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# Modeling marine oil spill trajectory and fate off Hurghada, Red Sea coast, Egypt

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## ABSTRACT
The Russian-Ukrainian conflict has diverted European nations from purchasing Russian oil and correspondingly increased the demand from Arab Gulf countries, increasing the number of tankers transporting oil via the Gulf of Suez and the Suez Canal. Therefore, the shipping route is vulnerable to oil seepage accidents, affecting Egyptian tourist cities like Hurghada. Thus, the purpose of this study was to determine the most susceptible zones to contamination and calculate affecting processes (evaporation, natural dispersion, and emulsification) that may occur as a result of crude oil spill accidents in the strait of Gubal northern of Hurghada using the General National Oceanic and Atmospheric Administration Operational Oil Modeling Environment (GNOME) and Automated Data Inquiry for Oil Spills (ADIOS2) models. For this purpose, two scenarios were simulated in February and August 2021 of 1000 metric tons of Arabian light crude oil. The trajectory maps highlighted that the northern Red Sea islands (Ashrafie, Small Gubal, Geisum, Tawila, Shadwan, and Gifton), which have enormous economic and strategic significance are the most vulnerable areas to pollution. In addition, the estimated results demonstrated that the movement of the spilled oil is affected by the prevailing wind direction and marine currents. The ADIOS2 model results showed that more than a quarter of the amount of the light crude oil was evaporated. At the same time, the percentage of natural dispersion increased slowly and did not exceed 1.3% in both scenarios. Furthermore, the emulsion's water content increased rapidly to 90% by the end of the simulation, with obvious shrinkage in the surface volume of the spill body including the emulsion with time. Therefore, oil spill responders could use this study as a reference or guide to inform the systematic environmental conservation planning process near Hurghada coasts.

## INTRODUCTION

Oil is an essential component of contemporary life due to the tremendous rise of industry and the human need for energy. For this reason, crude oil exploration and production have risen, and the number of oil tankers transporting oil from producing countries has increased, and thus, the probability of oil spill incidents in the marine environment have also increased **(Keramea *et al*., 2022)**. Oil seepage is the accidental discharge of crude oil and petroleum products into the surrounding environment **(Kakalis & Ventikos, 2008; Mohammadiun *et al*., 2021)**. Tanker crashes, ship collisions, ruptured or leaking pipelines, blasted wells, deep sea drilling explosions, and refining activities are the most prevalent causes of oil spills into seawater **(Kachel, 2008; Singha, 2014; Fingas, 2016)**. In all cases, it severely harms the living marine communities, estuaries, coral reefs and mangroves **(Escobar, 2019; Magris & Giarrizzo, 2020)**. While in some cases, significant damage may occur to coastal infrastructure (as tourist resorts, ports and marinas) and industries that rely on seawater input (as marine salt production, coastal power stations, and desalination plants) **(Salomon & Markus, 2018)**.

Due to the oil spills worldwide **(Gurumoorthi *et al*., 2021)**, nearly two million tons of oil containing persistent and toxic chemicals enter the marine environment annually **(Ivshina *et al*., 2015)**. When oil spills into seawater, it undergoes a range of chemical and physical transformations, collectively known as weathering **(Daling & Strom, 1999; Fingas, 2005; Lončar, Beg Paklar & Janeković, 2012)**. The most prominent oil spill weathering processes are evaporation, natural dispersion, and emulsification **(Pradhan, Das & Pradhan, 2021)**. In recent years, societal demands for a sustainable ecological status of the marine environment have forced governments to establish appropriate and effective oil spill contingency plans **(Dietrich *et al*., 2012)**. According to **Abdallah and Chantsev (2022)**, assessing the impact of oil spills on vulnerable areas is necessary to develop appropriate and effective oil spill contingency plans. These plans could be realized using predictive mathematical models to simulate the oil slicks' trajectory and behavior **(Mishra & Kumar, 2015)**.

Mathematical oil spill models are mainly based on the Lagrangian method, which tracks particles. When oil particles are released into the sea, they move along distinct paths influenced by the prevailing winds and currents **(Keramea *et al*., 2022)**. Several attempts have been made to simulate the movement and fate of oil spills in real and hypothetical accidents. The most extensive and capable modeling used in the trajectory and fate of oil spills are: General NOAA Operational Modeling Environment (GNOME), Oil Modeling Application Package (OILMAP), Particle Transport Model (OILTRANS), MEDSLIK-II, Estuarine Oil Spill Model (EOSM), Delft3D-PART, OpenOil, Automated Data Inquiry for Oil Spills (ADIOS2), Oil Spill Risk Analysis (OSRA) **(Spaulding *et al*., 1994; Berry, Dabrowski & Lyons, 2012; Zelenke *et al*., 2012; Yang *et al*., 2013; Dagestad *et al*., 2018; Elizaryev *et al*., 2018; Balogun *et al*., 2021; Saçu, Şen & Erdik, 2021)**.

Recently, the Russian-Ukrainian conflict has hampered the world's supply of oil and petroleum products **(Adekoya *et al*., 2022)**. Moreover, in the wake of Europe's insistence on moving away from Russian oil **(Rob Schmitz, 2022)**, the demand from the Gulf countries such as Qatar and Saudi Arabia has risen, increasing the number of ships transporting oil across the Red Sea and through the Suez Canal. As the number of ships increases, so does the risk of oil spills, putting more stress on the Egyptian Red Sea coastlines and the touristic cities including Hurghada that provides a significant portion of the country's foreign currency. Several oil spill accidents along the Egyptian Red Sea coastlines have occurred since the 1970s, causing considerable damage to the shoreline and coral reef communities. The worst oil spill accident occurred in 1982, whereas loading a tanker in Ras Shukeir, 110 kilometers north of Hurghada, tens of thousands of tons of crude oil leaked into the water **(Hanna, 1983; Hussein, 2021)**.

Interestingly enough, despite the region's importance and the occurrence of several oil spills, as well as the probability of potential accidents, the number of studies that simulate such oil spills is limited **(Nasr & Smith, 2006; Omar *et al*., 2019; Hussein, 2021; Abdallah & Chantsev, 2022)**. Moreover, there is no existing reference for predicting oil spill trajectory in the area under investigation (Hurghada), making this the first research of its sort. Therefore, this study aimed to model the movement and fate of the potential crude oil spill off Hurghada coasts using two of the most common models (GNOME and ADIOS2) to determine the locations most vulnerable to pollution from probable oil spill accidents, and hence develop an adequate and effective contingency plan to mitigate oil spill consequences.

## MATERIALS AND METHODS

### Study area

Hurghada is one of the most beautiful tourist cities on the Red Sea coast. It covers about a 40km stretching along the western shore of the Red Sea on a longitude of 33° 48' E and latitude of 27°15' N. Hurghada's seafront is characterized by parallel coral reefs and is one of the most influential tourism regions on national income. In addition to coral reef habitats, Hurghada shelf contains diverse marine habitats, including sheltered shallow lagoons, mangroves, seagrass, and open deep-water habitats **(Nour *et al*., 2018; Abo-Taleb *et al*., 2020)**. Hurghada city is bordered by Ras Shukeir in the north, Safaga in the south, the Red Sea coast in the east, and in the west by the Red Sea Mountains. In front of the beaches of Hurghada there are several significant islands, which joined the protected islands of the Red Sea, such as Shadwan, Abu Ramada, Small and Great Giftuns as well as Abu Minqar. Northern of Hurghada at Gubal striate (at the northern entrance of the Red Sea), the islands of Tawila, Ashrafie, Ghanim, Small Gubal, North Geisum, South Geisum, North Um Elhimat, and South Um Elhimat are found **(Ghallab *et al*., 2020)** (Fig. 1). Annually, around 15% of worldwide maritime commerce and 10% of global seaborne oil travel through the Gulf of Suez *via* the Suez Canal, and after the 2015 rebuilding of the new Suez Canal, which led to an increase in ship traffic **(Kostianaia *et al*., 2020)**. Fig. 2) shows the ship traffic going along the coasts and marine resorts of Hurghada and the northern islands. Besides the heavy traffic, offshore oil fields' production and operations threaten the coastal and marine environment. Egypt extracts 85% of its crude oil from the Gulf of Suez, where a 450-nautical-mile underwater pipeline network connects 26 offshore fields with a total of 570 oil wells **(Hussein, 2021)**. According to Egypt **Independent (2017)**, the beaches of Hurghada have been constantly exposed to oil spill accidents.

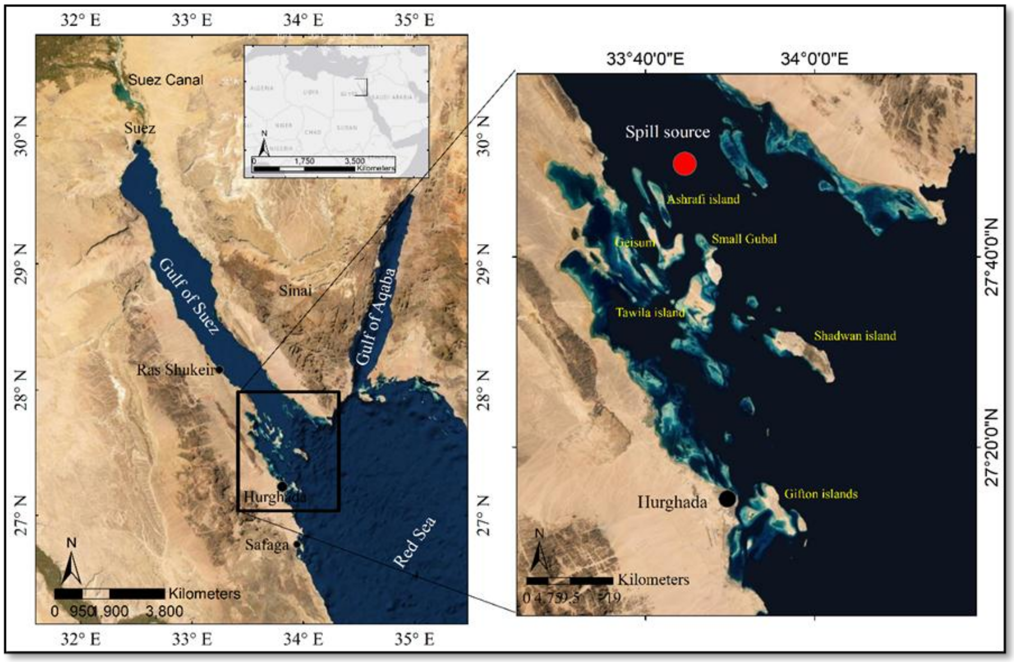


**Fig. 1.** General map of Egypt's Red Sea showing Hurghada beaches, islands, and the source of the spilled oil symbolized by a red dot

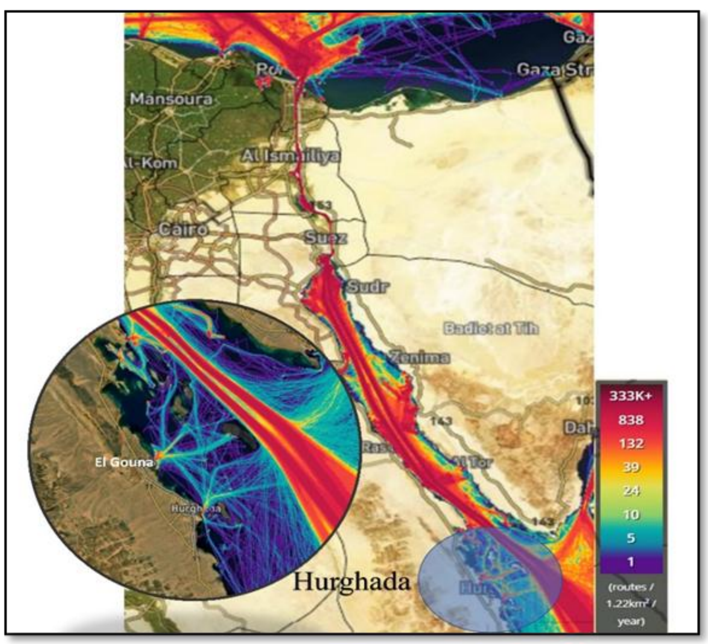


**Fig. 2.** The ship traffic density between the Gulf of Suez and the Mediterranean Sea through the Suez Canal. The circle depicts the ship's activity off the coast of Hurghada **(MarineTraffic, 2022)**

**GNOME Oil spill trajectory model**

General NOAA Operational Modeling Environment (GNOME) is a freely accessible simulation model created by NOAA's Hazardous Materials Response Division to help in response to hazardous spills of oil, diesel, kerosene and fuel oil **(Başar, 2010; Duran *et al*., 2018)**. It calculates the movement of fluid particles over time using the following equation **(Beegle-Krause, 1999, 2001)**

$$\frac{\partial X}{\partial t} = U_h + K_W U_W + D \quad (1)$$

Where, $\frac{\partial X}{\partial t}$ is the particle displacement; $U_h$ is the hydrodynamic forcing velocity; $K_W$ the windage coefficient; $U_W$ is the forcing velocity, and $D$ is the turbulent diffusion component **(Lebreton & Franz, 2013)**. The GNOME model uses the Euler-Lagrange particle (LEs) to represent oil spills or other pollutants within Eulerian currents and wind **(Beegle-Krause, 1999; Zelenke *et al*., 2012)**. However, the oil membrane on the sea surface is separated into oil particles, each with its coordinate system that varies over time. Thus, oil particle mobility is affected by the wind and current fields. Compared to other models, the GNOME model can be used worldwide, requiring fewer input parameters **(Cheng *et al*., 2011)**. However, the outputs of an oil spill model should be validated using remote sensing data of an actual oil spill's trajectory. Unfortunately, due to a lack of clarity about oil spills in the Egyptian waterways and the government's strong interest in boosting the tourist business, this last step cannot be achieved in this research **(Hussein, 2021)**. Nevertheless, GNOME has been validated based on observations of many oil spills worldwide **(Beegle-Krause, 2001; Zelenke *et al*., 2012; Prasad *et al*., 2018, 2022; Gurumoorthi *et al*., 2021).**

**ADIOS2 Oil spill weathering model**

Oil weathering is a set of processes affecting spilled oil's chemical and physical properties, the most significant of which are evaporation, emulsification, and natural dispersion **(Boehm *et al*., 2008; Wardlaw *et al*., 2008; Lebreton & Franz, 2013; Fingas, 2015)**. The National Oceanic and Atmospheric Administration (NOAA) developed the (ADIOS2) model to calculate the processes of oil weathering **(Lehr *et al*., 2002)**. In its computations, the ADIOS2 model uses real-time environmental data, such as wind speed, along with the physical and chemical properties of the spilled oil from its oil library. It blends a library of about 1,000 oils with a short-term oil fate and cleaning model to evaluate the persistence of spilled oil in the marine environment and propose cleanup strategies **(Samuels *et al*., 2013)**. The model can compute the weathering processes of oil spilled in different aquatic environments such as nearshore, open sea, semi-confined coastal waters and rivers **(Toz, 2017)**. Several studies have used the ADIOS2 model to simulate the behavior of oil when spilled into the marine environment

**(Yang *et al*., 2013; Toz, 2017; Elizaryev *et al*., 2018; Huynh *et al*., 2021; Abdallah & Chantsev, 2022; Akinbamini, Anifowose & Obioma, 2022)**.

## Model setup and data used

This study simulated a possible instantaneous oil spill from a tanker incident at the strait of Gubal (27°48'55.10" N 33°44'11.85" E). As shown in Fig. (1), the oil spill source is located on the main shipping lane, approximately 50km northern of Hurghada. Two scenarios were simulated in February and August 2021 for 108h at a step of 0.25 hours. Using a computation step of 0.25h improves the model's accuracy **(Zelenke *et al*., 2012)**. The diagram of the study's input and output is shown in Fig. 3).

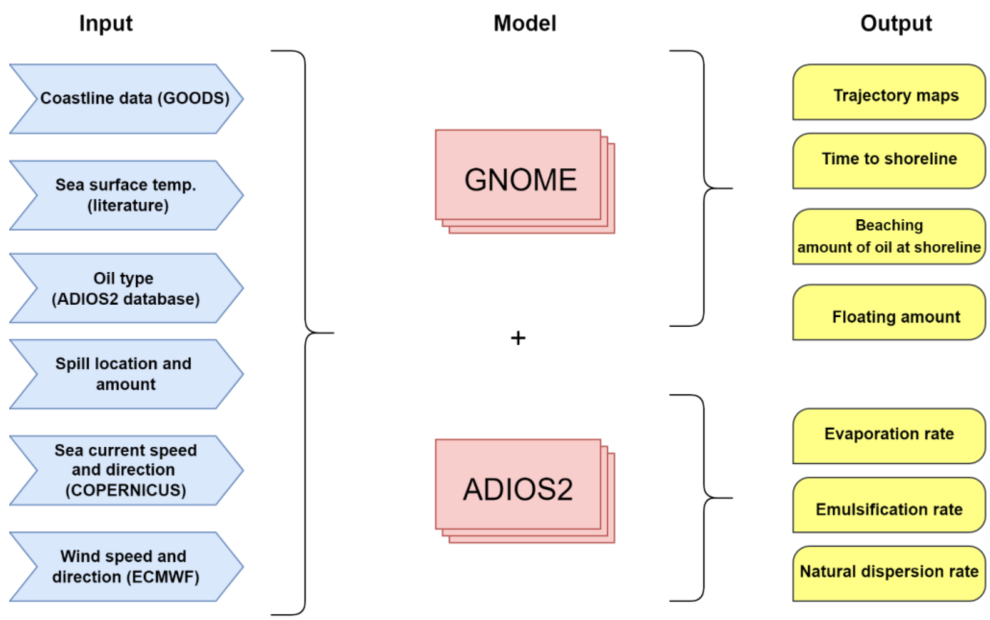


**Fig. 3.** A diagram framework of the GNOME and ADIOS2 models' input and output data

### *Spill volume and oil type*

This simulation used a thousand metric tons (mt) of the Arabian light crude oil (API of 33.4). The Arabian light crude oil was selected due to the availability of its physical and chemical parameters and the constants in the ADIOS2 model library, required to solve the weathering equations. Furthermore, the Arabian light crude oil was utilized in prior studies on oil spills in the Gulf of Suez **(Nasr & Smith, 2006)**.

### *Coastline data and sea surface temperature*

The GNOME model only works with coastline data in (bna) format, which could be obtained from the global self-consistent, hierarchical, high-resolution shoreline (GSHHS) database and then converted to (bna) format using the GNOME online oceanographic data server (GOODS) (https://gnome.orr.noaa.gov/goods/tools/ GSHHS/coast_subset). Due to the comprehensive processing of the GSHHG data set, any errors or outliers should be removed. The shorelines consist of hierarchically closed polygons **(Wessel & Smith, 1996; Pradhan, Das & Pradhan, 2021)**. The coastline data for the simulation model extends from 30º E to 36º E and from 27º N to 31º N, covering the northern portion of the Red Sea. The seawater temperature used in this study was extracted from previous studies, which found that the average seawater temperature around the coastlines of Hurghada is 20.2°C (68.36°F) in February and 29.20°C (84.56 °F) in August **(Mohamed & Mohamed, 2005; El Saman, 2022)**.

***Wind and marine currents data***

The European Centre for Medium-Range Weather Forecasting (ECMWF) Reanalysis (ERA5) (https://www.ecmwf.int/) was used to extract hourly wind data as a Network Common Data Form (NetCDF) file format. The GNOME model suggested a wind factor between 1 and 4% as the default value and windage, which is the wind-driven movement of the oil, approximately 3% of the surface wind speed **(Gurumoorthi *et al*., 2021)**. Fig. 4) shows wind data from 2011 to 2020 in Hurghada. The wind was moving mainly in the NW, N, and NNE directions, and the average wind speed reached 5.4 miles per hour.

Unfortunately, the area under investigation has no marine currents data throughout the simulation period. Therefore, marine currents data were gathered from the Operational Mercator global ocean analysis and forecast system (https://doi.org/10.48670/moi-00016) in a NetCDF format. It is an ocean-atmosphere data assimilation and prediction model that offers daily 1/12° three-dimensional global ocean predictions. The data assimilation scheme used for the ocean is the Nucleus for European Modeling of the Ocean (NEMO) variational data assimilation scheme. The technique assimilates *in situ* and satellite SST data, satellite altimeter of sea level anomalies (SLA), and *in situ* temperature and salinity profiles from various sources, including Argo, moored buoys, and temperature profiles from marine mammals **(Lea *et al*., 2015).**

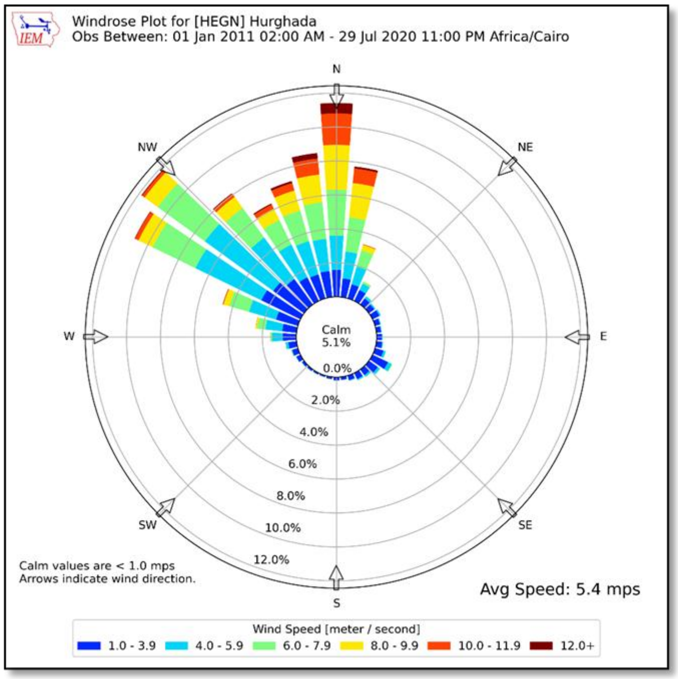


**Fig. 4.** Wind rose diagram at Hurghada city from 2011 to 2020

## RESULTS

In this study, two hypothetical oil spill scenarios in the strait of Gubal, about 50 kilometers northern of Hurghada area, were simulated using GNOME and ADIOS2 models. The results of oil spill trajectories and oil spill weathering were discussed in this section.

### Scenario #1 trajectory and weathering

In this scenario, we assumed that a tanker accident had leaked 1,000 metric tons of the Arabian crude oil near strait of Gubal. The model started at 12:00 pm on February 09, 2021, and lasted 108 hours to 12:00 am on February 14, 2021. The spill is shown as a collection of black and red dots. The black dots show the best-guess solution, assuming there is no certainty about the input parameters. The red dots, in contrast, represent the minimum regret solution that accounts for wind and wave uncertainty. Fig. (3) presents maps depicting the results of spill movement simulations at 12-hour intervals. Additionally, these results are available on video (Online Resource 1).

When the simulation began, the oil slick moved southeast with black and red dots when the simulation started (Fig. 5). Forty-two hours after the simulation began at 6:00 pm on February 11, less than one ton of the spilled oil reached Small Jubal Island (33°47'51.05"E 27°40'45.01"N), which is about 16 kilometers south of the main spill location. Then, the oil traveled a distance of 20 kilometers from Small Jubal Island to

Shadwan Island, about 36 kilometers from the spill source, in approximately 72 hours at 12:00 pm on February the 13th. During the following 30 hours until the simulation ended, a total of 434mt of oil accumulated on the eastern shore of Shadwan Island, covering the whole eastern shoreline of the island about 17 kilometers from 33°55'26.39"E 27°31'40.06"N to 34° 2'23.23"E 27°27'27.37"N. After 108 hours, the simulation duration, a substantial quantity of oil, about 276 mt, was still floating in the sea and flowing toward south Hurghada city at the western shore of the Red Sea.

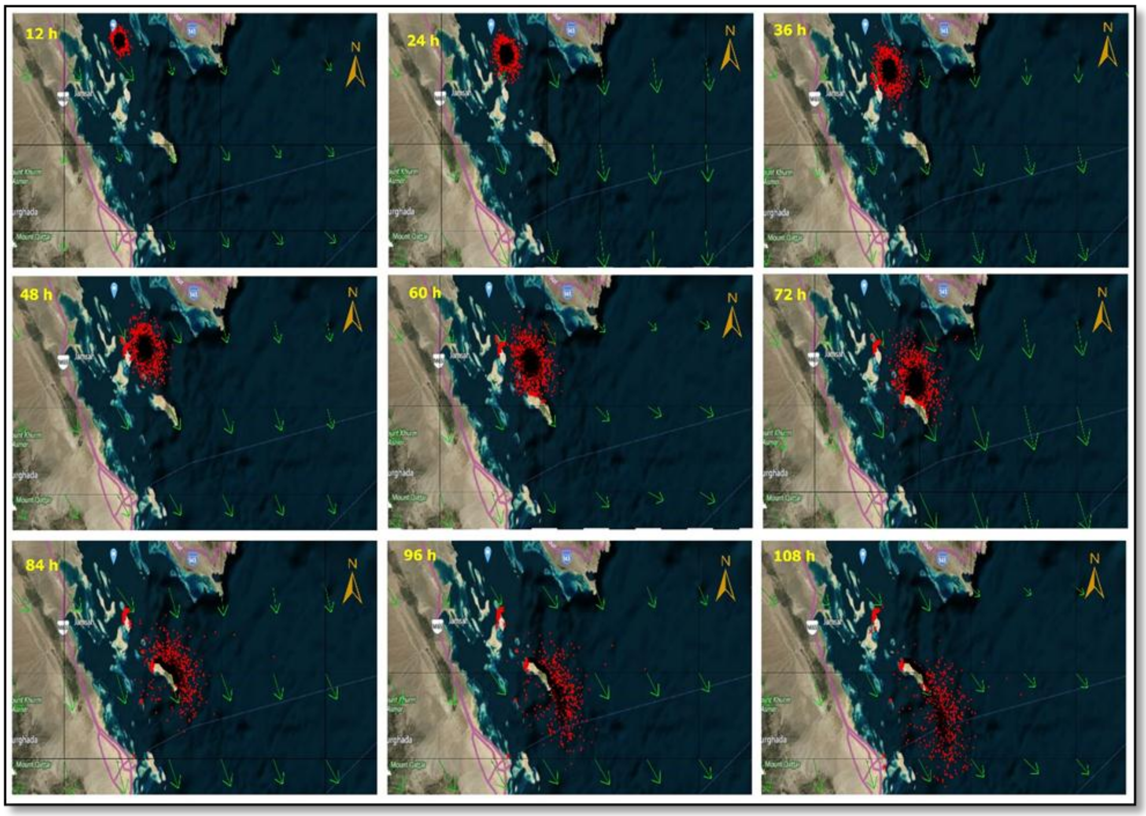


**Fig. 5.** Scenario #1 trajectory modeling with green arrows representing the wind direction, and the big blue dot for the spill location

Weathering processes (evaporation, natural dispersion and emulsification) occur at varying rates following oil spills. The evaporation process began shortly after the oil was spilled into the water. Around 54mt (5.4%) of oil evaporated in the first hour, and the evaporation rate continued to increase until approximately 277mt (27.7%) after 108h. Natural dispersion, on the other hand, began six hours after the spilling incident and reached 12.6mt at the end of the scenario (Fig. 6). As shown in Fig. 7), in the first hour of the oil spill into the sea, the emulsion's water content increased rapidly and reached 90% after two days. This proportion persisted until the end of the simulation. The surface volume, including the emulsion, decreased during the first six hours from 1000 metric tons to less than 800 metric tons; after that, it increased until it reached more than 1350 metric tons on February 13, and then it began to decrease again until approximately 425 metric tons after 108h.

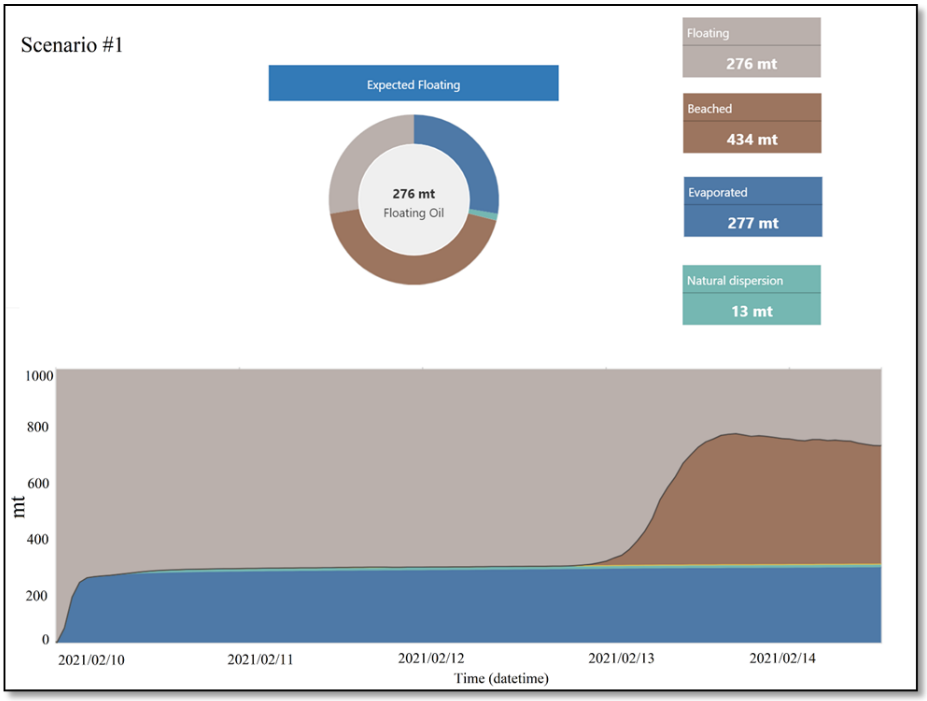


**Fig. 6** Arabian light crude oil budget in Scenario #1

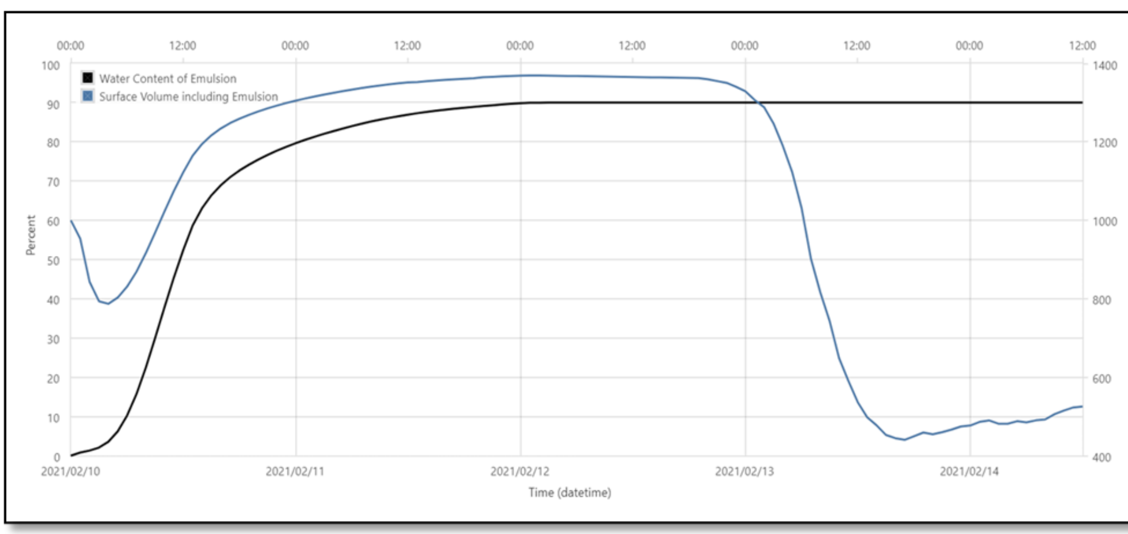


**Fig. 7.** Emulsification rate of Scenario #1

### Scenario #2 trajectory and weathering

Wind and marine current data for August 2021were used in Scenario #2. The oil type, amount, and source are the same as in Scenario #1. The scenario began at 12:00pm on August 09, 2021, and lasted for 108 hours until 12:00am on August 14, 2021. The output of the GNOME model is available as a video in (Online Resource 2). The floating oil initially drifted in the South-Southwest SSW direction, and about three metric tons reached Ashrafi Island (33°41'58.61"E 27°46'19.62"N), 6 kilometers from the initial spill location in 21 hours at 9:00pm. Afterward, the oil particles drifted southward and accumulated on The Small Gubal, Geisum, and Tawila islands (Fig. 8). In the next 87 hours until the end of the simulation, about 610 metric tons of oil flowed onto these islands. At the end of the simulation, around 96 metric tons of oil remained afloat in a south-southwesterly trajectory, moving toward Giftun Island and the beaches of Hurghada.

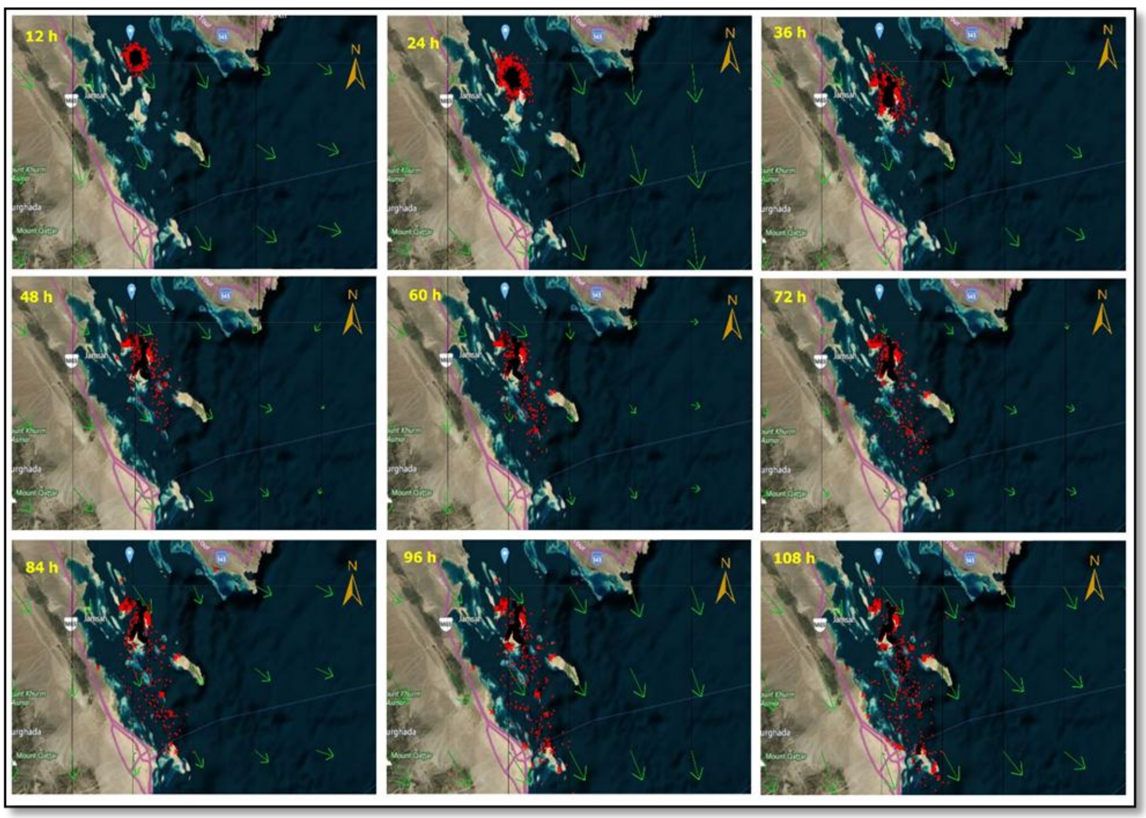


**Fig. 8.** Scenario #2 trajectory modeling; the green arrows represent the wind direction, and the big blue dot represents the spill location

As shown in Fig. 9), evaporation began immediately after the oil was spilled into the seawater. In the first hour of the spill, almost 100mt (10%) of oil evaporated, and this rate doubled in the second hour. After that, the evaporation rate gradually increased until it reached 280mt (28%) at 12:00 am on August 14, 2021. On the contrary, the natural dispersion rate was slow, starting with the first hour of the spill occurrence and reaching around 12.9mt at the end of the simulation. Fig. 10) shows the emulsification rate during 10–24 August 2021. It was observed that, in the first hour of the oil spill into the sea, the emulsion's water content increased gradually and reached 90% after 36h, and this proportion persisted until the end of the simulation. The surface volume, including the emulsion, grew to more than 1300 on February 13, then decreased again until approximately 225 at the end of the scenario.

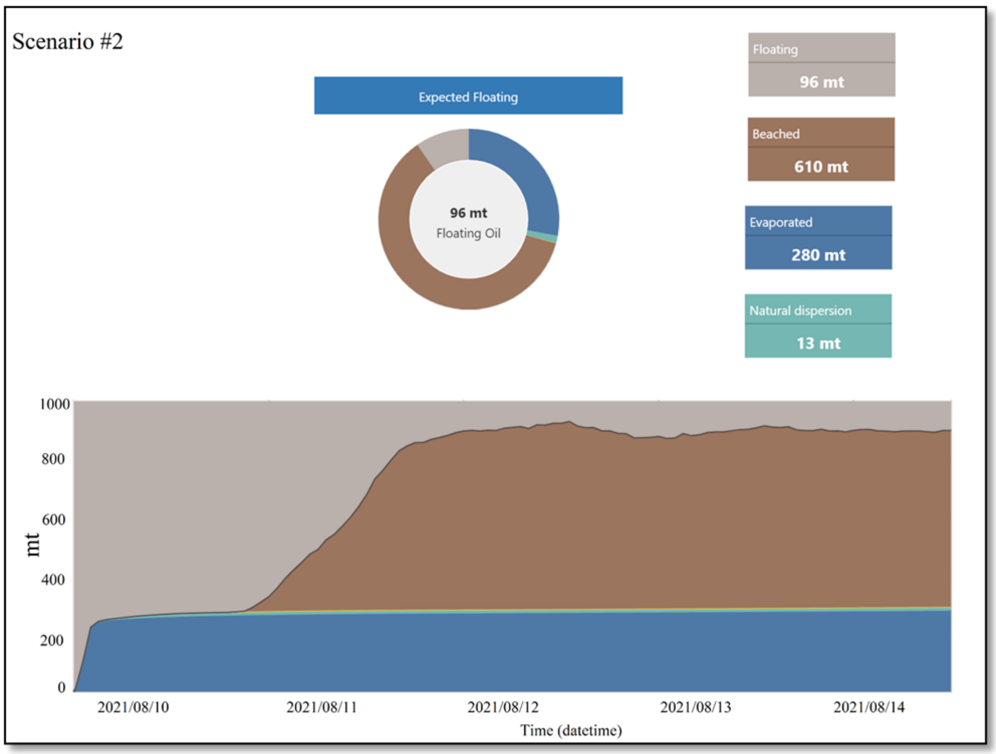


**Fig. 9.** Arabian light crude oil budget in Scenario #2

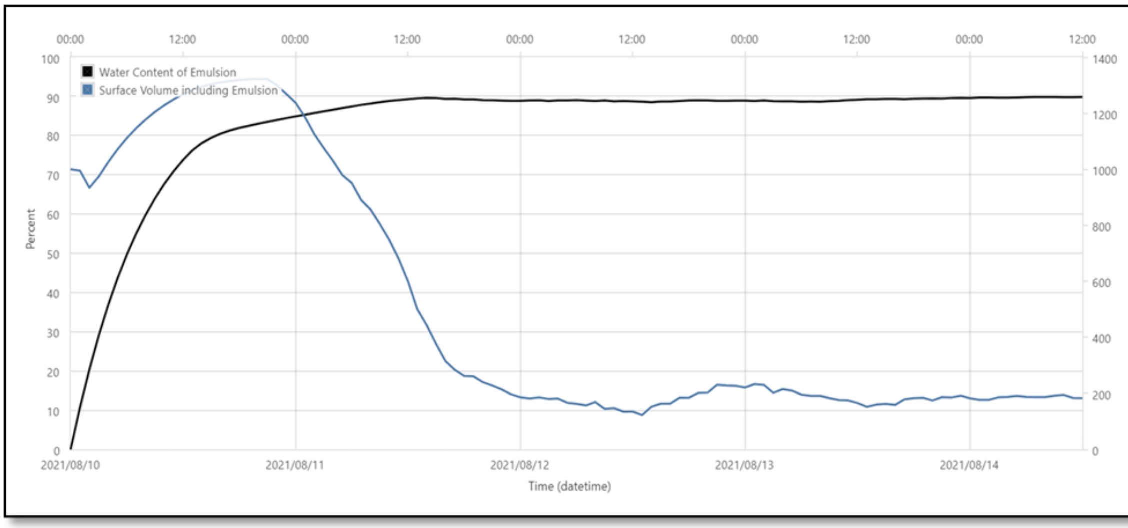


**Fig. 10.** Emulsification rate of Scenario #2

## DISCUSSION

Oil spills into the seawater may have catastrophic effects on the marine ecosystem. It may take decades for the ecosystem to recover, and it will never be able to return to its original condition **(Dhaka & Chattopadhyay, 2021)**. Globally, oil spill models have been used extensively to predict the fate and transport of oil spills. The results can serve as the foundation for assessing the environmental, economic, and health implications **(Dong *et al*., 2022)**. This study aimed to identify the probable sites an oil spill would impact by simulating two scenarios resulting from a tanker accident off Hurghada.

The GNOME model's trajectory maps revealed that the oil spilled in Scenario #2 traveled in a southwesterly direction and took 21 hours to reach Ashrafie Island and after that to Small Gubal, Geisum, and Tawila islands, which is half the time it took in Scenario #1, moving in a southeast direction to reach the Small Gubal Island and then to Shadwan Island. This result may be explained by the fact that the prevailing wind direction in Scenario #2, which occurred in August, was northeast (NE), pushing oil toward Ashrafi Island. In contrast, the first scenario occurred in August; hence the predominant northwest winds (NW) this month caused the oil leak to move toward the Small Gubal Island. Therefore, the wind speed and direction greatly influence the direction of the spilled oil in the region. This explanation is compatible with **Eladawy *et al*. (2018)** data, which indicate that the predominant wind in the Gulf of Suez is the NW surface wind during winter, and according to **Hussein (2021)**, the other dominant wind in summer is the northeast wind (NE). Additionally, these results are congruent with those of **Abdallah and Chantsev (2022)**, who simulated an oil spill from a tanker accident in the Gulf of Suez using the GNOME model. They found that when the winds are northwest, the spilled oil moves in the southeast direction, and when the winds are northeast, the oil moves in the southwest direction.

The trajectory maps of the oil spilled in both scenarios showed the movement of oil in general in the southern direction, which is the same direction as the movement of the sea currents in the Gulf of Suez **(Frihy *et al*., 2004)**. Therefore, the winds and ocean currents affected the oil's trajectory. Numerous global studies have shown that wind and sea currents significantly affect the movement and direction of oil spilled into the marine environment **(Gurumoorthi *et al*., 2021; Yildiz *et al*., 2021; Ju *et al*., 2022; Keramea *et al*., 2022; Liu *et al*., 2022)**. The results highlight that, although the two scenarios were at different times (February and August), the spilled oil threatened the islands at the entrance of the Gulf of Suez. These islands are of enormous economic and strategic significance and have been declared a protected area by Egypt's Ministry of the Environment by Law 102/1983. (nature conservation sector) **(Mahdy *et al*., 2021)**. Therefore, this study warns that future leaks would harm these islands.

Immediately following an oil spill, weathering processes change the spilled oil into new compounds with distinct physical and chemical properties. The first process of oil weathering that happens is evaporation. During this process, most of the oil's volatile parts are removed within hours of a spill **(Lončar, Beg Paklar & Janeković, 2012; Fingas, 2016)**. In this study, the results showed that in the initial hours of the simulation, the percentage of evaporated oil in Scenario #2 was twice as high as in Scenario #1 because Scenario #2 occurred in August, and the temperature was higher than in February for Scenario #1. According to **Omar *et al.* (2021)**, the high temperature tends to increase the evaporation rate and the proportion of oil lost. Although the evaporation rate was expected to be significantly higher in Scenario #2 (August) than in Scenario #1 (February), at the end of the simulation, the percentage of oil evaporated in both scenarios was close (27.7% and 28%). It may be because the quantity of the oil that reached the islands in Scenario #2 was large (610 mt), and only a minimal amount of oil remained floating (96 mt) exposed to evaporation. While in Scenario #1, a large amount of oil remained floating in the water (276 mt) and was prone to evaporation. This explanation is compatible with **Ali Cemal Toz *et al*. (2016)** who concluded that, the behavior of the oil spilt into seawater depends on many factors, one of which is whether the oil remains in the sea or is washed ashore.

Natural dispersion is the breakup of oil slicks by waves, currents, and wind energy, into microscopic, neutrally buoyant droplets and the distribution of these through the water column **(Hook *et al*., 2016)**. The results reveal that, although Scenario #1's natural dispersion process began after six hours of simulation, while Scenario #2's started in the first hour, the natural dispersion rate was low for both scenarios. Furthermore, the naturally dispersed oil quantity was 13mt (1.3%) at the end of the simulation in both cases. These results align with those of **Abdallah and Chantsev (2022)**, who also used ADIOS2 to compute the natural dispersion of the Arabian light crude oil spilled in the

Gulf of Suez and found that the natural dispersion did not exceed 1%. On the contrary, the results of natural dispersion are less than those of **Nasr and Smith (2006)** who found that, the rate of natural dispersion of the same oil was 8%. This divergence is due to their employment of a different mathematical model (SL Ross model).

Emulsification is a process that forms a liquid, known as an emulsion, containing tiny droplets of fat or oil suspended in a fluid, usually water **(Das & Mukherjee, 2007; Pacwa-Płociniczak *et al*., 2011)**. The results demonstrated that in both scenarios, the percentage of water in the emulsion rose as soon as the oil entered the water within the first hour of the spill, reaching 90% by the end of the simulation. Furthermore, the surface volume including the emulsion increased with time until the beaching process started and decreased after the oil reached the shore. By the end of the simulation, the surface, including the emulsion, was twice as large in Scenario #1 as in Scenario #2 since the quantity of oil floating in Scenario #1 was more than in Scenario #2. The emulsification process increases the viscosity of the slick and its volume, making it difficult to remove, and induces the formation of mousse and tar balls, thus making cleaning difficult **(Dave & Ghaly, 2011; Dhaka & Chattopadhyay, 2021)**. Therefore, the results of weathering processes for oil spills in the marine environment are essential for response team members to establish the optimal method for oil removal and mitigation **(Fathalla, 2007; Fingas, 2016; Toz & Koseoglu, 2018)**.

## CONCLUSION

Due to the sanctions imposed on Russia, the European country's demand for oil and petroleum products from Arab Gulf states have soared. This demand increases the number of tankers passing through the Suez Canal, the main gateway between the East and the West, thus raising the probability of oil spills along the shipping route and threatening important tourist cities such as Hurghada. Therefore, this study used the GNOME and ADIOS2 models to simulate two potential oil spill scenarios in February and August 2021 due to a tanker incident in the Gubal Strait, approximately 50km northern of Hurghada, to determine the probably affected regions, estimate when the oil would reach the shoreline, and compute the oil's weathering processes (evaporation, natural dispersion, and emulsification). The results highlighted that wind and oceanic currents significantly affect the movement and direction of oil spilled into the marine environment. The oil spill in Scenario #2 (August) moved southwesterly under the influence of northeast NE winds and arrived after 21 hours at Ashrafie Island and then at Jubal, Geisum, and Tawila Islands. While in Scenario #1 (February), the oil moved in the southeast direction under the influence of northwest NW winds, and it took 42 hours to reach Small Jubal Island and then Shadwan Island. Therefore, any oil seepage in this region, the northern Red Sea islands, which are of enormous strategic and economic importance, would be the most susceptible to contamination.

The results of modeling the spilled oil weathering processes showed that about 27% of the Arabian light oil had evaporated, and the natural dispersion rate was modest, about 1.3% in both scenarios at the end of the simulation. Furthermore, the amount of water in the emulsion rose as soon as the oil was introduced to the water, reaching 90% after 108h. As a result, the oil's surface volume, including emulsion, grew until beaching began, then declined. This study's findings can serve as a reference for establishing an effective emergency plan to mitigate the impacts of future oil spill incidents in the strait of Gubal. The limitation of this study is that the current model version lacks a module for anticipating the slick's breakup owing to waves that may influence its lateral movement. However, the predicted overall trajectory of the leak should be sufficient to deploy emergency reaction measures immediately. Consequently, more research using various spill models should be done to compare the oil trajectories after the spill incident off Hurghada.

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