Oil spill modeling of diesel and gasoline with GNOME around Rajaee Port of Bandar Abbas, Iran

Farzingohar, M. [1,2]*; Zelina Z. Ibrahim[2]; Yasemi, M.[3]

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Abstract

Rajaee port in Bandar Abbas is one of the important-oil transport hubs in Persian Gulf and any oil spill incidents can result in pollution, which impact on human habitats and the marine environment. Oil spill trajectory modeling is a tool which applied to increase the knowledge about oil spill fate. The GNOME model is a physical model which indicates the oil spill movements on sea water and potential risk areas. The model inputs include GIS data, time of spill release, release duration, spill chemistry and physical characteristics of wind and current data. Two scenarios for 10 and 200 bbl of diesel and gasoline spills are run on the model. Both the general Persian Gulf circulation which is from the south west and the local wind direction cause to move the oil spills toward the Bandar Abbas coast and Qeshm Island that pollutant these areas. Both regions are very valuable economic and environmental zones. They have known as risk places due to the oil spills that release from Rajaee Port in this study. The model results can assist organizations in preparing their emergency management systems for responses in the potential risk areas.

Keywords: Modeling, Oil Spill, Oil pollution, Persian Gulf, Rajaee Port, GNOME, Trajectory

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1-Faculty of Science, Hormozgan University, Iran.
2-Faculty of Environmental Studies, Universiti Putra Malaysia, Malaysia.
3-Fisheries & Aquatic Department, Technical and Vocational Higher Education of Jihad-E- Agriculture, Iran.
*Corresponding author's email: mfgohar@yahoo.com

Introduction

The Persian Gulf has the most oil resources and oil transport activities in the world. Due to a large number of oil resources and heavy tanker traffic the potential for oil pollution is high. In 1978 the Regional Organization for the Protection of the Marine Environment (ROPME) was formed, by Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates, to protect water quality, marine and environmental systems and to abate pollution from development activities in the region. The ROPME Sea Area is from the end of the Persian Gulf in the west to the northwest corner of the Indian Ocean in the east (Fig.1). Rajaee Port, near the Hormuz Strait, at the eastern entrance of the Persian Gulf, is an important oil terminal for Iran (Fig. 1) and is a possible source of pollution. The pollution is harmful to survive of many aquatic species (Yasemi, et al., 2008). It is located 20km west of Bandar Abbas, significant urban center at the entrance of the Strait of Hormuz. Persian Gulf is considered to be one of the most pollutant seas in the world (CEDRE, 2007). In 1998 estimated amount of oil transported here was 15.4 million barrels of oil per day. The U.S. Energy Information Administration (1999) considered the Persian Gulf and the Strait of Hormuz as one of the world's most important "chokepoints" for oil transport (CEDRE, 2007). Bandar Abbas city and Qeshm Island are the important areas in Hormozgan Province of Iran. Bandar Abbas is the provincial capital and the business and trading center. This region is the source of ecotourism, fisheries, shipping and supports the total economy of the province. Qeshm Island is one of the most valuable environments due to the presence of the mangrove forest in the Middle East. Qeshm Island mangrove forest is recorded in the list of protected areas of UNESCO (UNESCO World Wide Heritage Center, 2007). Qeshm Island is one of the biggest habitats in Iran. Mangrove ecosystems are very sensitive. Oil spill causes toxic sea water and has negative impacts on mangrove. Many bird species migrate to Qeshm Island in winter but Hormozagan Department of the Environment reported a large amount of birds contaminated by oil and trapped in spills during the recent years (Report, Hormozgan Department of the Environment, 2004).

In case of any problem in the operational system at the Port, oil can be released into sea water and pollutant coastal areas. The resulting oil pollution can have negative effects on human health, the life of marine environment, fisheries industry, ecotourism and the province's economy. The pollution will impact on all the industries. Oil spill damage fishing instruments and decreases fish population as well as has negative effects on marine transportation. Therefore, it is very important to identify the potential pollution time scale. The information can be used by the provincial emergency management system for developing protection policies.

GNOME has also been used by ROPME (Regional Organization for the Protection of the Marine Environment) countries for marine spill sources and ship accidents (NOAA, Office of Response and Restoration, 2001).

In the Persian Gulf, the littoral countries have used different software to model and predict the trajectory and fate of oil spills. For oil spill response action, it is important to have information on oil spill movement by currents and winds, and where it can accumulate on the coastal area.

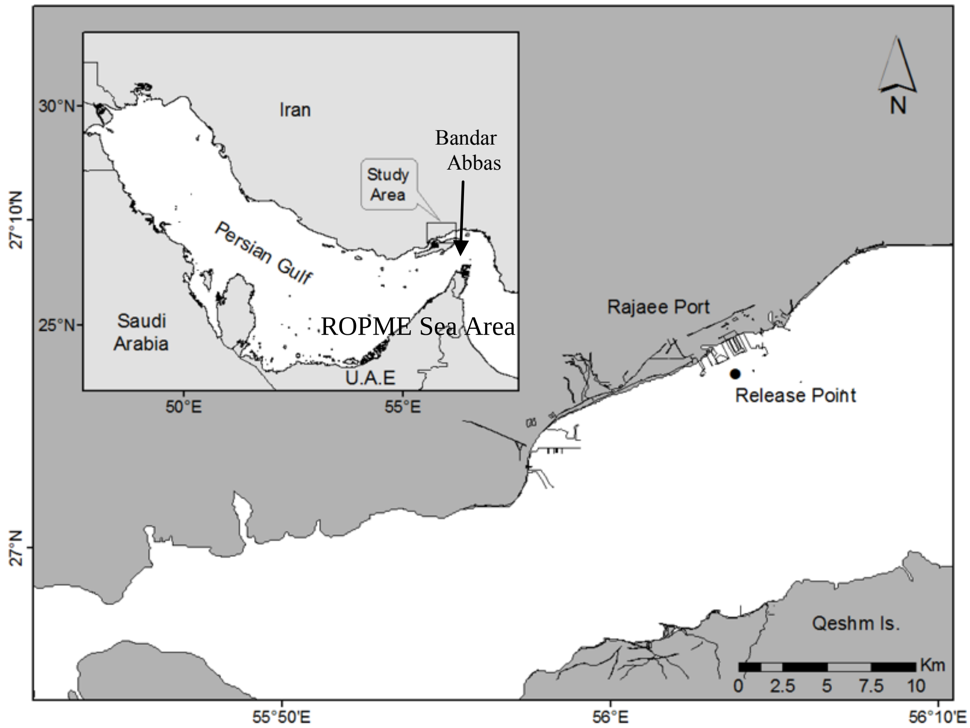

Figure 1: Study area map: Rajee Port, and areas in the Hormuz Strait, Persian Gulf and ROPME Sea Area

In 1979 Lehr used GULFSLIKI for Saudi Arabia and OILMAP has been used for Dubai waters by Howlett et al, 2008 for forecasting. GULFSLIK II and OILPOL together have been used to simulate fate of oil spills of Al-Ahmadi in Kuwait (Al Rabeh et al., 1991). The U.S. National Oceanic and Atmospheric Administration (NOAA) has developed and applied the GNOME (General NOAA Oil Modeling Environment) model from 1992 to track the trajectory and fate of the oil spills in various fields (NOAA, Office of Response and Restoration website). It is a free model that has been verified by several organizations in the world (NOAA, Office of Response and Restoration, references website). GNOME has been used by many countries for marine spill trajectory and ship accidents (NOAA, Office of Response and Restoration, location files, website). GNOME has a location file for the ROPME Sea Area (http://response.restoration.noaa.gov/book_shelf/819_Gnome_ROPME_ UG.pdf) which contains information to simulate the local Oceanographic condition. It is easy to work with and has many usable references by this way has been selected for this study.

The purpose of this study is trajectory and fate of the ship tankers spills in Rajaee Port from the first hour until accumulate and beach. Predict about the

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situation of possible accidents in the future. Identify the polluted zones and high risk points to contribute the province's environmental protection plans.

Materials and methods

The GNOME model enables us to study about the fate of past and current oil spills or predict the probable oil spill pathways of potential incidents in the future. Simecek and Lehr William (2007) noted that in order to "predict any pollutant movement it is necessary to understand the different physical processes, affecting the pollutant". Aside from the oil characteristics ; winds and currents are the main factors that effect on the spill trajectory (Lighthill, 1978). Basar, et al. in 2006 has applied GNOME for Istanbul Strait and found that current is more effective than wind in affecting oil spill movement. They identified four areas as the most pollutant areas in the strait. Thus the main input data required are: time of release of spill, GIS components, spill information, type of oil, wind speed, current direction, and dispersion. In this study, the GNOME model is used to simulate scenarios of diesel and gasoline spills released from the terminal tanker of Rajaee Port located on the north coast of the ROPME Sea Area. In the ROPME Sea Area the GNOME location file simulates ocean circulation due to three current patterns, that is, river, estuarine and wind driven circulation. The overall circulation in the inner ROPME Sea Area is cyclonic (NOAA, Office of Response and Restoration website, international location files, ROPME 2001). Tide is not regarded important in this area due to the scale of the model area. To find the oil spill movement fate, oil characteristics and meteorological data input the model. Some of the main oil characteristics and related information are installed in GNOME and can be selected by the user. Other oil product data that used in the simulation is obtained from Bandar Abbas Oil Refining Company (BAORCO). Hourly, daily, and monthly average meteorological data were gathered from the Hormozgan Metrological Organization (HMO) (Table 1).

Table 1: Input data categories and sources

Source	Time	GIS	Map	Spill Info	Oil type	Wind	Current
Location File		X	x				x
HMO						x	
GNOME library					x		
BAORCO				x	x		
User Selection	x	X		x			

The local current vector patterns have been compared with the noemal current patterns that obtained from the researches been done on the Persian Gulf (Sabbagh-Yazdi and Zounemat-Kermani, 2007) and (K¨ampf and Sadrinasab, 2006).

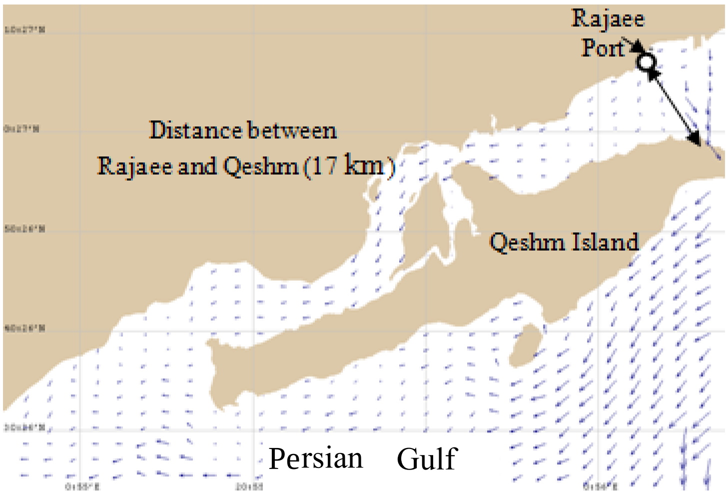

Figure 2: Distance from Rajaee port to Qeshm Island, ROPME Sea Area map with Current Pattern around study area (www.reponse.restoration.noaa.gov.Location file)

The north east of Qeshm Island coast is located 17km from south of Rajaee Port. The Persian Gulf current direction and circulation has been investigated in many studies. Emery, 1956, Brewer, 1979, Hunter, 1983 and Reynolds, 1993 declared that Indian Ocean Surface Water normally flows into the Persian Gulf from the open ocean along the northern side of the Strait and continues northward along the Iranian coast (Swift and Bower, 2002). Then turns south and flows from the north west to the east and finally exit from the Persian Gulf then enter the Oman Sea and Indian Ocean. There is a narrow strait between Qeshm Island and Bandar Abbas shoreline (Fig. 2). Water friction and shear stress increase due to the mainland (Hormozgan province coast) and Qeshm coast. Therefore sea water encounters the Island and mainland that the current direction and water path changes permanently (Sabbagh-Yazdi and Zounemat-Kermani, 2007). In the model run for spill tracking, the spilled oil is represented by dots on the map whch are called splots (Lagrangian elements). Black dots indicate GNOME's "best guess trajectory estimate of the oil spilled from the tanker" while red dots indicate GNOME's "larger minimum regret trajectory estimate" (GNOME Manual, 2002). The minimum regret splot locations indicate a roughly 90% probability of the maximum extent of the spill. That is, it indicates the area outside of which an oil spill responder would have minimum regret of not taking action. These splots shows floating and beached oil. Minimum regret area is negligible for small spills, but it would explore the implications of alternate areas for big spills. Low density of accumulated splots indicates high evaporation rates. Time is the parameter that has no limitation. Spill information is based on the oil types that are classified by viscosity. Wind speed, wind direction and time are the factors that impact on the degradation rate. The first scenario is 10 barrels of diesel and gasoline released from Rajaee Port. An example of such an

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incidence could be leaking from a connector pipe to the ship tank pipe. The start time of the scenario is 1st June 2006 at 1:30pm. The release point is : longitude 56°, 4′E, latitude 27°, 6′ N. Wind speed was selected as the variable with average speed of 7kn and the direction is south south west (SSW). The model has run based on the actual hourly weather data. GNOME runs for 24 hours to find the direction oil dispersion in the sea. Most of the Gasoline evaporates during the first hours due to low viscosity. As diesel is more viscose, the floating and beached part is greater than evaporation and dispersed (Figs1, 4, 5).

Table 2: Summery of studied scenarios with spill information, meteorological data set and model duration

Scenario	Oil Type	Amount, bbl	2006 Meteorological Data	Length Model Run
1a	Diesel	10	hourly	24 hours
1b	Gasoline	10	hourly	24 hours
2a	Diesel	200	Daily	35 days
2b	Gasoline	200	Daily	2 days
3a	Diesel	10	Average monthly	1 month for each of 12 months
3b	Gasoline	10	Average monthly	1 month for each of 12 months

Second scenario runs for 200 bbl from the first hour until oil evaporates completely and all dots on the map disappear. The data for diesel and gasoline with the same weather conditions has input model in order to find the capacity role in modeling. Hourly and daily meteorological data was input. The model is able to run with hourly, daily and even monthly data. Hourly data used for short term modeling [scenario one (1a, 1b) but for long term the data used as daily (scenario two (2a, 2b)] and monthly (3a, 3b) (Table 2). In this study the model used with hourly data. The purpose of the third scenario is to identify the high risk zones. GNOME was run with average monthly meteorological data for 12 months of 2006 (Table 3).The model duration time is for a month. Monthly oil spill fate is shown in terms of percentage (Fig. 7).As Gasoline evaporates quickly in short time, it disappeared from the map. GNOME output values for gasoline after 2 days for degradation rates were zero so there were no pictures for both scenarios in (Fig. 4) for gasoline (Tables 4, 5).

Results

GNOME footprint (Figs 3, 4) shows that spill movement direction is dependent to currents and wind direction in this area. Tracking and the relation between wind direction and oil fate is shown in table 3. In (Tables 3, 4, 5) the degradation rates displayed with abbreviations as: Evp & Dis, beached: Bch, floating: Flt. The two scenarios have compared then the200 bbl oil spill covers a bigger area than 10 bbl. The area affected includes Rajaee coast, coastal sea water, and North of Qeshm Island (Figs 3, 4) .

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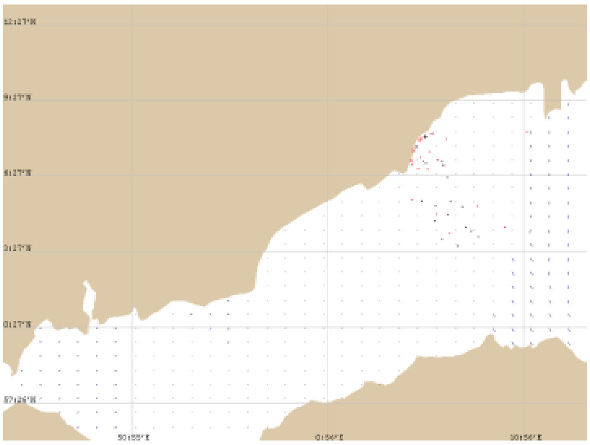
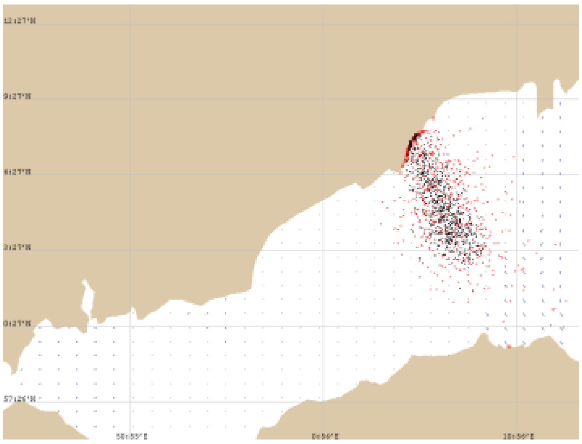
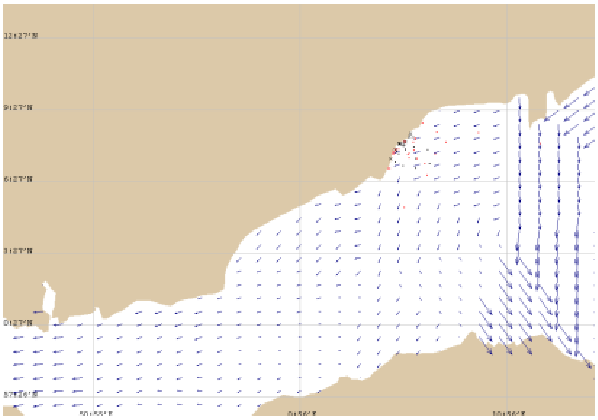


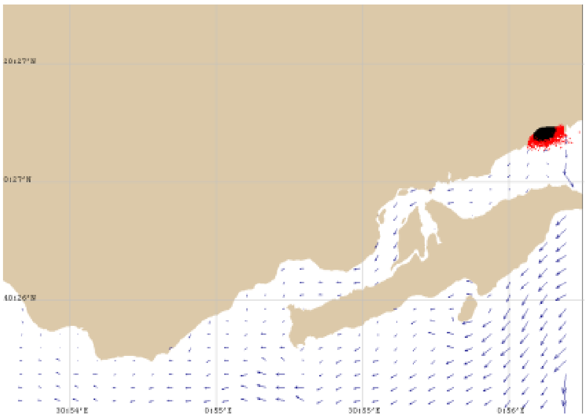
a) 10 bbl Gasoline, 24h after release



b) 10 bbl Diesel, 24 h after release

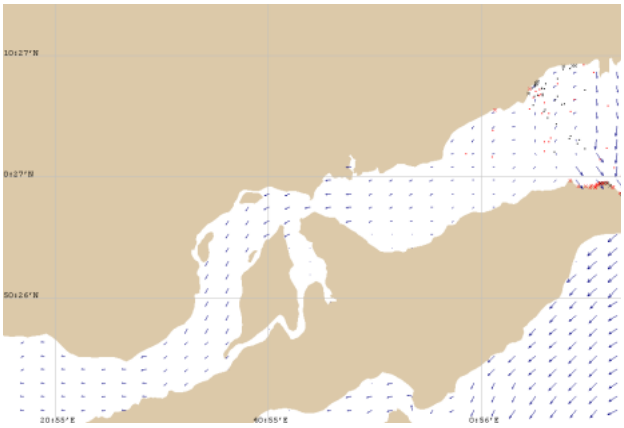


c) 200 bbl Gasoline, 24 h after release

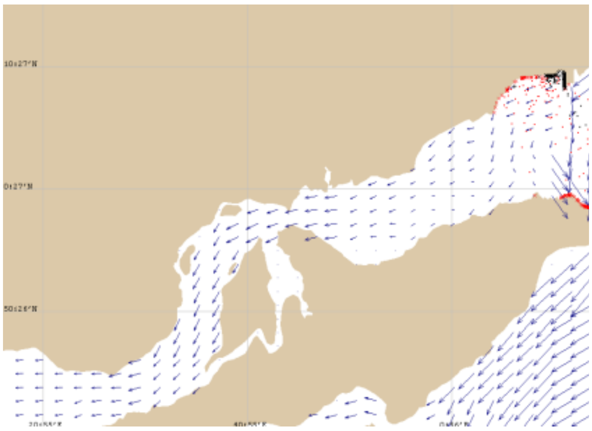


d) 200 bbl Diesel, 24 h after release

Figure 3: a-d, GNOME printpicture for scenarios: (1,2)



a) 10 bbl Diesel spill after 10 days



b) 200 bbl Diesel spill after 10 days

Figure 4: a-b, GNOME print picture for Diesel, first and second scenario output

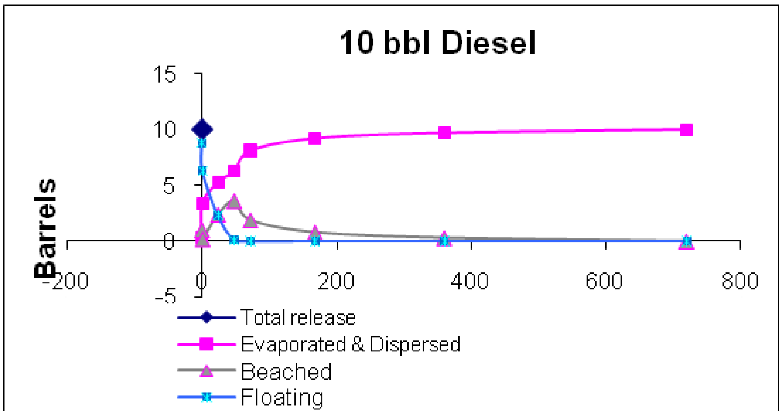


Figure 5: Diesel degradation chart, 10 bbl

Table 3: Mean wind data of 12 months 2006 which made the GNOME output rates and identify the spill trajectory and fate area

Month	Mean wind Direction	Mean wind speed (kn)	Evp&Dis ba	Bchba	Fltba	Trajectory & Fate Concentrate	Mean Seasonal Trajectory
Jan	WSW	4.1	8.6	0.6	0.8	To Sea (East), North East of	Winter North East of Qeshm coast
Feb	WSW	3.7	9.4	0.1	0.5	To Sea (East), North East of Qeshm coast	
March	WSW	5.3	9.7	0.2	0.1	To Sea (East), North East of Qeshm coast	
April	W	5.5	9.6	0.4	0	North East of Qeshm coast	Spring North East of Qeshm coast
May	WSW	5.2	9.6	0.2	0.2	To Sea (East), North East of Qeshm coast	
June	WNW	6.1	9.7	0.3	0	N,North East of Qeshm coast	
July	WNW	6.5	9.7	0.3	0	North East of Qeshm coast	Summer North East of Qesh coast
Aug	NW	6.7	9.7	0.3	0	North East of Qeshm coast	
Sept	WSW	6.3	8.7	0.9	0.3	To Sea (East), North East of Qeshm coast	
Oct	WSW	5.3	9.6	0.2	0.2	To Sea (East), North East of Qeshm coast	Around Rajaee coast, North East of Qeshm coast
Nov	SW	6.2	9.5	0.2	0.3	Rajaee Coast, To Sea (East),North of Qeshm	
Dec	SSW	5.7	9.7	0.2	0.1	Rajaee Coast	
Year	WSW	5.6	---	---	---	To Sea (East), North East of Qeshm coast	---

Table 4: GNOME output quantities for 10bbl diesel and gasoline during 35 days

Type of oil 10 bar amount		Barrels	Time duration After 1 hour		1 day		2days		7 days		15 days		30 days		35 days	
G	D	E& D	G	D	G	D	G	D	G	D	G	D	G	D	G	D
			5.6	0.3	9 .8	3.4	10	5.3	-	8.1	-	9.2	-	9.7	-	10
G	D	B	0.8	1	0.1	0.2	0	2.4	-	1.9	-	0.8	-	0.3	-	0
G	D	F	3.6	8.8	0.1	6.3	0	2.3	-	0	-	0	-	0	-	0

G= Gasoline, D= Diesel, E& D= Evaporate & Dispersed, B= Beached, F= Floating

Table 5: GNOME degradation rate for 200 bbl diesel and gasoline

Type of oil 200 bar amount		Barrels	Time duration After 1 hour		1 day		2days		7 days		15 days		30 days		60 days		90 days	
G	D	E&D	G	D	G	D	G	D	G	D	G	D	G	D	G	D	G	D
			112	5	197	68	200	108	-	162	-	181	-	193	-	198	-	200
G	D	B	9	24	1	43	0	27	-	35	-	18	-	7	-	2	-	0
G	D	F	78	171	2	88	0	65	-	3	-	1	-	0	-	0	-	0

G= Gasoline, D= Diesel, E&D= Evaporate & Dispersed, B= Beached, F= Floating

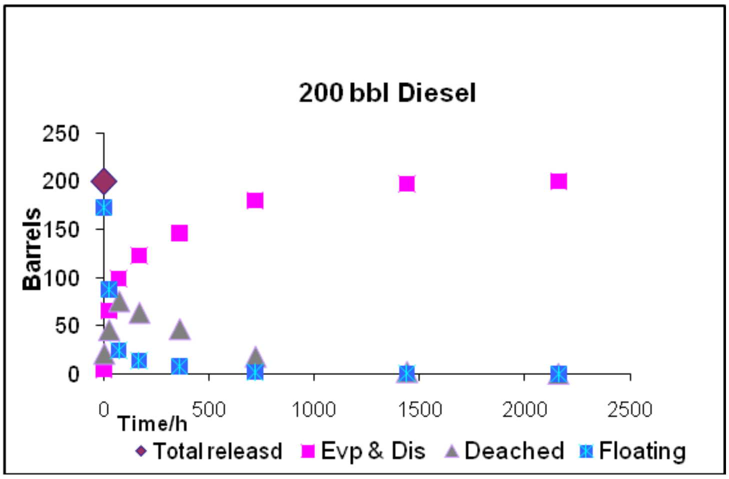


Figure 6: diesel degradation chart, 200 bbl

The oil viscosity or oil type is the main factor which effects on evaporation, floating and beached rates (Tables 4, 5). After 1 day 9.8 bbl of gasoline and 3.4 bbl of diesel evaporate and disperse. Diesel needs approximately 35 days to evaporate completely and disappear but gasoline needs 2 days (Table 2, 4), (Figs3, 4, 5).The second scenario was for 200bbl of oil spill. Diesel evaporates in 90 days while gasoline evaporated in 3 days (Tables 2, 5 and Figs 4, 6).

Comparison between 10 and 200 bbl indicated enlarging the volume will increase the degradation rates, spill time extent (life time) and spill area. However, it does not affect the place and direction of spill accumulation. The determination of high risk zones is independent of oil spill capacity. Regarding to model results, weather condition and local shore configuration, the life time is a function of release volume and oil viscosity.

For the third scenario monthly spill fate proportion calculated for year 2006 and the results has been shown in figure 7.

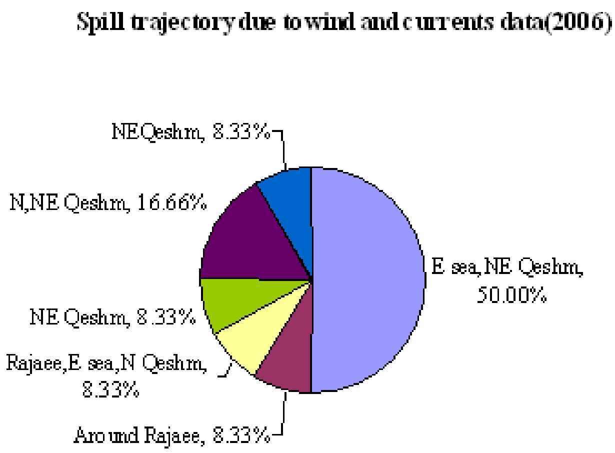


Figure 7: Monthly spill fate of 2006 regarding to wind direction, 50% and 16.66% due to same wind direction, It must consider that the directions of other months are dfferent hence the fate may similar

The Wind direction of six months of 2006 was west south west such as January, February, March, May, September and October. The dispersed oil moved to the west of Rajaee Port toward Bandar Abbas city. After a few days, the pollution disperses with current and moves into the sea water toward the north and north east of Qeshm Island coast and accumulates on the beach. In April, June, July, August, November and December wind was the type of west such as west North West, North West, and south south west. It moved the pollution to the south toward the sea then accumulated on the North East of Qeshm Island coast. During the year 2006 the commonly mean wind speed is (4-7) kn. Current pattern and most of the wind direction is as type of west (W). Therefore, more than 90% of oil spill disperses and accumulates on the Rajaee port coast then extends to the west, east and also Qeshm Island (Table3), (Fig.7). It can be concluded that the regions of Bandar Abbas coast around Rajaee and North of Qeshm Island are risky areas.

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Discussion

In scenario one it is identified that the degradation life time is dependent to the oil type and viscosity. The result of scenario two showed that life time, degradation rate and oil spill area extent is the function of spill volume. In scenario three current and wind are the most effective factors on the spill fate which can be used for predicting where oil spills may move towards and pollution beach contingency. In case of big spillage in Rajaee Port for wind directions from west south west (WSW) or west (W) the spill will reach Bandar Abbas city coast, cover a large area of coastal sea water and at last beached on the north coast of Qeshm Island.This study investigated oil spill fate, which is released around Rajaee Port and predicting the fate of future accidents. The results will be useful for many organizations such as Bandar Abbas Oil Refining Company (BAORCO), Port and Maritime Organization (PMO), Hormozgan Fisheries Company, Hormozgan Department of the Environment (HDOE) and even local people. This project increased the knowledge and information about oil spill fate in case of accidents. The information can be used to improve the emergency management systems in order to protect the human health, coastal management, and marine environment.

Acknowledgments

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