

The winds are weaker during the monsoon transition in April, May, September and October. This season spills from the Dulang platform do not spread as far and remain near the spillage. The spreading processes model has discovered that 50.9 % of the total is floating contaminants after a month, whereas the remaining 49.1 % is dispersed and evaporated. However, the Resak platform is closer to the Kuala Terengganu coast. The wind in April carries about 11 barrels of oil on the 13th day and then pollutes the shoreline along the district of Batu Rakit to the Pulau Kerengga (Figure 5). Therefore, based on the results from modelling, it is revealed that the processes that occur in the oil spill depend on the state of the ocean's current and the influence of monsoon winds or weather conditions. In contrast, based on the forecasting for Resak Platform, results show that only a few oil particles contaminated the Terengganu offshore areas by the 23rd day of September and October, and they were headed to the North of Malaysia

Peninsular and created a significant likelihood of polluting the island at the North of Malaysia Peninsular.

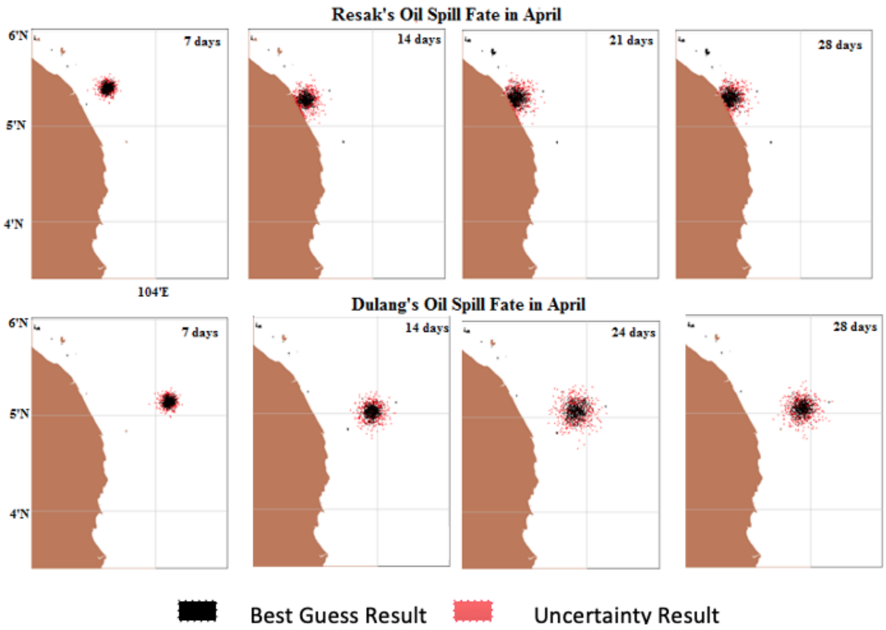

Figure 5: Oil particles movement during Inter-monsoon in April

The analysis and forecasting model demonstrate that the wind direction and capacity can indirectly impact and will influence the oil particles and wave strength of their size and movement. If the spill happens during the northeast monsoon season, the possibility of the risk of particles reaching the shoreline is almost 100%. In contrast, the Northeast Monsoon data shows wind from the Northeast in November until March is blowing from the North to the south throughout the year, most of the time during the monsoon. The result shows that an oil spill modelling is moving in the wind direction to the land. However, the NE wind direction indicates that the oil spill movement was slower in the early monsoon in November than in December. This is because, in the second week of December, the oil spill reached the land and polluted a few areas compared to the early monsoon, and the contaminants were still in the sea during the second week.

Also, according to the modelling forecast, the oil movement in November and March is more concentrated and in groups compared to December, January and February, in which the activities are more spread and scattered. Furthermore, the wind is strong during this season, and the sea condition is usually wavy. Thus, the waves break up the oil slick and form the oil droplets that later become suspended in the water. Only a small proportion of these droplets and neutral buoyancy remain dispersed in the water, and most of it floats back to the surface. The oil slick breaks up into smaller droplet sizes before it disperses down through the water column, and all these activities are the effect of the current, also known as 'the intrusion depth' (Delvigne & Sweeney, 1989).

Based on the results of oil spill observation and modelling, the oil spill process is heavily dependent on the density of oil, sea surface temperature and wind direction as well as the wind speed, which can cause the surface waves to transform the oil particles into a much smaller and thicker in size and is regarded as the physical and dynamic process. As a result, it impacts the movement and spreading of oil spills, while the chemical and biological process reduces the thickness of the oil. Thus, the oil spill modelling showed that the process of dispersion, dissolution, spreading and evaporation can be seen within seven days. It begins when the oil forms a slick being moved by the surface current and the winds.

Later, the majority of the oil components evaporate from the surface. Still, the lighter hydrocarbons get separated into the water column, and by breaking waves generated by the wind, the oil eventually emulsifies. Moreover, this process still depends on the amount and the type of oil involved as well as on the location of the incident. Apart from that, the wind movement in this month during the Northeast monsoon season produces a different rate of oil fate according to the other months. The figure below (Figure 6) demonstrates that the wind blows more strongly in December.

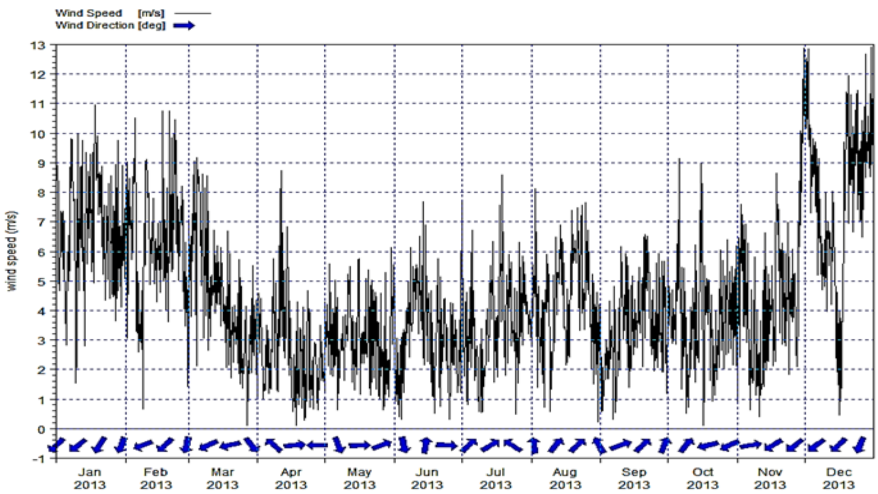

Figure 6: Show Wind direction and a capacity graph of the 2013 ECNWF source.

Consequently, it indirectly carried the oil particles on the sea surface to the coastal area. It polluted the whole area on the 14th day after the incident as opposed to the other months. Based on the result from the analysis of the northeast monsoon, it was also found that in January, the wind movements are lighter as compared to February, in which the wind sometimes becomes relatively strong and can carry the oil particles to the land in a massive quantity as compared to December on the 20th day after the incident. This reveals that the wind blows and direction can significantly influence the radius of oil particles spreading patterns with the quantity of the particles that reach the land before contaminating the affected area.

However, the schedule for March shows that wind movement changes and sometimes becomes windy, causing the wind to carry the oil molecules to the coast earlier than in January and February. However, the total of spills brought and affected the east coast shoreline is still lesser as compared to the aforementioned in December. These clearly showed that wind direction and speed got slower by the end of March. The wind direction and strength also influence the radius or habitat ecosystem's destruction rate due to the oil spill. Through oil spill fate trajectory observation, the results of the research and wind-blowing graph demonstrate that in the northeast monsoon season, which begins in November, it was evident that the wind movement was from West-Southwest to East Northeast. By the middle of November, the wind direction had changed from East-Northeast to West-Southwest up until February. According to the forecast results for the Resak platform, the destructive area radius in the upcoming months is almost the same and concentrated more on the area from Marang to Dungun, where the radius of the oil particles spreading is 22 km to 38 km.

However, in January, the oil particles are found to be in excess in the south of Terengganu, but different in March, where oil particles concentrate more towards the North of Terengganu. For the Dulang platform, the oil spreading radius is much wider because of the distance factor of the Dulang, which is more remote than the Resak platform. This caused the oil particles to remain to exist much longer on the sea surface, and after undergoing a few processes and wave actions lead to the particles were separated and scattered on a broader scale, whereas, in February, the oil particles spread and contaminated the area from the Kemaman district to the Penor, Pahang. Since the oil particles' radius this month caused by the Dulang platform was extending over 101km, which means that the larger the radius, the longer the oil particles will stay in the water and wave action will indirectly carry them into multi directions, hence possibly exposes the area to the pollution in a larger scale of radius.

CONCLUSION

The OSTM can be used as a faster tool to define a trajectory for emergency response, and GIS is used to observe each attribute in the risky area more clear. Through this research, the OSTM provides a clearer picture of the dispersion of pollutants based on the current state of the oceans. Integration between these tools enables a more efficient analysis which is done in the case of any accident that may impact marine life and the surrounding areas. Moreover, the simulated OSTM shows that oil spread is directed to the northwest, heading towards land and reaching the coastal area, where the oil spreading model can assist in the contingency plan to tackle a potential incident that may pollute an area in Pahang and Terengganu.

Furthermore, OSTM is a very efficient and widely used model as it can easily be applied and does not require a substantial cost. Besides, modelling also makes it easier to observe and understand. In light of this research, a few precautionary steps might also be taken in the event of any accident in the National Sea. However, a plan should be executed for contingency and conservation according to the needs and interests of the area since the conservation plan cannot be taken lightly. Lastly, any research without knowing the background of the incident could result in a massive disaster.

Furthermore, GIS databases store the spatial data or affected area location and can also maximise the spatial data in one particular area that can be made as a research possibility of arriving at a decision or taking more certain actions, as well as connecting the spatial data with the attribute data. Spatial data are needed to understand the effects of the negative impact caused by the oil spill that indirectly influences the sea organisms and offshore areas. While modelling provides a better view regarding the movement or what is happening on the surface, along with making the prediction and the Disaster Recovery Management more easily planned and executed. A comprehensive strategy is one activity set under disaster management to reduce the risk by decreasing the elements of risk, ensuring precisely that planning is done before the incident happens, and effectively and efficiently taking counteraction to overcome the disaster when it occurs.

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