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Oil Spill Trajectory Simulation of The Dangote Single Point Mooring (SPM) Terminal Off the South Atlantic Ocean, Lagos Nigeria Using ADIOS2 and GNOME

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ABSTRACT: 689260

Crude oil is predicted to become one of the most detrimental sources of anthropogenic pollution to the marine environment. To meet Nigeria's energy need, Dangote Industries Ltd. was granted licence to build a refinery in the Lekki Free Trade Zone in 2014. There is a significant risk of oil spill from the Single Point Mooring terminal of the refinery as it shares close proximity to the Lekki deep seaport, closeness to the shoreline, sensitive environmental receptors as well as social spots (beaches and resorts). To address this gap, this study aims to design a stochastic model for oil spill prediction for the SPM terminal in order to provide an understanding of the trajectory, fate and uncertainties of spilled oil at different environmental and hydrodynamic conditions. The GNOME software was used to model oil spill trajectory in the SPM terminal while ADIOS2 modelled Bonny light crude weathering characteristics. The best guess solution and the minimum regret analysis shows the possibility of oil beaching on the coastline of Lagos, Edo and Delta State as well as the Gulf of Guinea. The fate simulation for 5 days revealed that evaporation will account for 23% and 27% of oil loss in dry and wet season while dispersion will account for 1.3% and 1.6% in the same time period. Within the same time period, Bonny light crude will form a stable emulsion that will increase the viscosity and density of oil. Also, 66% and 59% of oil was remaining after 5 days, while airborne benzene concentration evaporated in 36 hours and 12 hours in the dry and wet season respectively. The results obtained in this research work suggest that, the window of opportunity need to be utilised by stockpiling equipment and mechanical responders for shoreline clean-up

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to avoid the oil possibly beaching along the Coastline of Lagos, Edo and Delta state as well as countries on the Gulf of Guinea.

INTRODUCTION

Over the past 200 years, fossil fuel has remained a key driver for economic growth and development (Fankhauser and Jotzo 2017). However, this vital source of energy has profound impact on the environment when a spill occurs. Oil spills occur resultant of natural or anthropogenically induced causes (Nelson and Grubesic 2017). The three primary sources of oil spill in the marine environment are natural seepage, wellhead blowout and tanker spills (Nelson and Grubesic 2017).

An oil spill in the marine environment leave a trail of ecological, social, economic and health (carcinogenic and mutagenic effects) on fisheries, shoreline, marine population, ecosystem, facilities, tourism, and human life (Marta-Almeida et al. 2013). Hence, the damages associated with oil spill cannot be overemphasized.

The coastline of Lagos is home to a wide range of biodiversity, lots of beaches that serve as tourist attraction and large population (Adeniyi et al. 2016). The Lagos section of the Atlantic Ocean is also home to a wide variety of fish species, endangered species (Blue whale, sperm whale, Plata river dolphin, humpback dolphin and the manatee), sea birds, plankton and nekton, and benthic organisms (Acha et al. 2004). Therefore, the coastline is at risk in the event of a spill.

Considering the locational advantage, economic importance of the refinery, biodiversity and environmental sensitivity of the Lagos shoreline, an oil spill due to vessel collision or accident on the SPM can have a deleterious effect on the marine environment and inflict potentially serious damage to the area. Hence, it is paramount to have an understanding of potential oil trajectories across seasons, to enable stakeholders create a manageable decision tool to clean up oils, prevent, manage, and reduce the extent of damage (Wang et al. 2005).

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This study aims to provide a stochastic model that can serve as a decision tool for managers and stakeholders, providing a basis for the formulation of an OSCP on the coastline of the Lagos section of the Atlantic Ocean. This will be achieved through the following objectives:

1. To model and display the oil spill trajectory for different oil spill scenarios for the Dangote SPM under various environmental conditions using GNOME;
2. To predict the uncertainties “minimum regret” associated with the oil spill predictions;
3. To evaluate the fate of Bonny Light Crude Oil using the ADIOS2 weathering software

GENERAL NOAA OPERATIONAL MODELLING ENVIRONMENT (GNOME)

Developed using Eulerian/Langranian 2D model and written in the C++ programming language, GNOME was designed for modelling transport of oil slicks in marine environment (Eke and Anifowose 2017, Ibarra-Mojica et al. 2018). Because it was developed using the Eularian/Lagrarian model, oil slicks are represented by independent floating particles (Langrarian splots) advected with the surface Eulerian current velocity in the marine environment (Eke and Anifowse 2017). GNOME can be used to simulate for an instantaneous spill (pipeline leak or well blowout), spills from leaking vessel and from spills observed from an overflight (NOAA 2002). GNOME has found wide applicability in hind cast and forecast modes (Cheng et al. 2011).

The use of GNOME for oil spill trajectory returns results that predicts the Best Guess Solution assuming that winds and currents are free of errors (Marta-Almeida et al. 2013; Beegle-Krause 2001), and the minimum regret (worst case scenario) which factor in the uncertainty in input parameters (Xu et al. 2013; Marta-Almeida et al. 2013). Hence, GNOME require few input parameters such as maps, bathymetry, hydrodynamic data, type of oil spilled and the spill location, as well as the numerical hydrodynamic models (Zelenke et al. 2012). Therefore, GNOME can be used in any part of the world to provide reasonable ocean currents, surface wind and land sea mask (Marta-Almeida et al. 2013).

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Aside GNOME, there are other modelling tools (Elizaryev et al. 2018), however, GNOME is widely used because it is freely available, user friendly, simple and provides accurate and detailed analysis of oil spills in the marine environment (Ibarra - Mojica et al. 2018; Marta-Almeida et al. 2013). It also has the capacity to model different types of oil and provides the minimum regret (worst case scenario) of spilled oil (Korsah and Anifowose 2014). Despite all of this, GNOME has limited 3D capabilities (Marta-Almeida et al. 2013), weathering characteristics and oil-shoreline interaction processes (Beegle-Krause 2011).

AUTOMATED DATA INQUIRY FOR OIL SPILLS (ADIOS2)

ADIOS2 was a development work of the United States National Oceanic and Atmospheric Administration Hazmat Division (NOAA/HAZMAT) solely for the forecast of weathering and characteristics of oil slicks (Lehr et al. 2002). Oil weathering is the physical, chemical and biological process that spilled oil undergoes in the marine environment and transform it (NOAA 2002). The weathering characteristics of spilled oil can be understood (as shown in Figure 2.8) with the aid of weathering models such as ADIOS2 which according to Fingas (2013), is a key process that must be understood by decision makers and responders for the development of a holistic and effective clean-up strategy.

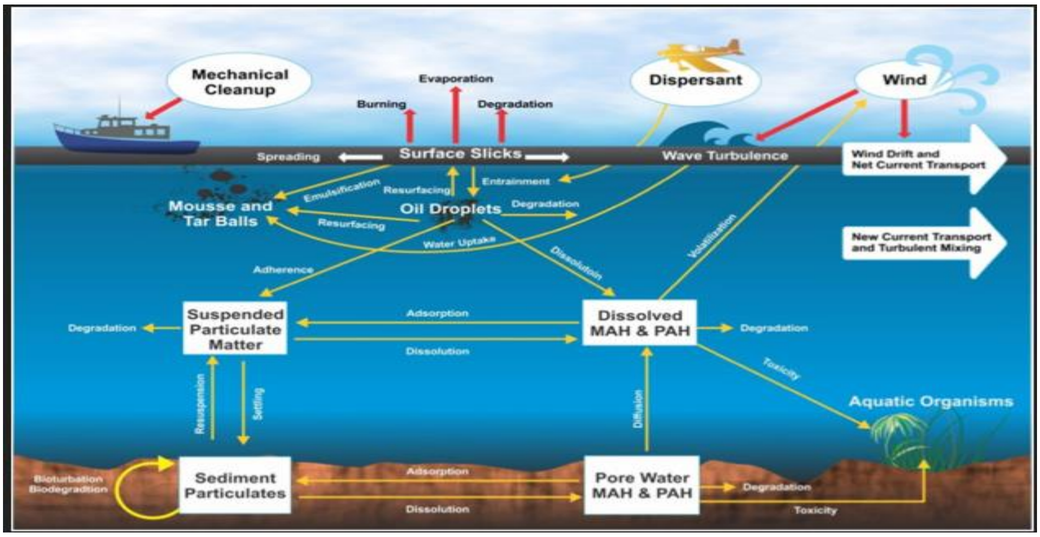

Figure 1: Oil weathering Process (Splauding 2017)

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Designed with more than a thousand database of wide ranging crude and refined oils, ADIOS2 provides a quick estimate of the weathering characteristics of oils and best guess answer with few input parameters that can be obtained from the field within the shortest time possible through mathematical equations that gives output as both text and graphics (Samuels et al. 2013). In addition, ADIOS2 software is also able to account for sedimentation as well as the effects of clean-up processes such as in-situ burning, chemical dispersants and skimming (NOAA 2006), however, the end user will have to do extra plugs-in to activate these features. The rate of weathering of oil is dependent on spill location, the rate and duration of release, and the prevailing environmental conditions such as salinity, temperature, wind speed, sediment concentration and wave height of the marine ecosystem before and after the spill (Eke and Anifowose 2017). Hence, in the event of an oil spill at the Dangote SPM, these factors will determine the extent and rate of weathering factoring the difference in seasons.

Despite all of these, ADIOS2 can only simulate for a maximum period of five days, therefore, processes such as biodegradation, photo-oxidation, tar balls formation and Langmuir effect that take more than five days cannot be accounted for (Lehr et al. 2002; NOAA 2015). According to Lehr (2010), most models do not model photo-oxidation except an early model developed at the University of Southern California. Nevertheless, OSCAR, SIMAP, and BIOB models cater for biodegradation (Li 2017).

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Table 1: Processes and properties modelled in ADIOS *(Lehr et al. 2002).*

Properties	Processes
Density	Dispersion
Viscosity	Evaporation
Water fraction	Emulsification
Benzene Hazard	Spreading
	Beaching
	In-situ burning
	Leak rate

METHODODLOGY

Study Area and Spill Information

The proposed Dangote Petroleum Refinery and Petrochemical Enterprise is located in the Lekki Free Trade Zone (LFTZ), Lagos State, Southwest Nigeria. It lies on $6^0$20’21.88” N and $3^0$52’21.27” E and covers an estimated 2,635 Ha in size and is located in the South East quadrant that lies in the south east side of the LFTZ. The Refinery lies between the Lagoon on the left and the Atlantic Ocean on the right (DPR 2018). In order to account for the probability of oil beaching/reaching on the maritime boundary lines of the GOG, Nigeria, Togo and Ghana, an extended boundary line was used (Eke and Anifowose 2017). For modelling this typical oil spill scenario, the quantity of oil used was 476,000 barrels, and the period covered dry and wet season. The choice of oil volume is hinged on the fact that, very large crude carriers having a capacity of 2,000,000 barrels of oil will be used to transport crude to the SPM terminal (Dibin et al. 2011).

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Research Design

In order to effectively address the research problem logically and in an explicit way, the cross-sectional design was adopted for this study. This is because the cross-sectional design has proven to be effective for data collection and analysis over a short period of time spanning a period of days, weeks and months (Saunders et al. 2016). Due to shortage of time, hydrodynamic data was obtained for December and January leading to the trajectory simulation of Bonny light oil (See Table 1).

Table 2: Overlapping Hydrodynamic data obtained for simulation of Bonny Light Crude at the Dangote SPM terminal

Period	Start Time	End Time	Duration (Days)
1	28th December 2017	12th January 2018	15
2	13th January 2018	23rd January 2018	10
3	24th January 2018	29th January 2018	5
4	27th May 2018	11th June 2018	15
5	12th June 2018	22nd June 2018	10
6	23rd June 2018	28th June 2018	5
7	11th January 2018	21st January 2018	10
8	6th June 2018	16th June 2018	10

DATA COLLECTION, TYPE AND SOURCES

In order to carry out an oil spill trajectory simulation using GNOME, it requires two key parameters in currents and winds (Diviaco, Leadbetter and Glaves 2016). However, to improve the accuracy of the modelling output, parameter's such as tides, coastline boundary and information on the spilled oil such as density and viscosity are required (Samuels et al. 2013). Though considered insignificant, diffusion was set at default due to its contribution to oil slick movement (Wang et al. 2008; Guo and Wang 2009). Using NOAA's Global Self-

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Consistent Hierarchical High-Resolution Shoreline (GSHHS) database, a high-resolution customized vector map for the Dangote SPM terminal was generated (Eke and Anifowose 2017) and saved in a boundary file (.bna) format, a format compatible with GNOME (Zelenke et al. 2012). The boundary data cover the study location shown in figure 2.

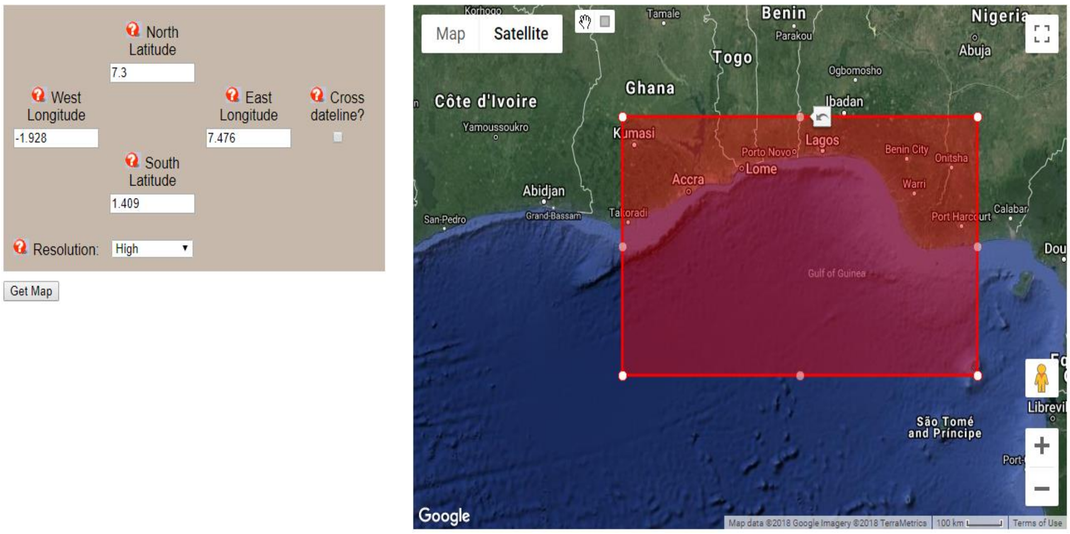

Figure 2: Extended latitude and longitude coordinates data available through GOODS NOAA website

Using the Latitude-Longitude Boundaries as the boundary map, ocean current was extracted from the Global Hybrid Coordinate Ocean Model from GOODS website. GNOME supports American standard Code for Information Interchange (ASCII) as well as Network Common data Form (NetCDF) (Zelenke et al. 2012). But because the current patterns were generated using the rectangular grid, the data was saved in another GNOME compatible format (.nc) file. Data required to simulate the fate of the spilled oil such as wind speed and direction, salinity, sediment load, sea surface temperature and information on the spilled oil and the Dangote refinery operations were obtained from peered reviewed journals and reports (see table 3.3).

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DATA ANALYSIS

In order to analyse the trajectory and fate of bonny light crude, the data obtained was analysed using GNOME and ADIOS2 software for modelling trajectory and weathering modelling.

OIL Trajectory modelling

In order to attain the overall movement of the velocity components u (east-west) and v (north-south) from the movers and adding them at every step, the advection-diffusion equation (equation 3.1-3.3) used in GNOME is computed using the 1st order Runge-Kutta method, a forward Euler scheme (Prasad et al. 2014). Furthermore, the 1st order Runge-Kutta method is used to calculate the two dimensional vertical, meridional and zonal displacement of the movers (Fernandez et al. 2013). From equation 3.3, Δz is held at 0 because of GNOME's inability to model movement between depth layers, highlighting one of GNOME's limitations (Prasad et al. 2014).

$$\Delta x = \frac{\frac{u}{111{,}120.00024} \times \Delta t}{\cos y} \qquad \text{Equation 3.1}$$

$$\Delta y = \frac{v}{111{,}120.00024} \times \Delta t \qquad \text{Equation 3.2}$$

$$\Delta z = 0 \qquad \text{Equation 3.3}$$

Where;

111,120.00024 is the number of metres for each latitude degree (based on the assumption that one nautical mile is equivalent to one latitude); y is the latitude in radians; Δt is time elapsed between time-steps'i; $\Delta x, \Delta y$ and Δz are the longitudinal, latitudinal and vertical displacements respectively.

GNOME used in diagnostic mode allows the user to create a model that represent real-time data, to use and modify the scaling options and model parameters, create movie visualization as well as to determine the coefficients that control the distribution and size of

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the minimum regret uncertainty of the GNOME model (Xu et al. 2013; Marta-Almeida et al. 2013). Hence, GNOME version 1.3.9 was used in the trajectory simulation of the spilled crude oil from the Dangote SPM. By setting GNOME in diagnostic mode, it allows the researcher to make data input into the model (Eke and Anifowose 2017). The vector map (figure 2) of the SPM terminal extracted from the GSHHS was loaded into the GNOME software. In order to increase the efficiency of the model, the computational time step of 0.25 hours was selected in the model settings (Zelenke et al. 2012), and the best guess solution was activated. Referred to as "movers", Current, diffusion and wind are the key physical processes that cause spilled oil to move in water (Prasad et al. 2014; Barker 2015). Hence, the obtained hydrodynamic model from GOODS website with the aid of HYCOM was loaded into GNOME alongside "along current uncertainty" at 50% and "cross current uncertainty" at 25% (figure 3.5). It is pertinent to note that, the "along current uncertainty" value is a representation of the uncertainty in currents forward and backward direction ($\alpha > 0$, and $\alpha < 0$) respectively whereas the "cross current uncertainty" is a representation of the uncertainty in the left and right direction ($\beta > 0$) and ($\beta < 0$). In order for the uncertainty to agree with the duration of the spill scenario, it was set as shown in Table 3.1. Still under movers, the wind data was uploaded. Taking into consideration the uncertainty in wind speed and direction, "speed scale" and "angle scale" were set at default in GNOME (1%-4%) (Zelenke et al. 2012). It is important to note that, the "angle Scale" unit was changed from radian to degree. Another key mover, diffusion that represents horizontal eddy diffusivity which by default has been set by 100,000 cm^2s^{-1} was activated (Zelenke et al. 2012), the term "ignorance coefficient" has been used due to the poor calibration of oil spill science (Simecek-Beatty 2011). This were all under movers.

The assumed spill source that was selected in GNOME is the "point/line source". The hypothetical spill was also configured at 1000 splots to account for the map window display output (Korsah and Anifowose 2014). The choice of pollutant used determine the output of

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GNOME and ADIOS2 (Zelenke et al. 2012). However, Langdon et al. (2016) stated that, non-weathered oils are mostly very heavy crude with API values below 10^0. Hence, Diesel was the choice of pollutant for the simulation since Bonny Light as the name implies is a light crude with an API of 34.6^0.

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Oil Weathering

The freely available ADIOS2 oil weathering software was used to simulate and analyse a continuous spill 476,000 barrels of Bonny Light crude over a five days period. In order to account for the behaviour of the spilled oil in both wet and dry season, the simulation was carried out to capture both seasons (Table 3).

ADIOS2 allows for the modification, customization and imputation of new oil properties or an existing one in their database (Eke and Anifowose 2017). This, however, has the risk of data inconsistency (Lehr et al. 2002). But because the crude of interest is in the database, Bonny Light was selected as the appropriate crude to create the spill scenario. Data such as wind speed and direction, wave height, current speed and direction, salinity, temperature and water sediment load required for the simulation of the weathering characteristics were inputted. Finally, continuous release was selected from the release section.

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Table 3: Environmental data for ADIOS2 oil weathering simulation

PARAMETRES	DRY SEASON	WET SEASON	SOURCES OF DATA
Mean current speed	0.2 m/s	0.4 m/s	(World Bank 2008)
Current direction	Northeast	Northeast	(Shehu 2017)
Wind speed	4.4 m/s (9 knots	15 m/s (29.16 knots)	(World Bank 2008)
Wind direction	North Westerly	South Westerly	(World Bank 2008)
Sea surface temperature	28^0 C	24^0 C	Akinbobola et al. 2015)
Mean salinity	35 PSU	35 PSU	Onyeama and Popoola 2013)
Water sediment load	5 mg/l	5 mg/l	NOAA (2013)
Mean Wave height	1 m	2 m	(World Bank 2008)

RESULTS AND DISCUSSION

Trajectory Analysis of Oil Spill for Dry and Wet Season

The result of the trajectory analysis for the period under review is as shown in table 3 and 4.

Table 3: Trajectory Analysis Result for Dry Season

Start Date	End Date	Oil Spill Afloat	Oil Spill off Map	Oil Beached
28th Dec. 2017	12th Jan. 2018	23.0%	0%	4.8%
13th Jan. 2018	23rd Jan. 2018	30.2%	0%	2.3%
24th Jan. 2018	29th Jan. 2018	43.0%	0%	2.9%
11th Jan. 2018	21st Jan. 2018	27.7%	0%	2.8%

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Table 4: Trajectory Analysis Result for Wet Season

Start Date	End Date	Oil Spill Afloat	Oil Spill off Map	Oil Beached
27th May 2017	11th June 2018	1.4%	0%	24.9%
12th June 2018	22nd June 2018	2.5%	0%	30.0%
23rd June 2018	28th June 2018	3.9%	0%	45.0%
6th June 2018	16th June 2018	2.2%	0%	30.3%

In all the spill scenarios for the period under review, oil did not travel out of the boundary (Cheng et al. 2011). It was observed that, there was rapid spreading within the first few hours of the spill, which according to the NOAA (2006) is enhanced by warm water temperature and is faster when the oil is less viscous. Furthermore, the amount of oil that evaporated and dispersed was on a steady increase over the periods. This is agreement with the findings of Fingas (2013), that evaporation is driven by time and temperature.

Analysis of the trajectory model shows beaching in all the spill scenarios simulated. Furthermore, the trajectory model obtained from GNOME indicates that a large proportion of oil is lost due to evaporation and dispersion in all the periods simulated. However, owing to the rudimentary modelling of weathering process by the GNOME model, ADIOS2 model is used to compliment GNOME weathering shortcoming (Zelenke et al. 2012).

Langmuir circulation (LC) have been observed in the South section of the Atlantic Ocean as highlighted by Shehu (2017) and Momoh (2017). LC side by side windrows formation are expected to be observed in the event of oil spills in dry and wet season. This is in agreement with the NOAA (2012) opinion that when wind speed is >6 knots (3 m/s), windrows formation begins. This means that, rather than the average 3% that wind speed contributes to oil slick movement, it is about 5.5% owing to windrows formation in dry and wet season (Lehr and Simecek-Beatty 2000). The wet season has an average wind speed of 15

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m/s and current velocity of 0.4 m/s (World Bank 2008), hence, Langmuir circulation is expected to be the driving factor in oil slick movement because according to Smith and Thorpe (1999), this happens when wind speed is 50 times over the current velocity. However, this phenomenon (effect of wind speed on oil slick movement and windrows formation) affects clean-up operations as the oil slick will be in parallel bands in the direction of the wind (Liu and Sheng 2014).

Minimum Regret Analysis

According to the NOAA (1996), the "minimum regret" uses available methods to analyse the sensitivity of various estimates to errors in the input data, thereby exploring the implication of alternate plausible scenario. The "what if" function has the capacity to increase the predictive accuracy of the model by taking into consideration errors and uncertainties in the environmental conditions inputted when setting up the model (Korsah and Anifowose 2014). Taking this into consideration, the minimum regret function in GNOME represented by "red splots" (Cheng et al. 2011), was activated and the spill scenarios created with the hydrodynamic data obtained for the periods shown in table 3. For both dry and wet season, it was observed that, the red splots has a wider area coverage compared to the best guess scenario. This finding is in agreement with the results obtained by Cheng et al. (2011), Saad and Hamz (2016), Eke and Anifowose (2017) whose research at different times have a wider coverage of the sea surface by the red splots. Therefore, the necessary equipment's should be in place to adequately clean up the place where the slick is headed (Newed et al. 2012).

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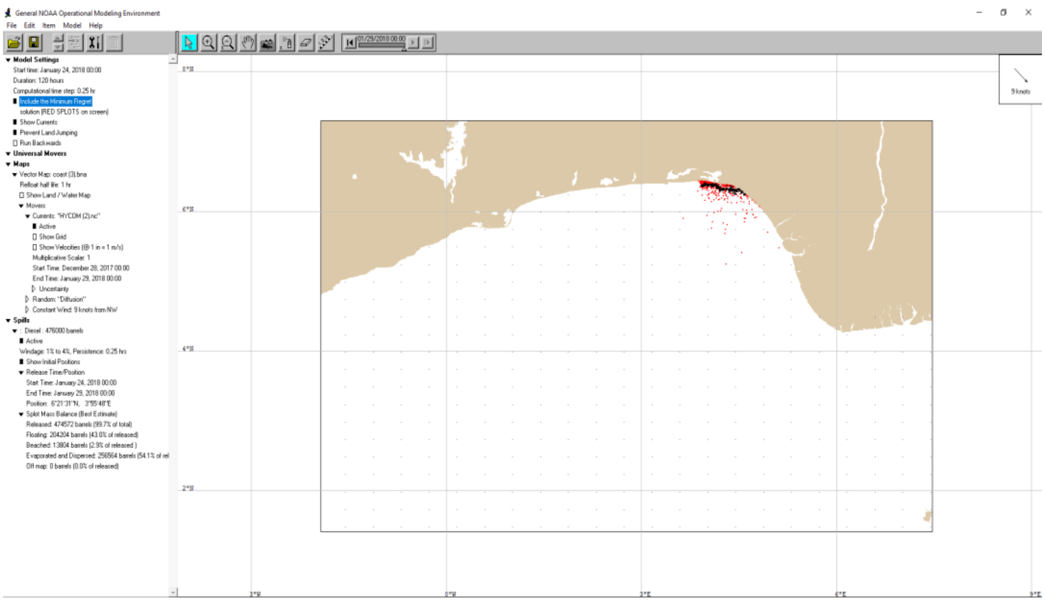

Figure 5: Possible oil spill trajectory model from January 24th – 29th using 1000 splots

OIL WEATHERING CHARACTERISTICS

Evaporation: The results of the simulation of Bonny light crude show that, evaporation seems to be increasing over the first 6-12 hours, and then flattens off due to other weathering influences, probably due to changes in viscosity, density and water uptake (Mishra and Kumar 2015). Results of the simulation of Bonny Light oil spill shows that 33% and 39% oil will be lost due to evaporation which is in agreement with the findings of Villoria et al. (1991) (20-40% of total crude loss) and Lehr et al. (2002) (25-33.3% of total crude loss). An analysis of oil lost within the first 24 hours suggest that 23% and 27% of oil is lost to evaporation in both seasons, which is in perfect simulacrum with the estimates of Sebastiao and Soares (1995) (25-30% total crude loss) in the wet season but falling short in the dry season. The amount in the dry season falling short of Sebastiao and Soares (1995) estimation may be alluded to the difference in light components of bonny light crude and the crude type used by Sebastiao and Soares (1995).

Furthermore, the difference in evaporation rate in both seasons may be due to difference in the size of the slick, wind speed and water temperature (see table 3) (Fingas 2013). The

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inability of ADIOS2 to accurately predict evaporation over a long term may also be responsible for the different values.

Table 5: Summary of Oil Weathering Results from ADIOS2

WEATHERING PROCESS	DRY SEASON	WET SEASON
Evaporation	23%	27%
Water uptake begins	0 hours (80)	10 hours (90%)
Type of emulsion formed	Stable Emulsion	Stable Emulsion
Viscosity	1000 to 8000 cSt	10 to 1000 cSt
Density	860 – 985 kg/cum	900 – 1005 kg/cum
Dispersion	1.3%	1.6%
Airborne Benzene Concentration	36 hours	12 hours

Emulsification: The type of emulsion formed by the oil is determined by the uptake of water (Fingas 2013). The water in oil content as computed by ADIOS2 shows that water uptake begins after 0 hours and 10 hours after the spill in dry and wet season respectively. The water in oil content analysis shows that a stable emulsion will be formed in both seasons after a five-day period. This is because the water uptake falls between 70% and 80% in the dry season and 80% and 90% in the wet season (Fingas 2013). Stable emulsions begin to form when 15% of the oil evaporated in both seasons; highlighting the effect of evaporation on emulsification rate (Lehr et al., 2002). The similarity in the formation of stable emulsion in both seasons may be due to the fact that, ADIOS2 uses emulsification calculation as propounded by Fingas et al., (1996). However, the equation ignored resin fraction, hence, the resin fraction may have played a significant role in the formation of stable emulsion (Afenyo et al. 2016).

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Dispersion: In this research, dispersion was responsible for 1.3% and 1.6% lost in Bonny Light crude oil in dry and wet season. The higher rate of dispersion in wet season may be attributed to the breaking waves, and high wind speed (15 m/s) that results in greater mixing (Chapman et al. 2007). Generally, the rate of dispersion for both seasons was low due probably to the asphaltene and wax content of the oil (Chapman et al. 2007). Another factor that could be responsible for the low dispersion rate is the sediment scavenging model incorporated into ADIOS2 that takes into account the effect of sedimentation and Langmuir circulation (Lehr et al. 2002, Afenyo et al. 2016).

Airborne Benzene Concentration: Airborne benzene concentration evaporated within 36 hours and 12 hours in dry and wet season respectively supporting the findings of Lehr (1996) and Jansen (2010) that, upon reaching the sea surface, benzene will evaporate within hours. According to Mackay et al. (1983), the rate of benzene volatility is enhanced by high temperature, as well as wind speed, thus, it is responsible for difference in benzene concentration for both seasons which affect the proportionality term employed in the computation of mass evaporation rate of benzene in ADIOS2 algorithm (Brutsaert 1982; Lehr 1996). Personal protective equipment's against benzene exposure must be provided within these hours as suggested by Cahyono and Tjahjono (2013).

Oil-sediment Aggregate: The water sediment load of the Atlantic Ocean is reported to be 5mg/l (see table 3), however, the Lagos lagoon has a sediment load of 100-500mg/l and empties it content into the Atlantic. Hence, may likely contribute to the formation of oil sediment aggregates (OSAs) which influence oil movement (Payne et al. 2003).

According to Khelifa et al. (2005), breaking waves results in the formation of OSAs due to dispersion, therefore, with breaking waves expected in both seasons OSAs formation will be enhanced. However, only 20% and 30% of the water upper limit can be sedimented

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(Muschenheim and Lee 2002). The fate and transport of OSAs can be determined through further analysis.

Density and Viscosity

With the formation of mesostable emulsion, oil viscosity is expected to rise (Xie, Yapa and Nakata 2007). Density and viscosity drastically increased over the first 6-24 hours driven primarily by evaporation and emulsification. This then levels off eventually, indicative of the fact that, despite continuing wave action, emulsification has reached an effective maximum (AMSA 2018).

According to Kotzakoulakis and George (2018) aside emulsification, evaporation is one of the key and second most important weathering characteristics that influences other weathering processes. The difference in viscosity values for dry and wet season can be linked to the difference in evaporation rate with wet season having a higher rate driven primarily by wind speed.

CONCLUSION

A hypothetical oil spill scenario of Bonny light crude was simulated using GNOME and ADIOS2, an analysis of the fate and trajectory from of the oil from the Dangote SPM terminal was carried out. The results obtained and the conclusions drawn are that, in the event of an oil spill, the oil is likely to travel in the direction of the wind in both season with only a slight difference and will beach for all periods. Windrows may be formed in both seasons, which means that, oil movement is driven by 5.5% of the wind speed rather than the 3% average. The formation of windrows and the influence of wind speed to the trajectory of oil slick is going to have a profound influence on clean-up and response operations. The minimum regret analysis shows that, in the event of a spill, the oil is likely to beach along the shore of Lagos, coastline of Benin, Warri, Bayelsa and even Port Harcourt. Other areas are Port Novo, Coastline of Ghana.

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The weathering model showed that, evaporation is the driven force for the loss of volatile components of oil in both dry and wet season (23 and 27%). The rate of evaporation in the wet season is higher than the dry season and it is driven by wind.

Hence, in the event of an oil spill, the economic, social and social consequences are likely to be monumental on the Lagos coastline of the Lekki axis, the coastlines of Benin, Delta, Bayelsa, and Rivers states. Neighbouring countries like Ghana, Benin Republic and the Gulf of Guinea are likely to be affected.

REFERENCES

Acha, E., Mianzan, H., Guerrero, R., Favero, M. and Bava, J. 2004. Marine Fronts at The Continental Shelves of Austral South America. Journal of Marine Systems 44 (1-2), 83-105.

Adeniyi, T., Oyebanji, O. and Adeonipekun, P. 2016. FLORAL DIVERSITY IN THE WETLANDS OF IBEJU-LEKKI AREA, LAGOS, NIGERIA. Ife Journal of Science 18 (3).

Afenyo, M., Veitch, B. and Khan, F. 2016. A State-Of-The-Art Review of Fate and Transport Of Oil Spills in Open and Ice-Covered Water". Ocean Engineering 119, 233-248.

Barker, C. 2015. NEW DEVELOPMENTS IN THE GENERAL NOAA OPERATIONAL MODELLING ENVIRONMENT (GNOME). National Oceanic and Atmospheric Administration. Office of Response and Restoration. Emergency Response Division. Seattle WA, USA.

Beegle-Krause, C. and O’Connor, C. 2005. GNOME Data Formats and Associated Example Data Files. NOAA Office of Response and Restoration'. Emergency Response Division, Seattle, WA, USA

Beegle-Krause, C.J. 2011. General Noaa Oil Modelling Environment (GNOME): A New Spill Trajectory Model. International Oil Spill Conference, American Petroleum Institute.

Brutsaert, W. 1982. Some Exact Solutions for Nonlinear Desorptive Diffusion. Zeitschrift Für Angewandte Mathematik Und Physik (ZAMP) 33 (4), 540-546.

Cahyono, D. and Tjahjono, E. 2013. Biological Effect Monitoring Benzene at Oil Company, What Is New?’. SPE Asia Pacific Oil and Gas Conference and Exhibition. Cited in Eke, C. D. and Anifowose, B. (eds.) (2017) SPE Health, Safety, Security, Environment, & Social Responsibility Conference-North America. 'Oil Spill Trajectory Simulation for the Clair Oilfield, Faroe Shetland Channel, United Kingdom Continental Shelf': Society of Petroleum Engineers.

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Chapman, H., Purnell, K., Law, R. and Kirby, M. 2007. The Use of Chemical Dispersants To Combat Oil Spills at Sea: A Review of Practice and Research Needs in Europe". Marine Pollution Bulletin 54 (7), 827-838.

Cheng, Y., Li, X., Garcia-Pineda, O., Anderson, O. and Pichel, W. 2011. SAR Observation and Model Tracking of An Oil Spill Event in Coastal Waters. Marine Pollution Bulletin 62 (2), 350-363. http://dx.doi.org/10.1016/j.marpolbul.2010.10.005

Dibin, J., Darshan, S., Jithin, K.P., Jithin, R., Mahboob, A., and Mahesh, P.D. 2011. Model of an Oil Tanker. (July), 78.

Drozdowski, A., Nudde, S., Hannah, C., Niu, H., Perterson, I. and Pierre, W. 2011. Review of Oil Spill Trajectory Modelling in The Presence of Ice. Canadian Technical Report of Hydrography And Eke, C. D. and Anifowose, B. 2017. SPE Health, Safety, Security, Environment, & Social Responsibility Conference-North America. Oil Spill Trajectory Simulation for the Clair Oilfield, Faroe Shetland Channel, United Kingdom Continental Shelf. Society of Petroleum Engineers.

Elizaryev, A., Maniakova, G., Longobardi, A., Elizareva, E., Gabdulkhakov, R., Nurutdinov, A. and Khakimov, R. 2018. Numerical Simulation of Oil Spills Based on The GNOME And ADIOS. International Journal of Engineering & Technology 7 (2.23), 24.

Fankhauser, S. and Jotzo, F. 2017. Economic Growth and Development with Low-Carbon Energy'. Wiley Interdisciplinary Reviews: Climate Change [online] (301), e495. available from http://doi.wiley.com/10.1002/wcc.495

Fernandez, R., Neves, R. and Viegas, C. 2013. Integration of an Oil Inert Spill Model in a Framework for Risk management of Oil Spills at Sea – A Case Study for the Atlantic Area. Instituto Superior Tecnico – MARETEC. http://dx.doi/10.13140/2.1.1740.3200

Fingas, M. 2013. Review of Solidifiers: An Update 2013.' Prince Williams Sound Regional Citizens' Advisory Council, Edmonton, Alberta.

Fingas, M. 2015. Handbook of Oil Spill Science and Technology.

French-McCay, D. 2004. OIL SPILL IMPACT MODELING: DEVELOPMENT AND VALIDATION". Environmental Toxicology and Chemistry 23 (10), 2441

Guo, W. and Wang, Y. 2009. A Numerical Oil Spill Model Based on a Hybrid Method'. Marine Pollution Bulletin 58 (5), 726-734.

Gustitus, S.A., John, G.F., and Clement, T.P. 2017. Effects of Weathering on the Dispersion of Crude Oil through Oil-Mineral Aggregation'. Science of The Total Environment 587–588, 36.

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Ibarra - Mojica, D., Barajas - Ferreira, C., Kafarov, V., Forero, K. and Duran, D. 2018. Application Of Free Software (GNOME) For Simulation of Oil Spills Trajectories in A Sector of Magdalena River (Colombia)". The Italian Association of Chemical Engineering Online At www.Aidic.It/Cet

Khelifa, A., Stoffyn-Egli, P., Hill, P. S., and Lee, K. 2005. Effects of Salinity and Clay Type on oil mineral Aggregation'. Marine Environmental Research 59 (3), 235-254.

Kim, J., Kwak, B., Ha, M., Cheong, H. and Yi, J. 2012. Modeling Human Exposure Levels To Airborne Volatile Organic Compounds by The Hebei Spirit Oil Spill". Environmental Health And Toxicology 27, e2012008.

Korsah, P. E. and Anifowose, B. 2014. Oil Spill Trajectory Simulation for the Saltpond Oilfield, Ghana, West Africa': In: Abu Dhabi International Petroleum Exhibition and Conference. Society of Petroleum Engineers.

Lehr, W. 1996. Modelling the Benzene Inhalation Hazard From Spilled Oil. Spill Science & Technology Bulletin 3 (4), 199-202. http://dx.doi.org/10.1016/S1353-2561(97)00012-1

Lehr, W. J. and Simecek-Beatty, D. 2000. The Relation of Langmuir Circulation Processes to the Standard Oil Spill Spreading, Dispersion, and Transport Algorithms'. Spill Science & Technology Bulletin 6 (3), 247-253.

Lehr, W., Jones, R., Evans, M., Simecek-Beatty, D., and Overstreet, R. 2002. Revisions of the ADIOS Oil Spill Model'. Environmental Modelling & Software 17 (2), 189–197.

Li, S. 2017. EVALUATION OF NEW WEATHERING ALGORITHMS FOR OIL SPILL MODELING. Masters. Dalhousie University Halifax, Nova Scotia.

Makinia, J. 2013. Mathematical Modelling and Computer Simulation of Activated Sludge System. IWA Publishing.

Marta-Almeida, M., Ruiz-Villarreal, M., Pereira, J., Otero, P., Cirano, M., Zhang, X. and Hetland, R. 2013. Efficient Tools for Marine Operational Forecast and Oil Spill Tracking. Marine Pollution Bulletin 71 (1-2), 139-151.

Mishra, A. and Kumar, G. 2015. Weathering of Oil Spill: Modelling and Analysis". Aquatic Procedia 4, 435-442.

Muschenheim, D. and Lee, K. 2002. Removal of Oil from the Sea Surface through Particulate Interactions: Review and Prospectus'. Spill Science & Technology Bulletin 8 (1), 9-18.

Nedwed, T., Tidwell, A., Buist, I. A., Belore, R., and Canevari, G. 2012. International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production. 'Advances in Treating Agents for Oil Spill Response': Society of Petroleum Engineers.

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Nelson, J. and Grubesic, T. 2017. Oil Spill Modeling. Progress in Physical Geography: Earth And Environment 42 (1), 112-127.

NOAA. 2006. ADIOS2. NOAA's Office of Response and Restoration [online] available from <http://archive.orr.noaa.gov/book_shelf/538_adios.pdf> [22 April 2018].

NOAA. 2015. Downloading, Installing and Running ADIOS [online] available from <http: response.restoration.noaa.gov.oil-and-chemical-spills/response-tools/downloading-installing and-running-adios.html> [11/11 2017].

Payne, J. R., Clayton, J. R., and Kirstein, B. E. 2003. Oil/suspended Particulate Material Interactions and Sedimentation'. Spill Science & Technology Bulletin 8 (2), 201-221.

Prasad, S., Nair, B., Francis, P., and Vijayalaksmi, T. 2014. Hindcasting and Validation of Mumbai Oil Spills using GNOME'. International Research Journal of Environment Sciences 3 (12), 18-27.

Saad, S. and Hamzi, R. 2016. Simulation of Oil Spill Trajectory Using Gnome Model; Skikda Port, Algeria". Middle East Journal of Scientific Research [online] 24 (5), 1823-1831. available from <https://www.idosi.org/mejsr/mejsr24(5)16/36.pdf> [2 December 2018].

Samuels, W.B., Amstutz, D.E., Bahadur, R., and Ziemniak, C. 2013. Development of a Global Oil Spill Modelling System. Earth Science Research 2 (2), 52.

Saunders, M., Lewis, P. and Thornhill, A. 2016. Research Methods for Business Students. Harlow Essex): Pearson.

Sebastião, P. and Guedes Soares, C. 2006. Uncertainty in Predictions of Oil Spill Trajectories In A Coastal Zone". Journal of Marine Systems 63 (3-4), 257-269.

Sebastiao, P. and Soares, C. G. 1995. Modeling the Fate of Oil Spills at Sea'. Spill Science & Technology Bulletin 2 (2-3), 121-131.

Simecek-Beatty, D. 2011. Oil Spill Trajectory Forecasting Uncertainty and Emergency Response'. in Oil Spill Science and Technology. ed. by Anon: Elsevier, 275-299.

Smith, W. N. and Thorpe, S. 1999. Dispersion of Buoyant Material by Langmuir Circulation and a Tidal Current. Marine Pollution Bulletin 38 (9), 824-829.

Spaulding, M. 2017. State of The Art Review and Future Directions in Oil Spill Modelling". Marine Pollution Bulletin 115 (1-2), 7-19.

Villoria, C., Anselmi, A. and Garcia, F. 1991. An Oil Spill Fate Model Including Sinking Effect". SPE Health, Safety and Environment in Oil and Gas Exploration and Production Conference

Wang, S., Shen, Y., and Zheng, Y. 2005. Two-Dimensional Numerical Simulation for Transport and Fate of Oil Spills in Seas. Ocean Engineering 32 (13), 1556-1571.

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Wang, S., Shen, Y., Guo, Y., and Tang, J. 2008. Three-Dimensional Numerical Simulation for Transport of Oil Spills in Seas'. Ocean Engineering 35 (5), 503-510.

Xu, Q., Li, X., Wei, Y., Tang, Z., Cheng, Y., and Pichel, W. G. 2013. Satellite Observations and Modeling of Oil Spill Trajectories in the Bohai Sea'. Marine Pollution Bulletin 71 (1), 107-116

Zelenke, B., O'Connor, C., Barker, C. H., Beegle-Krause, C., and Eclipse, L. 2012. General NOAA Operational Modeling Environment (GNOME) Technical Documentation.

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