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Modeling Of Oil Spill Trajectory and Fate in Sudanese Red Sea Coastal Water

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Abstract- Prediction and simulation of the trajectory and weathering of marine oil spills are essential to the development of pollution response and contingency plans, and the evaluation of environmental impact assessments. In this study, SL Ross Trajectory and fate modeling was applied to identify the shortest time for oil to reach Bashayer Red Sea shoreline in order to model the worst case scenarios. Four different scenarios were tested out, two for winter and two for summer. Results showed that in winter the spill movement is towards south and southwest while it moves to the northwest in summer. In both cases the spill will contact Bashayer Marine Terminal (BMT) shoreline within 4 hours in winter and 6 hours in summer rely on the combined effect of wind and tidal current. It was also shown that between 47.7 to 64% of the oil remain on the surface after 10 hours of spill.

KEYWORDS: *Oil spill, SL Ross model, Bashayer Marine Terminal (BMT), Shoreline contact.*

مستلخص:

أن توقع ومحاكاة مسار بقعة نفطية علي ساحل البحر ضروري لمكافحة التلوث النفطي ووضع خطة طوارىء وتقييم الأثر البيئي. في هذه الدراسة تم تطبيق نموذج SL Ross للتعرف علي أقصر زمن تأخذه بقعة نفطية للوصول لشاطئ ميناء بشائر أذا ما حدث تسرب نفطي وذلك للا 63 لأسوأ الفروض. أجريت أربعة سيناريوهات مختلفة أثنان في فصل الشتاء واثنان في الصيف. أظهرت النتائج أز لنفط تتجه الي الجنوب و الجنوب الغربي في فصل الشتاء بينما تتجه ناحية الشمال الغربي في فصل الصيف. في كل الأحوال ستصطدم البقعة النفطية بشاطئ ميناء بشائر. أطراف البقعة تصل الشاطئ خلال 4 ساعات في فصل الشتاء و6 ساعات في فصل الصيف أعتماداً علي اتجاه وسرعة كل من الرياح والتيارات البحرية. ما بين 47.7 الي64% من البقعه تكون متبقية علي سطح البحربعد مرور10 ساعات من الأنسكاب.

63

Introduction

The world production of crude oil is about 3 billion tons per year and half of it is transported by sea [1].

Being strategically positioned between the Indian Ocean and Mediterranean Sea, the Red Sea has been extensively used by international maritime traffic. A significant amount of oil is spilled into the sea from natural and non natural sources. Oil pollution threatens coastal environment and affects adversely the biological life and ecology. Trajectory models are used to identify the shortest time for oil to reach the shoreline. ch information is required in identifying response requirements. The intension is to model the worst case scenarios. The results of the trajectory and fate model calculation determine both travel times and location of shoreline oiling, together with slick volume and amounts evaporated, dispersed and beached. The three basic questions of practical importance concerning given oil spills are as follows: where will it move to, when will it get there, and what will be its state when it arrives. The main objective of this paper identify the shortest time for Sudanese crude oil to reach the Red Sea shoreline by modeling several scenarios and identifying the worst case scenarios using SL Ross trajectory model. A hypothetical accidental spill of Sudanese crude oil was used in this study.

SL Ross model Description

SL Ross is a company that is recognized internationally as a leader in oil spill management and control. The oil spill behavior model developed at SL Ross is one of the most comprehensive available models and has been "ground-truthed" on a number of experimental and real offshore spills. The model describes the trajectory and behavior of marine oil spills as a function of type, size, oil properties and prevailing environmental conditions. The oil slick is represented by a collection of particles; each of these particles has the ability to account for spreading and weathering of the slick as it moves through the marine environment, affected by winds and sea current. A videotape management system is also built into the model. The user selects the location and the system automatically identifies the predicted video clip for that portion of the shore, advances the media to that location and plays the video record either on-screen or on the television set.

Model Formulation

SL Ross spreading model relies on the work of Fay (2) and Mackay et al (3), but includes the modifications to account for oil viscosity changes and the development of a yield stress in the oil (i.e., pour point). Longer term spreading takes into account oceanic diffusion processes according to relationship developed by Okubo (4). Evaporation models use the work of Stiver and Mackay (5) with modification developed by Ross and Mackay (6). Natural dispersion is modeled using Audunsons (7). Natural dispersion model is modified to account for oil density, viscosity, interfacial tension and pour point. For emulsification the model uses the relationship developed by Zagorski and Mackay (8) with modification by Bobra (9), Ross and Mackay (6).

The movement of slicks discharged in the model is determined through the vector addition of the local surface water current and 3% of the prevailing wind speed. Wind forecast are entered by the user for each spill scenario of interest based on the best available data. Surface water currents are provided, in map form that identifies the spatial variation in the water velocities. If surface water current varies with time, such as in a tidal situation, a number of map sets can be used to represent the variation. The model is given a schedule of the time histories for the use of the predicted map at a given time in the life of the spill.

Simulation Case

A simulation example is proposed to illustrate the use of the assessment of the risk of Portsudan and Bashayer shore contamination by offshore oil spills. The results of the trajectory and fate mode calculation produce both travel times and location of shoreline oiling, together with slick volume and amounts evaporated, dispersed and beached. A simulation of a hypothetical accidental oil spill of 1000 m^3 of Nile Blend (NB) Sudanese crude oil with density of 854.4 kg/ m^3 was used. The sizes of spills were selected based on consultation with experts and in line with common practice. The spill is located at Latitude 19^o 24' 13" and Longitude 37^o 12' 32" at the Bashayer sea surface. The initial location of the oil slick is shown by a star in the Figures. Wind and tidal current are two main factors to control the oil spill distribution. Of course, the winds will likely change speed and direction over the period of time being simulated. Thus the wind predictions are the key assumption. Unfortunately, wind forecasts are difficult to be accurate. In this study, wind prevailing condition at any specified season was considered based on 30 years historical records of wind data and wind direction obtained from Sudan Meteorological Authority.

Two main situations were modeled, winter and summer conditions. In winter scenario conditions the sea temperature condition taken as 25^{o} C, the air temperature as 30^{o} C, with a current which moves from north to south. A completely inverted situation, in the summer where currents flow towards north, sea temperature condition of 35^{o} C, and air temperature of 40^{o} C were considered. Four different scenarios were carried out in this study, two for winter and two for summer. Prevailing wind condition in winter was taken to be 10 and 9 knots with prevailing direction of Northeast and North, respectively.

In the summer conditions, the oil was subjected to prevailing wind speed of 8 and 4 knots with prevailing direction of east and northeast. The wind data for the period was obtained from Sudan Meteorological Authority. As the model simulates the movement of the oil slick and its change in the size, it also determines at every time step whether the periphery of the oil slick has contacted the shoreline or not. The simulation time used was 10 to 21 hours. The length of simulation time was chosen according to the time of oil-shore contact. Two figures for scenario 1 and scenario 3 were selected to simulate positions of oil slick.

RESULTS

Winter (First scenario)

This scenario used a wind speed of 10 knots. The simulation results are shown in Figures 1 and 2. The results show that the movements of oil rely on the combined effect of wind and tidal current. The spill was moving to the southwest, mimicking the prevailing wind and current conditions.

The model indicates that oil would reach the coastline approximately 4 hours after the initial release. The slick may affect large area of the shore after six hours.

The shoreline interaction oil represent about 5.6% of total amount spilled at the beginning of the contact (5 hours after the release), this amount increases rapidly to 18.9% at the hour 6 then fall gradually to reach 11.3% at the hour 10. After 6 hours, oil started to return back to the sea.

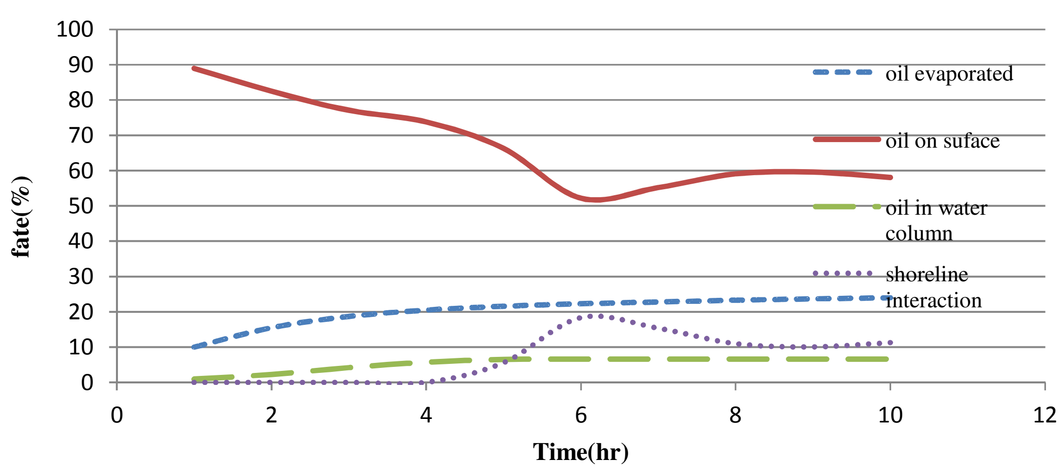
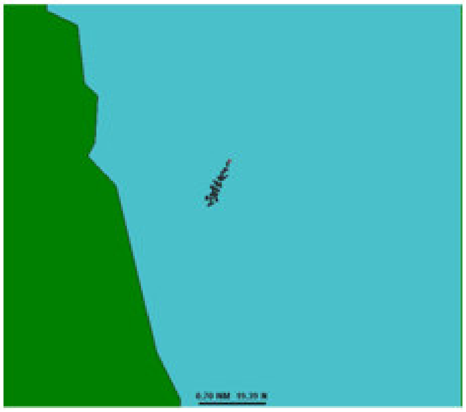
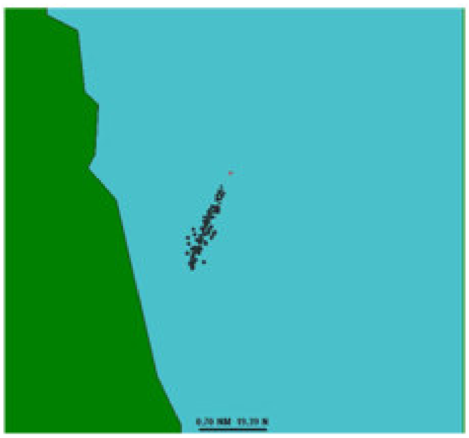
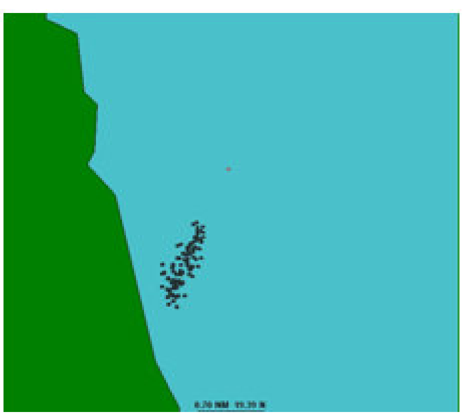
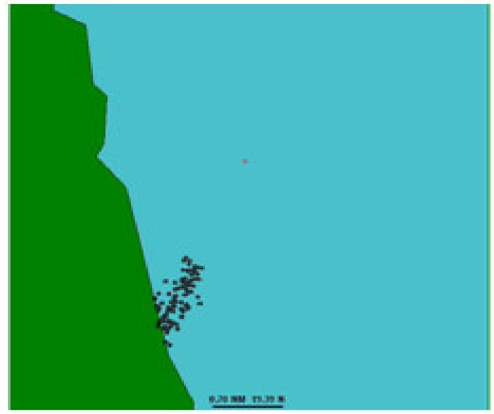


Figure 1: Fate of Nile Blend crude oil (scenario 1)


(a) After 1 hour


(b) After 2 hour

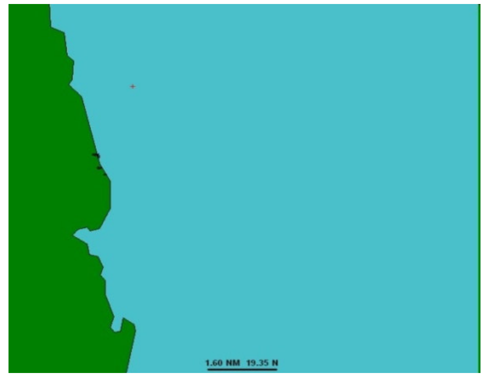

(c) After 3 hour


(d) After 4 hour


(e) After 5 hour

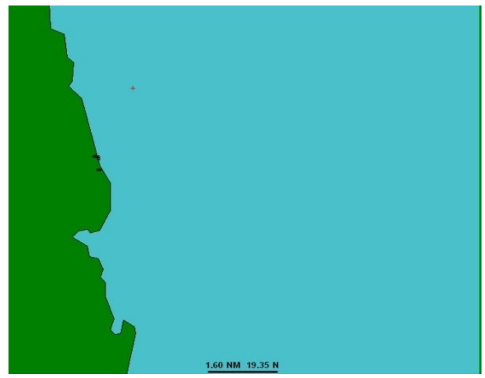

(f) After 6 hour

(g) After 7 hours



(i) After 9 hours

(h) After 8 hours



(j) After 10 hours

Figure 2(a-j): Simulated trajectories of NB crude oil slick originated at offshore location using wind prevailing of 10 knots NE (scenario 1).

Consequently shoreline interaction started to decrease. The length of the shoreline affected by an oil spill depends on the size of the oil slick, on the wind direction after the initial shore contact, as well as on longshore currents that may cause further migration of the oil slick along the shoreline. For example, if the wind continues in a direction normal to the shoreline, then the affected length of the shoreline will be at least equal to the diameter of the oil slick at the time of initial contact [(10)].

Clearly oil does not remain permanently on the sea surface. It may disperse into the water column either completely or partially under the action of natural forces. According to the simulations, at the first hour 89% of the spilled oil remains on the water surface, the amount decreased gradually due to weathering processes such as evaporation to reach to about 58% at the end of hour 10. Immediately at the beginning of spill the lighter fractions of oil evaporate. It has been observed that this evaporation will remove as much as 20% of the spill during the first 4 hours, after that evaporation will increase the loss of spilled oil gradually to reach 24% at the hour 10. The dispersion into the water column is gradually increased (from 1% at hour 1 to 6.5% at hour 5) then the amount remains constant at 6.6% till the end of simulation. Results showed that, oil may accumulate along the coast and may be removed partially by evaporation and re-entrain to the water column through the flow. Similar phenomena may happen for the tidal zone. These areas may change to dry point during the ebb-tide period. This process is essential for the evaluation of the degree of coast impact.

Winter (Second scenario)

This scenario used a wind speed of 9 knots, the winds were predominantly from the north and the current moves from north to south (the most common situation in this period) [11, 12]. The simulation suggests that north winds would hold the oil to the shore. Simulation time was 15 hours. Simulation clearly shows the spill moving to the south, following the prevailing wind and current directions. After 9 hours oil started to move a bit towards shore due to geographical characteristics at that area of Bashayer terminal, it seems like a semi-enclosed basin and hence oil accumulates at this basin. Accumulation of spill increased with time which may affect large area of shore at that place. Oil started to hit the shoreline after 11 hours from the spillage. After contact with the shoreline, the model changes progressively the shape of the oil slick from elongated shape to a semicircle.

Within 11 hours, about 0.6 % of the spilled oil landed on Bashayer Red Sea beaches increased to 2.6% after 14 hours from the start of oil spill. Oil travels as far as 8 kms from the spill site. The lightest, most toxic fractions probably evaporated within the first 4 hours and constituted more than 20% of the total amount (1000 m3). 14 hours after the spill, about 57% of the oil remained on the surface, 14% of the total oil spilled entered to water column and 26% has evaporated.

Summer (Third scenario)

Figure 3 shows the simulated trajectories for the third scenario. The model was carried out to reflect the simulation of the likely trajectory of the Nile Blend (Sudanese) crude oil spill at prevailing wind of 8 knots, with East prevailing wind direction. According to the simulations, the oil slick was moving to the Northwest i.e. towards the Bashayer coast. The model indicated that oil would reach the coastline approximately 6 hours after the initial release (Figure 3.f).

Computations showed that if the countermeasures are taken after 1 hour about 12 % of Nile Blend crude oil lost by evaporation. Evaporation rate increased very steep at the first four hours (from 11.4% at the first hour to 22% at the fourth hour) then the process increased gradually to 26.4% at the end of the hour 10. The lightest, most toxic fractions evaporated rapidly at first.

The oil remains on the sea water surface decreased from 87.4% at the first hour to reach only 47.7% at the end of the hour 10.

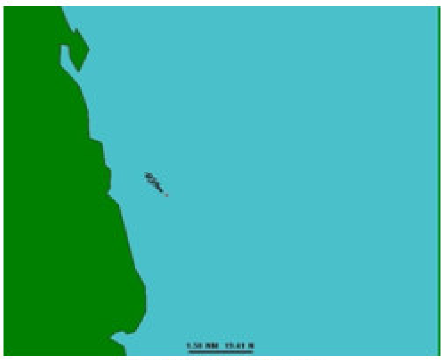
At this time the oil lost in the water column about 15%, while only 1.2% of the total oil spilled was entered to water column in the first hour. According to the simulations, the oil slick was moving back and forth with the tidal cycle. After 6 hours oil started to return back to the sea which made shoreline interaction decreased from 1.9 to 1.2% at 6 and 8 hours respectively, and then oil returned back to the shoreline which made shoreline interaction increased to11% at 10 hours after Nile Blend crude oil release (Figure 4).

Summer (Fourth scenario)

This scenario used a wind speed of 4 knots and the prevailing direction was NE. The output from these trajectories provides information on the likely trajectory of a spill by wind and current transport. The trajectory was allowed to continue for as long as 21 hours. The results of the simulation show that, the slick is moving in the northwest direction.

The output from these trajectories provides information on the likely trajectory of a spill to contact shoreline. The first map consists of a source and an initially visible spot of oil, both located near the oil terminal. The diagram of this spot increase gradually as it moves towards the shore due to spreading.


(a) After 1 hour


(b) After 2 hours


(c) After 3 hours


(d) After 4 hours


(d) After 4 hours


(e) After 5 hours


(f) After 6 hours


(g) After 7 hours

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(e) After 5 hours

(h) After 8 hours

(i) After 9 hours

The winds and current tended to carry the oil in Northwest direction along the coast. Oil started to hit the shoreline after 16 hours from the spillage. After contact with the shoreline, the circle shape of the oil slick, increased and became more and more elongated as the oil slick was pushed against the shore.

(j) After 10 hours

Figure 3 (a-j): Simulated trajectories of NB crude oil slick originated at offshore location using wind prevailing of 8 knots E (Scenario 3).

Result showed that largest spot of the spilled oil was concentrated around the small gulf at the coast. The shoreline interaction oil represent about 0.6% of the total amount spilled at the beginning of the contact (16 hours after the release), this amount increased gradually to reach 13.2% at the hour 21. Oil on surface seawater decreased rapidly from 90.1% at first hour to only 38.8% at the hour 21. This is due to the evaporation of the light component of the Nile Blend crude oil, as well as the chemical and biological weathering processes of the NB crude oil.

The fate of spilled oil showed that evaporation removed 9.4% of the total spilled amount (1000 m^3) during the first hour, the amount increased rapidly to more than 20% at the fourth hour, then the removal due to evaporation increased gradually to reach 28.4% by the end of the hour 21. At this point, the dispersion into the water column was greatly increased (19.6 % of the total amount of spilled oil). The oil in water column at hour 1 was 0.5% of the total spilled oil.

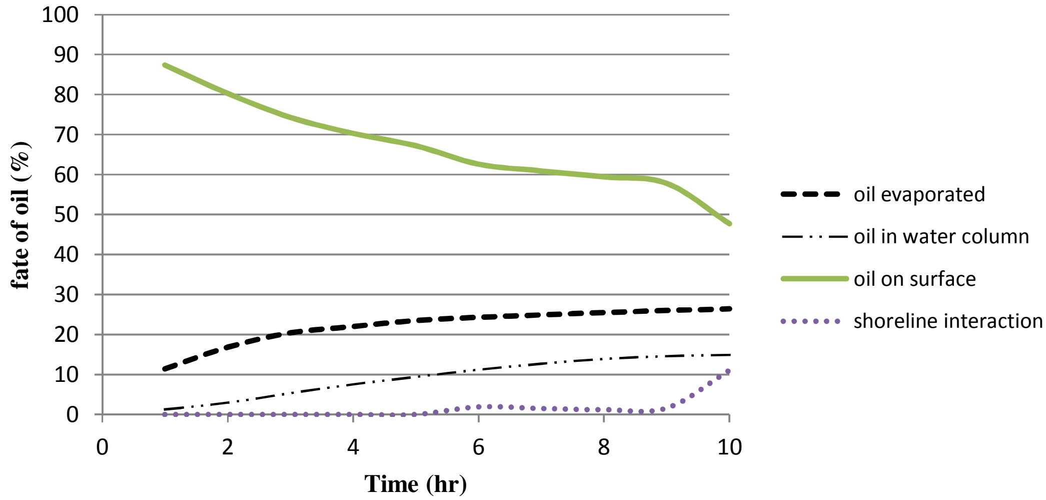

Figure 4: Oil fate in summer

Conclusion

A simulation of a hypothetical accidental oil spill of Nile Blend (NB) crude oil using SL Ross model showed that, the movements of oil rely on the combined effect of wind and tidal current. In winter the spill moving to the south and southwest while it move to the northwest in summer. In both cases the spill will contact Bashayer Marine Terminal (BMT) shoreline. The results show that the shortest time to reach the shoreline in winter was from 4 to 11 hours and 6 to 16 hours in summer, depends on wind speed and direction.

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