

# Oil Spill Trajectory and Fate Modelling at the Bahamas Caribbean: Theoretical Framework

MS Lawan\*

*Department of Petroleum and Environmental Technology, Coventry University, United Kingdom*

\***Corresponding author:** MS Lawan, Department of Petroleum and Environmental Technology, Coventry University, United Kingdom, Tel: 08036687020, E-mail: lawanm3@uni.coventry.ac.uk

**Citation:** MS Lawan (2020) Oil Spill Trajectory and Fate Modelling at the Bahamas Caribbean: Theoretical Framework. *J Environ Pollut Manage* 2: 206

## Abstract

This paper briefly summarizes the oil spill trajectory and fate modelling concepts at the Bahamas Caribbean. As the dependency on offshore drilling to extract oil and natural gas continues in areas such as the outer continental shelf, transportation through vessels and pipelines is critical to ensure the consistent delivery of petroleum. Meanwhile, oil exploration in the marine environments will continue to have significant impacts associated with accidental discharge of oil on the environment and human health. Whilst new technologies in locating, extracting and exporting oil have reduced environmental impacts, a number of models have been developed to simulate weathering processes and forecast the fate of oil once spilled. Likewise, trajectory modelling using GNOME and ADIOS model tools were significantly important in defining the future occurrence of oil spill and address environmental impacts. To achieve this, an adequate knowledge and behaviour of the oil with respect to varied situations was considered in this framework. Assessment at the end of every significant oil spill usually done to ascertain the level of impact caused to socio-economic parameters especially the vulnerable marine species.

**Keywords:** Oil Spill; Modelling; GNOME; ADIOS; Trajectory; Fate Modelling

**Abbreviations:** NOAA: National Oceanic and Atmospheric Administration; GNOME: General NOAA Operational Modelling Environment; ADIOS: Automated Data Inquiry for Oil Spills.

## Introduction

Oil spill is a form of an environmental pollution whereby liquid petroleum hydrocarbon (basically crude oil) is released as a result of human activity [1]. Pollution due to oil spills in the marine environment as a result of exploration and production activities has over the years caused a lot of catastrophe [2]. Meanwhile, oil spill in the marine environments will continue to have significant impacts on the environment and human health, emerging new technologies in locating, extracting and exporting oil as well as spill trajectory and fate modelling have in the other way reduced the magnitude of such impacts. A number of models have been developed so far to simulate the weathering processes and forecast the fate of oil once spilled. Likewise, GNOME and ADIOS model tools were significantly important in defining the future occurrence of oil spill and address environmental impacts.

## The Bahamas Caribbean

A worst case scenario of the recent times is the 2010 Deep water Horizon oil spill at the Gulf of Mexico with an estimated 4.9 million barrels marking the second largest marine spill in the world after the Gulf war oil in Kuwait [3]. According to a report by the Deep Water Horizon Study Group published January 2011, the 89-day oil spill has attracted more than 40,000 responders aided control efforts. Hence the geological flows of the coastal environment and their changing structure has a significant influence on the outcome of oil spills [4]. Bahamas is a coastal area comprising of an extensive number of island located in the western Atlantic zone. It has the largest area of tropical shallow water which lies on the northern and eastern margins banks with a number of smaller isolated banks while separated from the North American continent by the Florida straits [5]. There is an average number of approximately 700 islands with area of about 13,0860 km<sup>2</sup> all distributed along the Caribbean zone. The sea which is the source of tourism for Bahamas, accounts for 60% of the Bahama's GDP. GNOME and ADIOS were used as environmental modelling software to predict a spill scenario at Bahamas. GNOME generates the spill trajectory during the spill based on the wind, current and other variables. Furthermore, the minimum regret and the spill uncertainties were also critically determined. On the other hand, ADIOS forecast for the likely fate and the weathering processes associated with the oil over time (Figure 1).

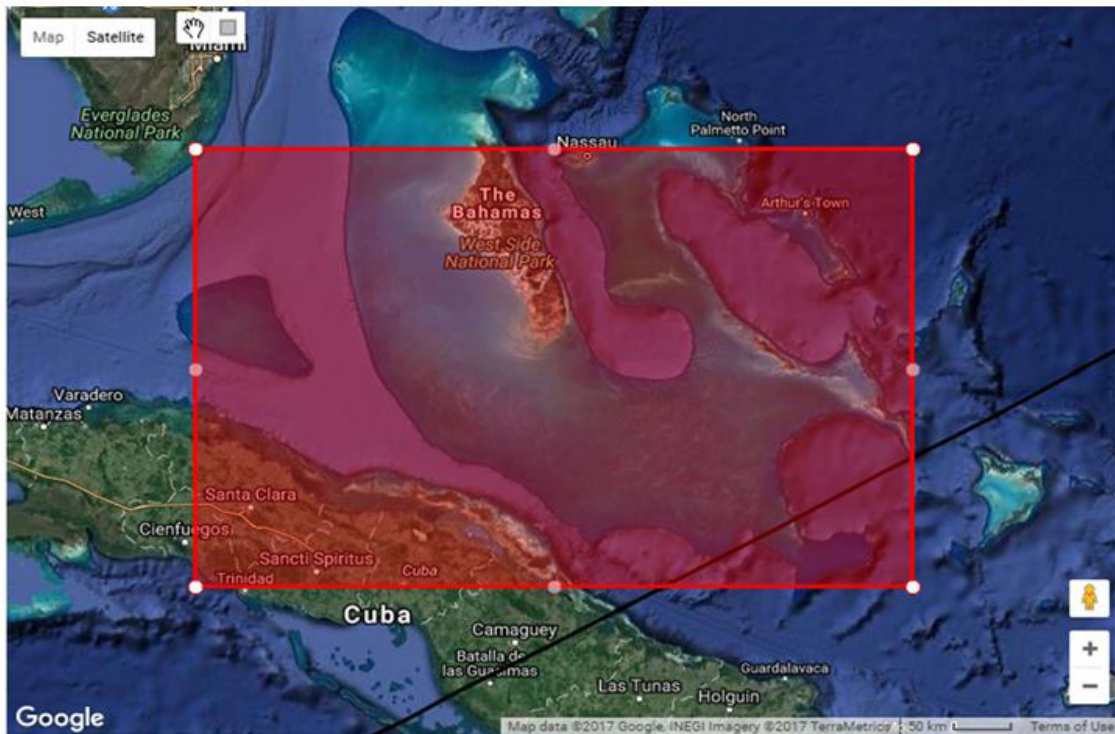


Figure 1: Map showing the location of Bahamas (Source: GNOME 2017)

## Understanding the Oil and Spills

With cause of time and other responsible factors, the oil spilled changes through different phases usually termed as transportation and weathering [6]. According to White [6] factors affecting oil spill can be summarised as follows.

1. Quantity and properties of the Oil spilled.
2. The prevalent weather and environmental factors.

The major United State trade association for oil and natural gas classification (API) has categorised crude oil on the bases of specific gravity into four different types. Table 1 below shows the oil types respect to their API values.

Oil Class	°API Value
Light Crude	°API $\geq 31$
Medium Crude	$22 \leq \text{API} <$
Heavy Crude	$10 \leq \text{API} < 22$
Extra heavy Crude	°API $\leq$

Table 1: Crude oil classification based on API range

According to Awardh, *et al.* [7] API of the oil is inversely related to its specific gravity or the density. Table 2 below shows the oil API values and their density variation.

Oil Class	API Ranges (S)	Density
Light	00-30	
Medium	22-31	
Heavy	10-22	
Extra heavy	00-10	

(Source: Speight 2007)

Table 2: Classification of Crude oil relative to density

Other physical properties of the oil important during spill include; solubility, Pour point, Volatility and Viscosity [8]. Beside the oil physical and chemical properties, there are environmental and weather factors which has the potential of determining the outcome of the oil during spill. Based on literature, these factors can be summarised under two headings.

1. The Prevailing seasonal or weather factors which includes the wind, temperature and other seasonal variations.
2. The Host spill environment which can be onshore or offshore such as fresh water rivers or coastal.

## Ethiopian Energy Situation

The Bahamas coordinate base map and point of the spill as generated by GNOME is as shown below in Figure 2.

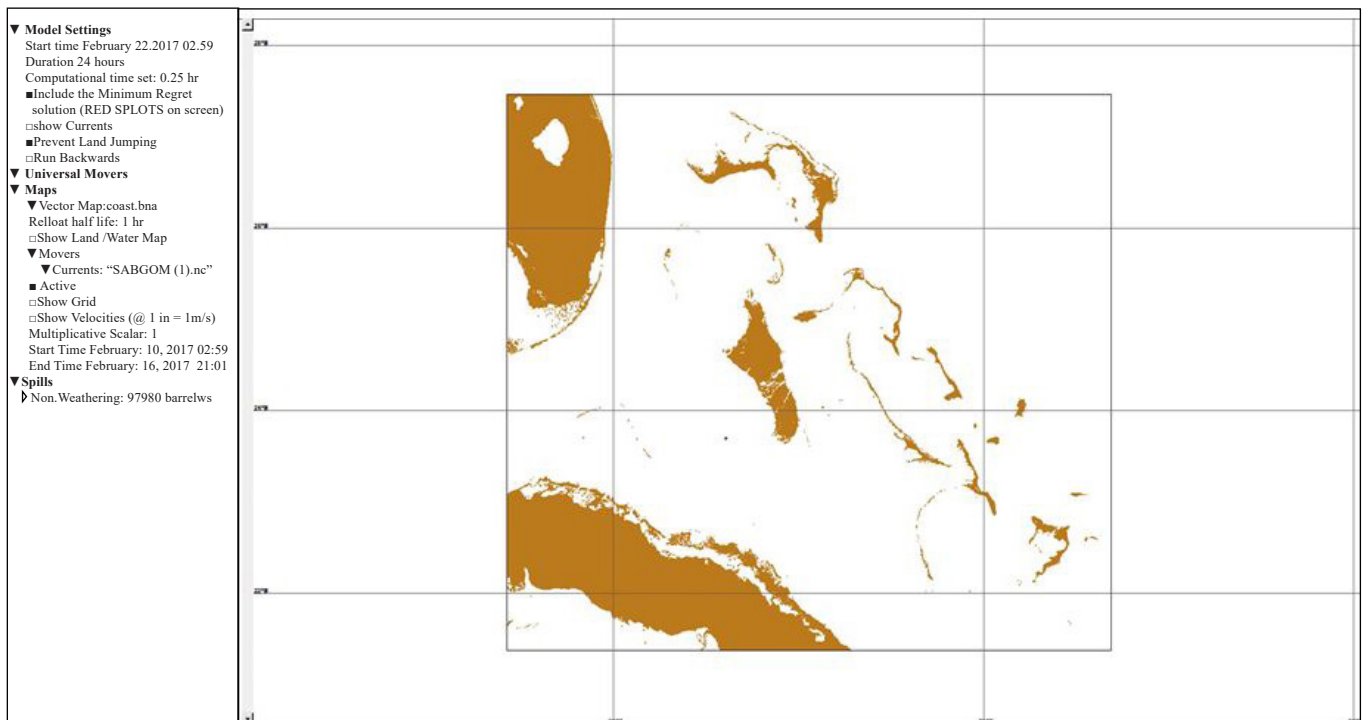


Figure 2: Boundary map showing the point of spill. (Source: GNOME 2017)

## Results

The trajectory of the oil at different time and conditions as predicted by the GNOME modelling tool were presented and individually discussed and presented in Figures 2-8. Meanwhile, the weathering processes which determines the oil fate and transport was predicted by the ADIOS were further discussed and presented in Figures 9-15.

## The Spill Probability

A spill from of 3,266 bbl. has been recorded from six production wells over a period of six days. Poisson's probability equation is used to determine the Probability of zero spills;

$$p(0) = \frac{(\lambda t)^n \cdot e^{-(\lambda t)}}{n!}$$

$$\lambda = \frac{6}{3266 \times 6 \times 6} = 5.10 \times 10^{-5}$$

$$e = 2.17828$$

$$t = 1.175 \times 10^{-4}$$

$$p(0) = \frac{(5.10 \times 10^{-5} \cdot 1.175 \times 10^{-4})^0 \cdot 2.17828^{-5.10 \times 10^{-5} \cdot 1.175 \times 10^{-4}}}{0!}$$

$$p(0) = 1.00$$

$$\text{In percentage} = 1.00 \times 100$$

$$= 100\%$$

Hence, there is 100% probability of spill from the Bahamas six oil production wells. Modelling results from the GNOME revealed the following (Figure 3).

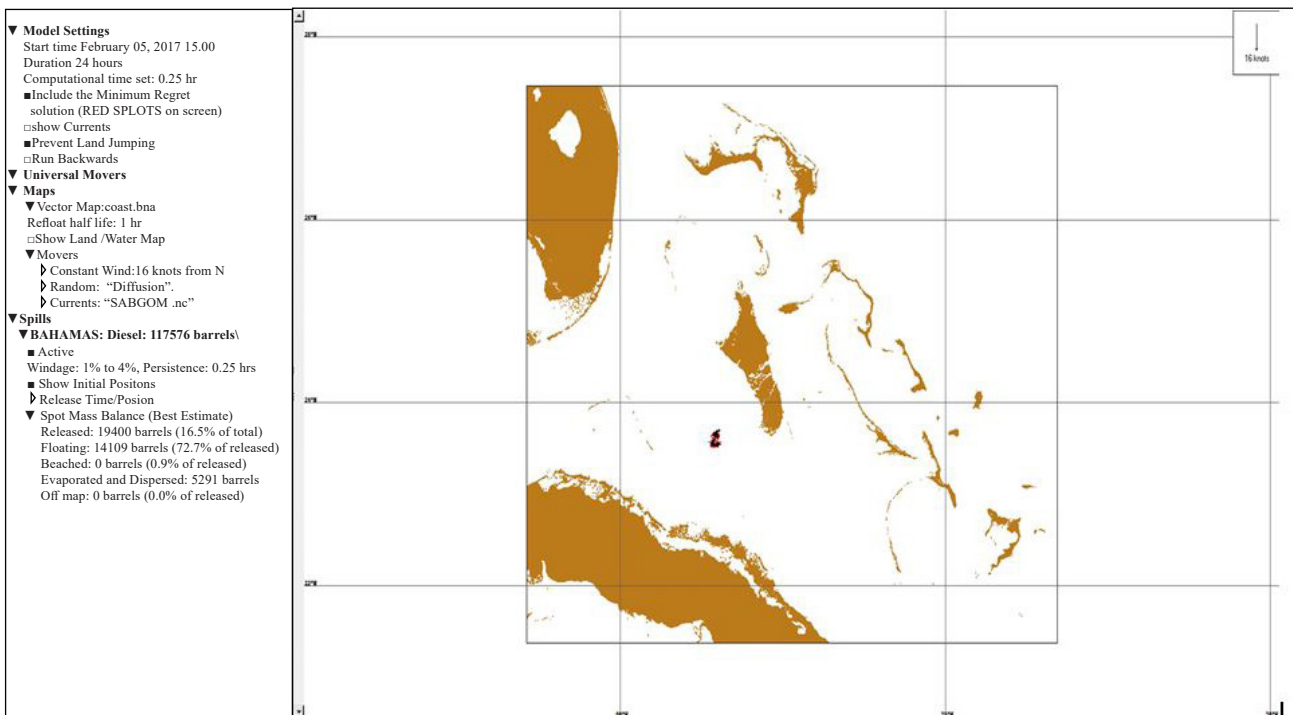


Figure 3: Level of Spill within initial 24hours

The suspended oil on the water surface experiences a force of gravity initiating the displacement. Although this is quite infinitesimal in smaller volume of oil (Camp and Berg 1987). Spreading and dispersion as a result of the advection mechanisms such as the wind, current and tides influence the displacement of the oil slick [3] (Figure 4,5).

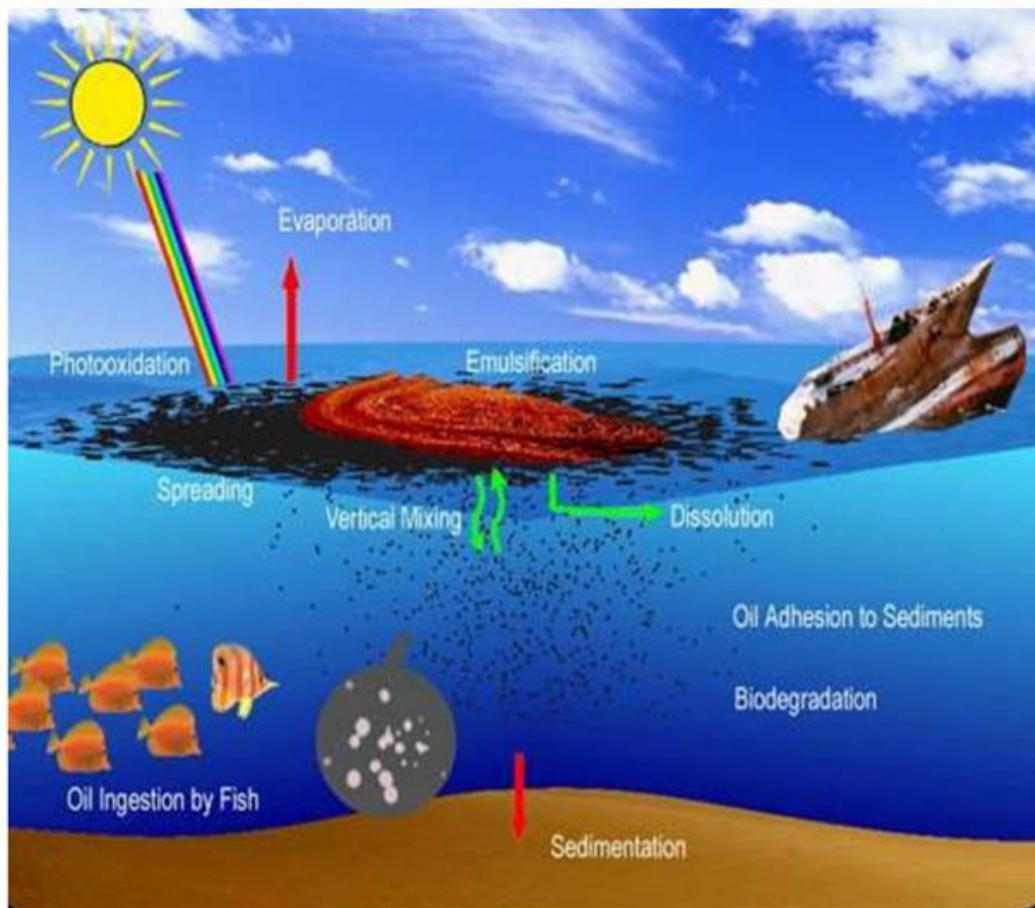


Figure 4: Weathering processes of the oil after spill [9]

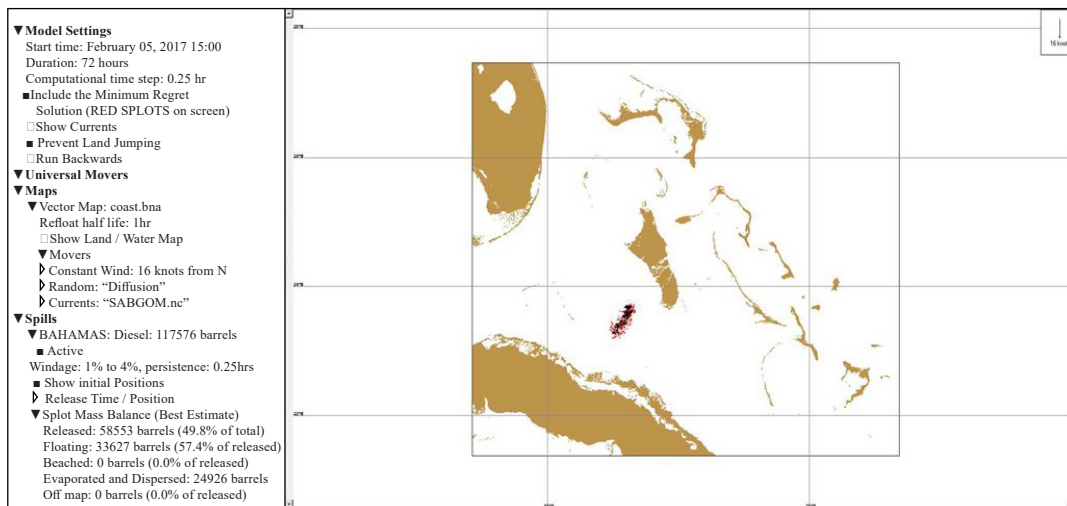


Figure 5: Day 3 level of the spill

Wang, *et al.* [10] maintained that oil slick movement can be influenced by 30% with respect to the wind velocity. On the other hand, Fingas [8] has the view that wind factor could have effect during spill only if the wind exceeds an average strength of 10knots. Hence the trajectory of the spill towards the south would be attributed to the wind strength of about 16knots north (Figure 6,7).

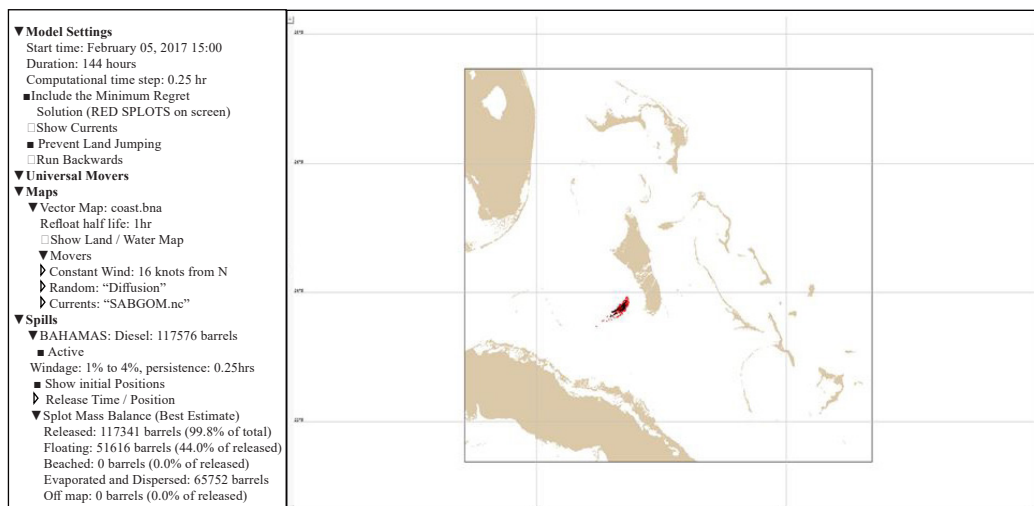


Figure 6: Level of spill after six days without the wind factor

This further confirms the effect of the wind as a factor in transport of the oil.

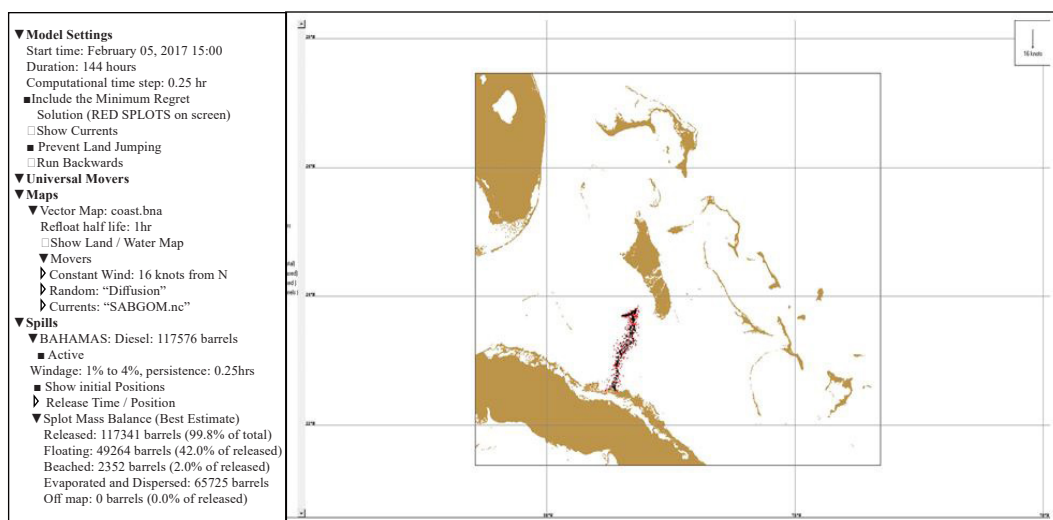


Figure 7: The Beaching of the spill after six days

Current as one of the advection forces earlier discussed has the influence to increase the level of minimum regret (the red spots) as seen from Figure 8.

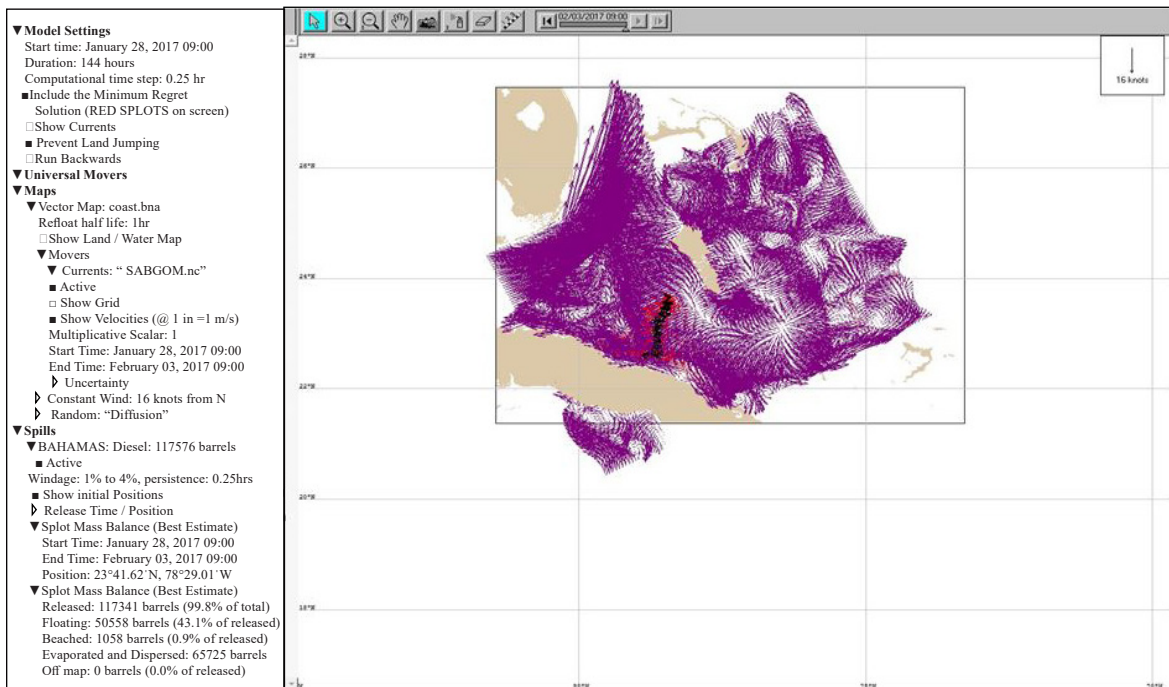


Figure 8: Level of spill under influence of the current

### The Spill likely Fate

The Spill scenario at Bahamas as defined from ADIOS revealed the weathering processes which determines the oil fate and transport as follows

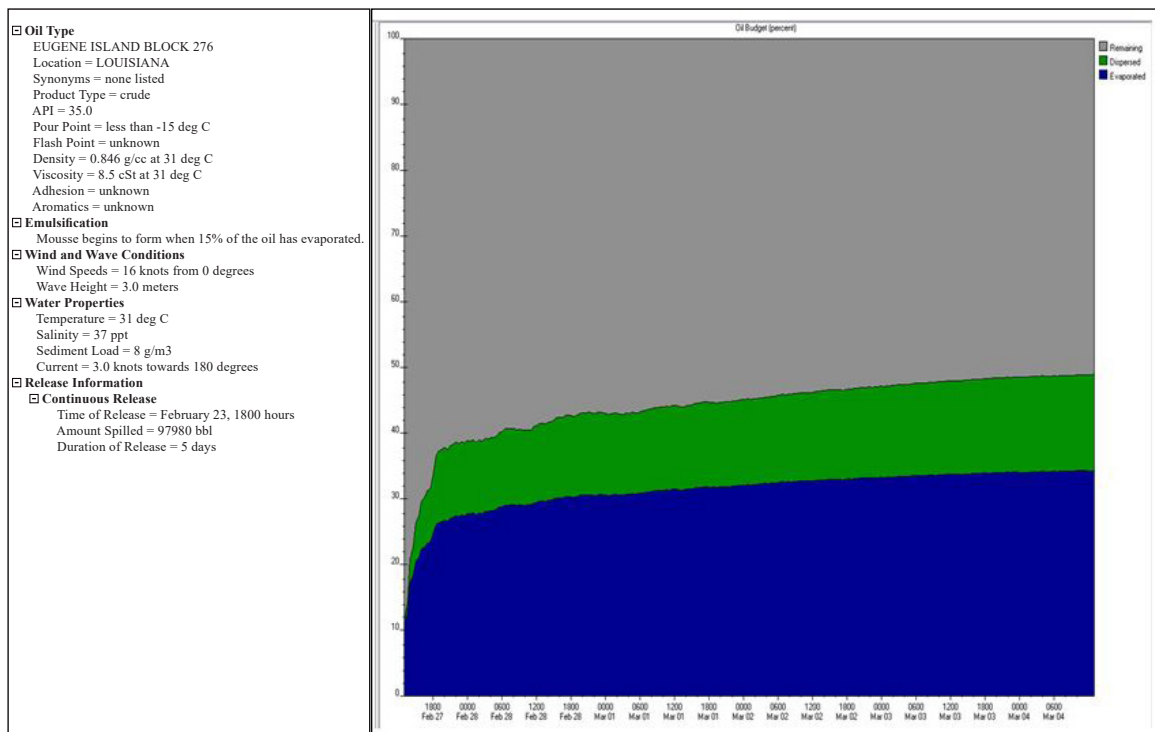


Figure 9: The relative quantity (budget) of the oil over time during winter.

Figure 9 shows a decrease in quantity of the oil over time. Fingas [11] stated that evaporation can cause the loss of nearly 45% of oil volume during spill. Further research by Fingas [12] asserted that temperature and time are the only determinants and wind factor is not influential. Therefore, the cause of the oil remaining and the level of evaporation are dependent on the wind and temperature factors with time. The oil budget shows different results for winter and summer times. The cause of this would be attributed to the temperature variation as suggested by Fingas [12] (Figure 10-13).

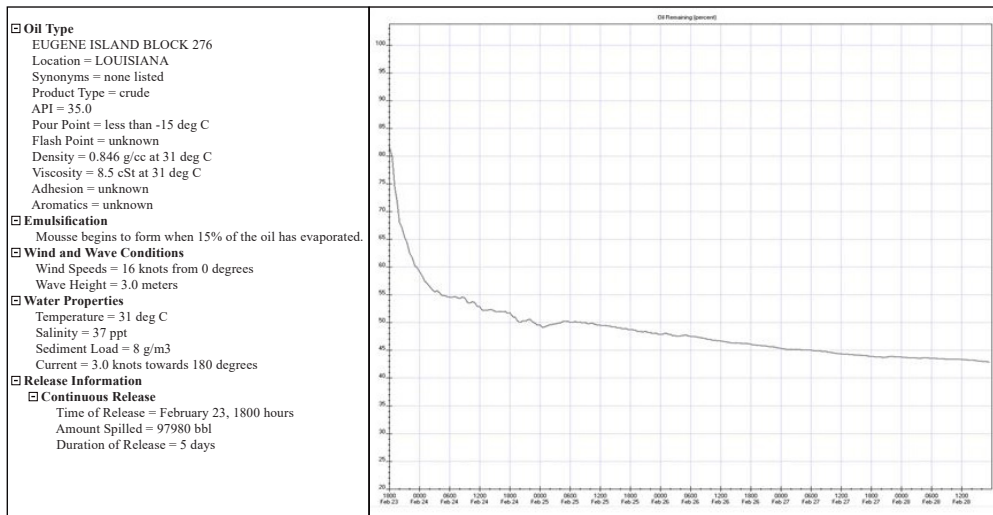


Figure 10: Graph of the oil budget during summer

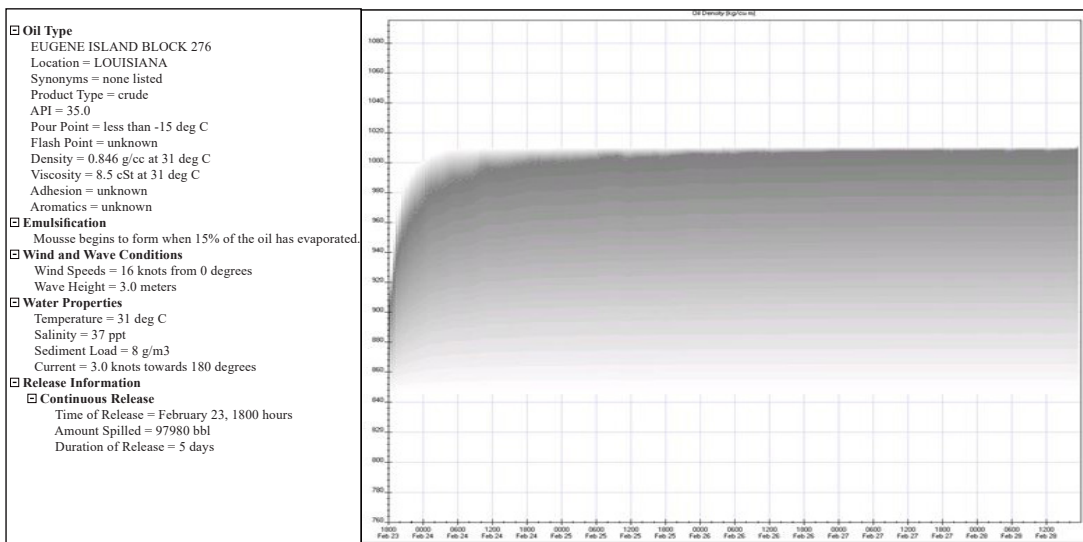


Figure 11: Density of the oil over time

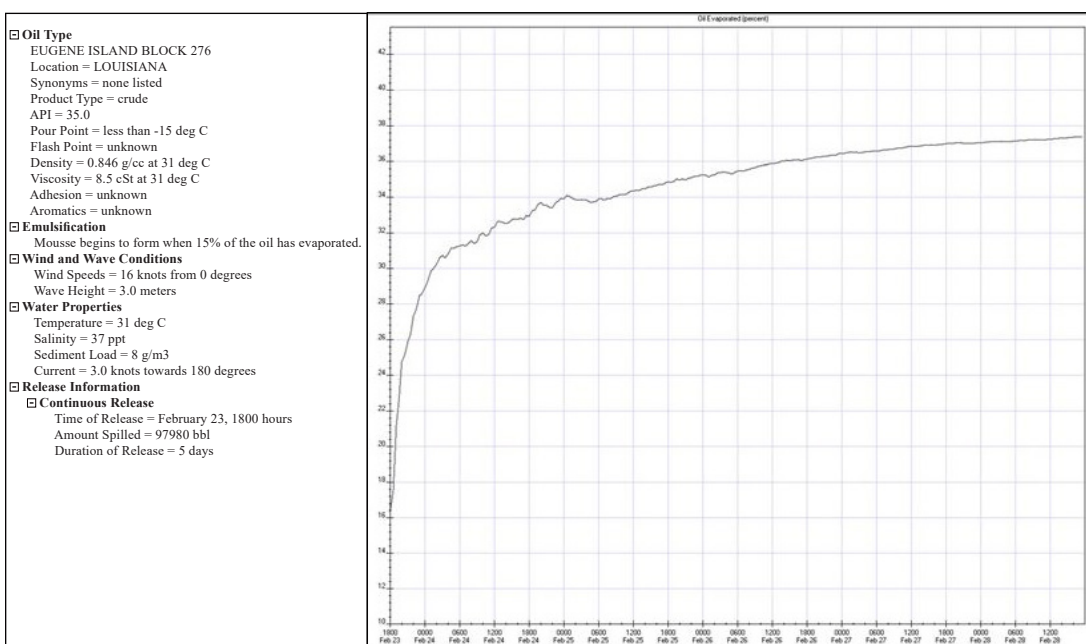


Figure 12: Evaporation of the oil over time

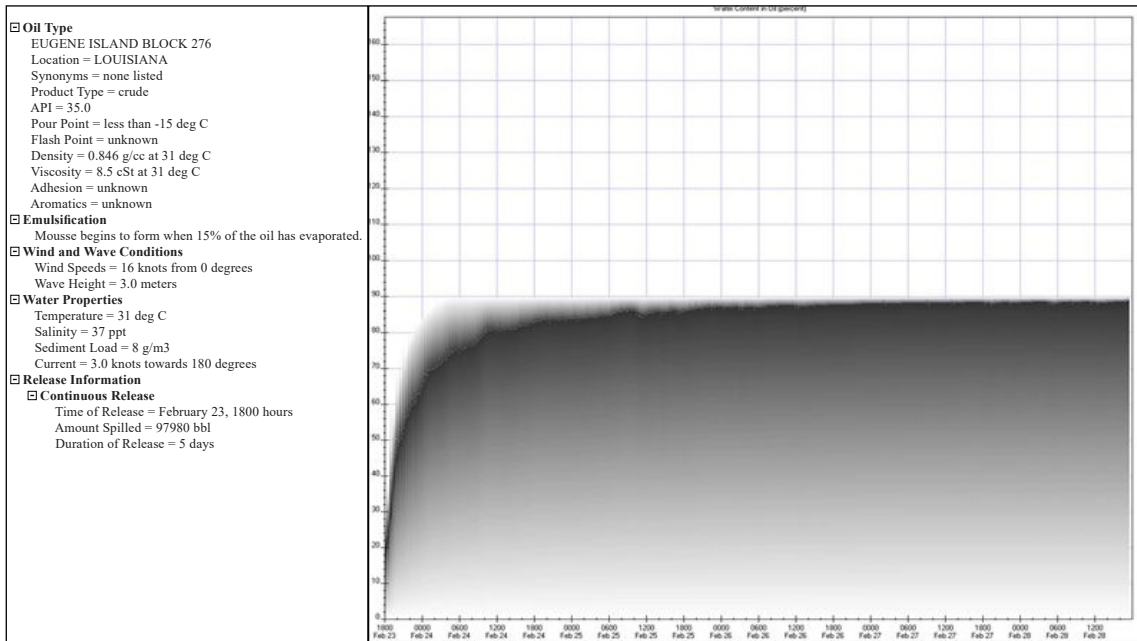


Figure 13: Emulsification level of the oil

Emulsification is one of the immediate weathering chemical processes occurring between the oil and water changing the chemical properties of the oil [9]. Although water and oil are immiscible however the driving force such as the current tides and temperature with respect to the soluble contents of the oil might generally be the cause of emulsion. Xie, et al. [9] maintained that 80% level emulsion indicates that the spill has five times its initial volume and in turn has greater implication towards response measures.(Figure 14).

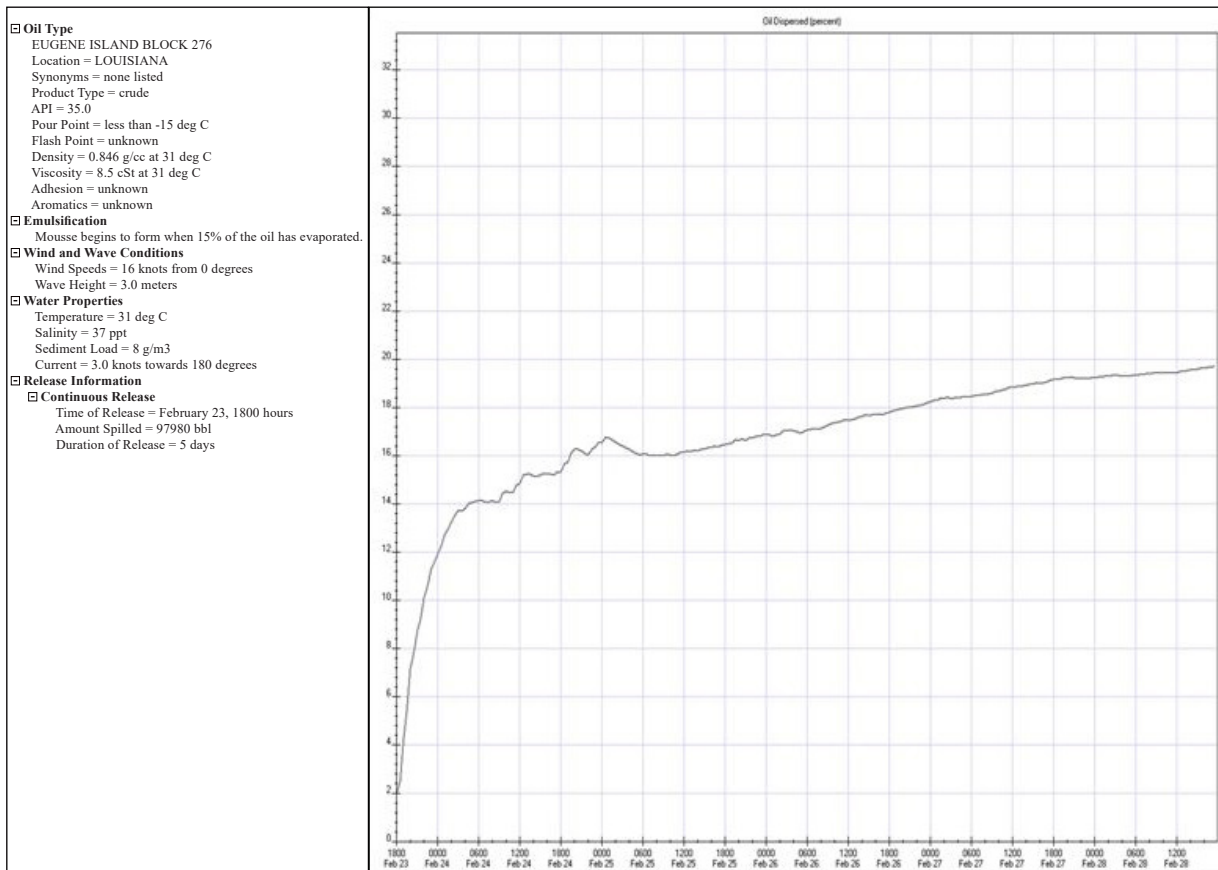


Figure 14: Increase in dispersion rate of the oil over time

The oil dispersion as earlier explained is basically attributed to the driving advection forces especially the wind and current having the influence during the spill.



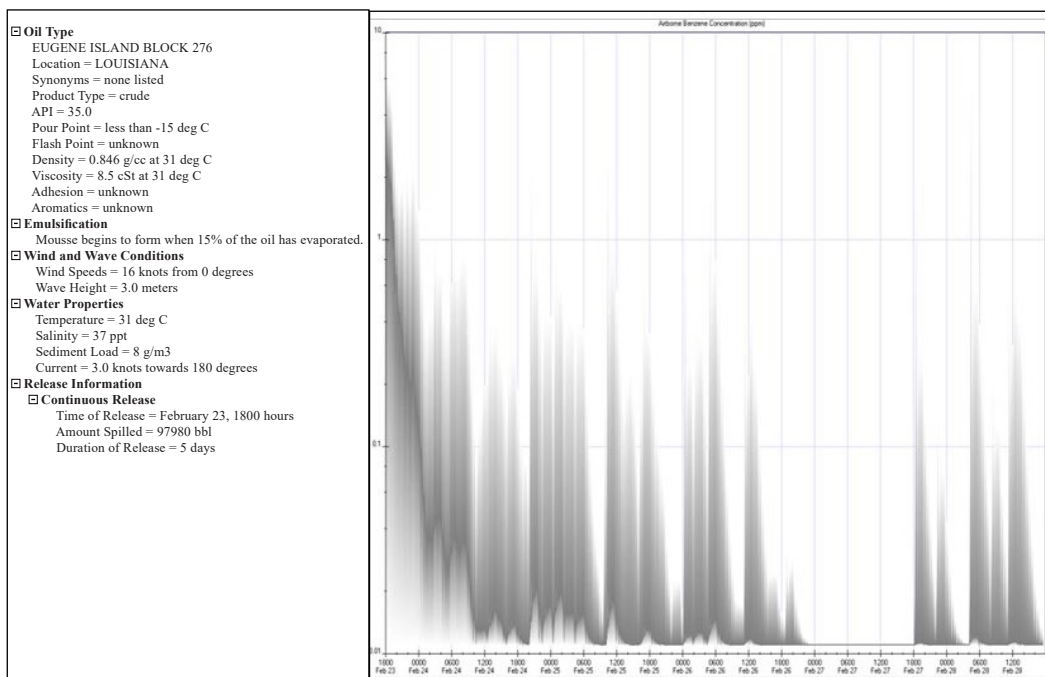


Figure 15: Reduction in Benzene Content of the oil over time

However, the benzene content in the composition of crude oil is ambiguous and quite not readily available in literature [13], GNOME could model out the graphical data degradation of benzene. Verma, *et al.* [13] further explained that benzene is rated as a toxic chemical that has an acute and chronic poisoning potential.

### Spill Response and Remediation

There are number of clean up techniques aimed to address spill scenarios. However, the effectiveness of every technique is a dependent variable of the spill environment, quantity of oil spilled and the characteristic physical and chemical properties of the oil [14]. Spill response techniques or equipment such as booms and skimmers, in situ burning, chemical dispersant are commonly employed during spills [2]. For the spill at Bahamas, booms and skimmers can be applied as about 42% of the oil still floating on the water surface. Booms and skimmers collectively prevent spreading and enable the opportunity to recover some amount of oil lost during spill. On the other hand, for the oil reaching the shore line, chemical dispersant can be used. The application of chemical dispersant in right amount enhances oil biodegradation reducing the risk impact of the oil on vulnerable shoreline habitats [15].

### Oil Spill Risk Assessment

Coastal areas invaluablely contribute to the economic growth as a result of activities such as fishing, tourism and ports. Therefore, spill cases have a catastrophic potential on the population especially the marine life [16]. According to Taylor [17], credits are attached to oil spill risk assessment towards implementing appropriate measures to manage risk impact. Stewart, *et al.* [18] categorised oil spill risk assessment into three distant approach; intuitive, simulative and empirical approach. In any approach, judgment is based on data analysis with respect to spill instances. For example, beside the impact to marine life species, the spill beaching the Cuban shoreline would have an impact on the level of tourist attraction to Cuba as Cuba has track record of over two million tourist visitors yearly [19].



Figure 16: Tourism around the Shorelines of Cuba (Source: google photo 2017)

In addition, Buchan [5] stated that 60% of Bahamas GDP is derived from the activities of tourism across islands. Hence oil spills may have the potential of harnessing the activities of tourism thereby affecting the economic growth [20].

## Tourists arriving in Cuba

Enticed by the potential flood of cash into the island's reeling economy, Fidel Castro opened Cuba to tourists in 1995, and it quickly became a top Caribbean destination. If U.S. restrictions are eased, the flow of Americans is expected to skyrocket.

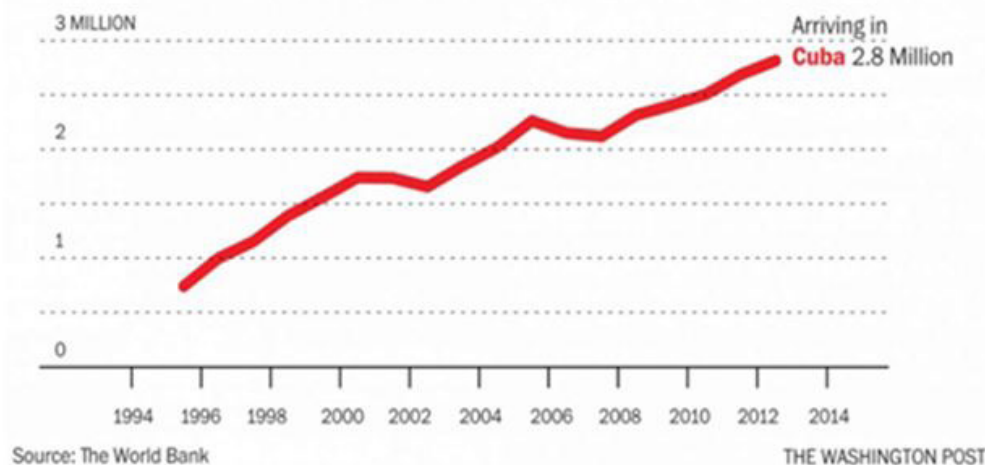


Figure 17: Record of tourist visitors to Cuba (World Bank 2016)

## Discussion

Oil spills along the coastal and selection of the best response strategy is always necessary in addressing the challenging impacts of spills. To achieve this, an adequate knowledge & behaviour of the oil with respect to varied situations must be considered [21]. Meanwhile there is no any distinct response strategy attached to all spill scenarios, but the best approach depends on multiple factors such as the quantity and properties of the oil spilled, the offshore features (such as current, tides, and salinity) and the prevailing weather conditions like the wind and temperature. Assessment at the end of every significant oil spill usually done to ascertain the level of impact caused to socio- economic parameters especially the vulnerable marine species [22].

## Conclusion

Environmental modelling tools such as the GNOME and ADIOS has a greater support in ascertaining the best future occurrences and predicting the possible minimum regrets [23,24]. However, such models have strength limitations and environmental datasets are mostly not constant but rather dynamic in nature. Xie, et al. [9] quoted that “although oil spill models have improved over the last twenty years, their capability of modelling of chemical processes is weak”. Indeed, among such limitations we find out that in GNOME, wind factor is taken as constant variable and the diffusion coefficient not quantifiable [25,26]. While in ADIOS the burning data of the oil also missing. Hence there is every need for further research to meet the gap of achieving reliable model representation of oil spills.

## References

- Adelana SO, Adeosun TA, Adesina AO, Ojuroye MO (2011) Challenges and management of oil Spillage in the Nigerian coastal areas. *Am J Sci Ind Res* 2: 834-45.
- Dave D, Ghaly AE (2011) Remediation technologies for marine oil spills: A critical review and comparative analysis. *Am J Environ Sci* 7: 423-40.
- Gong Y, Zhao X, Cai Z, O'Reilly SE, Hao X, et al. (2014) A review of oil, dispersed oil and sediment interactions in the aquatic environment: Influence on the fate transport and remediation of oil spills. *Mar Pollut Bull* 79: 16-33.
- Madrida JA, Olivaresa A, Poya BG, Garcia Ladonaa E (2015) Managing large oil Spills in the Mediterranean (E-08003) pp. 37-49.
- Buchan KC (2000) The Bahamas. *J Mar pollut bull* 41: 94-111.
- White I (2002) Factors affecting the cost of oil spills. Paper presented at the GAOCMAO Conference held 12-14 May 2002 at Muscat. Oman ITOPE.
- Awadh SM, Al-mimar H (2015) Statistical analysis of the relationship between API, Specific gravity and Sulfur content in the universal crude oil. *Int J Sci Res* 4: 1278-84.
- Fingas M (2016) Oil spills science and Technology. Texas: Gulf Professional publishers.
- Xie H, Yaba PD, Nakata K (2007) Modelling emulsification after an oil spill in the sea. *J Mar Syst* 68: 489-506.
- Wang SD, Shen YM, Zheng YH (2005) Two dimensional simulation for transport and fate of oil spills in seas. *J Ocean Eng* 32: 1556-71.
- Fingas MF (2012) Studies on the evaporation regulation mechanism of crude oil and petroleum products. *J Adv Chem Eng Sci* 2: 246-56.
- Fingas MF (2013) Modelling oil and petroleum Exploration. *J Pet Sci Res* 2: 104-15.
- Verma DK, Des Tombe K (2002) Benzene in Gasoline and crude oil: Occupational and environmental implications. *J Am Ind Hyg Assoc* 63: 225-230.

14. Tewaris S, Sirvaiya A (2015) Spill remediation and its regulations. *Int J Res Sci Eng* 1: 1-7.
15. Chandra SS, Sorial GA, Weaver JW (2006) Dispersant effectiveness on oil spills-impact of salinity. *ICES J Mar Sci* 63: 1418-30.
16. Marta Almeida M, Ruiz Villarreal M, Pereira J, Otero P, Cinaro M, et al. (2013) Effective tools for marine operational forecast and oil spill tracking. *Mar Pollut Bull* 71: 139-51.
17. Nissen Lie TR, Brude WL, Aspholm OO, Taylor PM, Davidson D (2014) Developmental guideline for spill risk assessment and response planning for offshore installations. *Int J Oil spill*.
18. Stewart TR, Leschine TM (1986) Judgement and analysis in oil spill risk assessment. *J of Risk Anal* 6: 305-15.
19. Lemos AT, Soares ID, Ghisolfi RD, Cirano M (2009) Oil Spill Modeling Off the Brazilian Eastern Coast: The Effect of Tidal Currents on Oil Fate. *Rev Bras De Geofis* 27: 625-39.
20. Jenkins TF, Johnson LA, Collins CM, McFadden TT (1978) The Physical, chemical and biological effects of crude oil spills on black spruce forest interior Alaska. *ARCTIC J* 31: 153-411.
21. Korinenko AE, Mainovsky V (2014) Field study of film spreading on a sea surface. *J Oceanologia* 56: 461-75.
22. Lewis AD (1997) Technical Report on putting dispersants to work: overcoming obstacles. (IOSC-004), 23. Washington DC. American Petroleum Institute.
23. National Environmental Research Institute (NERI) (2002) Potential environmental impacts of Oil spills in Greenland, Denmark: Ministry of environment.
24. National Oceanic and Atmospheric Administration (2014) The description of NGOME software.
25. Obi EO, Kamgba FA, Obi DA (2014) Techniques of Oil Spill Response in the sea. *IOSR J Appl Phys* 6: 36-41.
26. Santos RG, Loh W, Bannwart AC, Trevisan OV (2014) An overview of heavy oil properties and its recovery and transportation methods. *Braz J Chem Eng* 31: 571-90.
27. Speight JG (2006) *The Chemistry and Technology of Petroleum* New York: CRC Press.