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TRAJECTORY ANALYSIS OF OIL SPILL AT THE GULF OF GUINEA: CASE OF CAMEROON – KRIBI

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Abstract

Objectives: The objective of this study was to determine the trajectory and duration of oil slick touching or reaching the shore of kribi-Cameroon in case of an oil spill in the coast of Guinea. With the trajectory analysis known, better contingency planning can be done to protect sensitive areas and the beach activating oil spill response.

Methodology: systematic review past articles on oil spill trajectory analysis from peer was done. This article shows how the surface currents, waves and wind direction affects oil slick movement. The used of GNOME for oil slick modelling as well as the ADIOS for better analysis including the oil dispersed with the estimated budget to clean up the spill provides a better tool for spill trajectory analysis.

Findings: There are two factors that affects the accuracy of oil slick trajectory analysis. The inability to obtain or measure wind and current speeds at the time of the spill and the rotation of the earth thus deflecting the spill either to the northern or southern hemisphere.

Recommendations: Crude oil does not degrade easily and can remain in the environment for decades. Oil production companies needs to put in place a rapid clean up response group with frequent drill exercise. This can help to contain the spilled oil in a timely manner to avoid spreading and further contamination of the sea and other sensitive area. Focus should be on their operating equipment, processes put in place for maintenance strategies and trained qualified personnel to operate their facility.

Keywords: *oil slick, trajectory analysis, ocean currents, fate of oil, Gulf of Guinea*

Introduction

The marine environment serves as the most effective place for crude oil production and transportation to various destinations around the world. Despite all the strict safety regulations put in place, accident continue to occur thus causing the release of huge quantity of oil into the sea. Oil spill dispersion in large scale is favorable in the sea due to its open feature when there is loss of containment. When an Oil spill occurs, it dangerously affect marine life and socio economic activities. The toxic nature of crude oil contaminate the water, sediments and impact coastline activities **(Chang and al 2014**).

Recent discoveries of hydrocarbons deposit has increased the geostrategic importance of the Gulf of Guinea. The gulf of Guinea is made up of the following countries: Ghana, Togo, Benin, Nigeria, Cameroon, Gabon, Equatorial Guinea, Congo, São Tomé, Congo DRC and Angola. The regions petroleum resources are located in both shallow and deep waters. According to the Marine oil pollution legislation, the top five oil producing countries are Nigeria, Angola, Gabon, Equatorial Guinea, Congo Brazzaville and Cameroon (**AkA Aloysius 2003**).

Figure 1: Gulf of Guinea Province in west-central Africa and locations of oil and gas field Center points

Oil production and transportation in the gulf of Guinea cannot be performed without accidental released of crude oil to the environment despite the strict regulation and sanction put in place. The oil boom in the Gulf of Guinea presents prospects of economic growth and development of the respective petro-states of the region, but has enormous implications for the health of the marine environment (**Nelson Atanga 2016**). A common consequence of oil production activities is the risk of oil spills occurrence, which increases with the continuous rise in worldwide demand for petroleum and petroleum products (Chijioke David Eke 2017).

Countries that are connected to the Gulf of Guinea need to be prepared to respond to any oil spillage that may occur during drilling, loading, transportation and accidental release. They need to have a response program to contain the oil that may migrate to the shore. To achieve this, they need to understand the movement and trajectory of oil and predict the timeframe in which released product can reach their various coast.

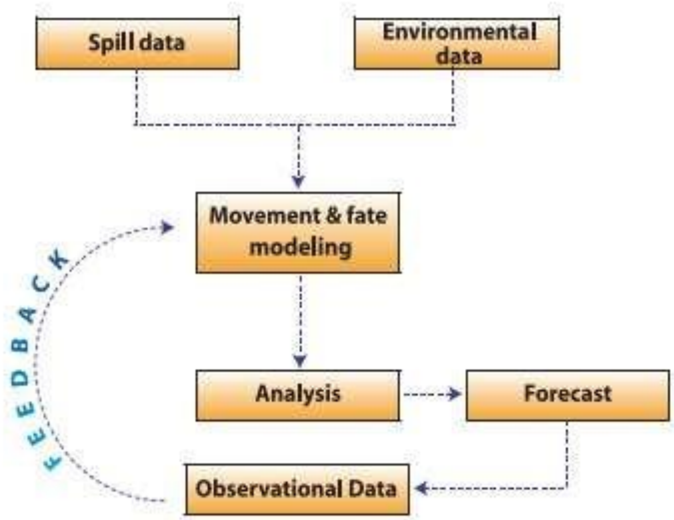

Figure 2: oil spill trajectory analysis schematics

Objectives of the studies:

The objective of this study was to analyze and see the possible oil trajectory when there is an oil spill or petroleum platform or tanker accident. For the purpose of simplicity this study will be limited to the Cameroonian section off the coast of Guinea in Kribi.

Literature review Description of Cameroon coast line

Cameroon is located in the Central Gulf of Guinea and has a coastline that stretches for about 402 km, extending from the border with Equatorial Guinea and Nigeria. The territorial sea is limited by the presence of the Island of Malabo (Equatorial Guinea) and there is need for an outer continental territorial sea that extends beyond Equatorial Guinea. This coastline is characterized by estuaries, mangrove forests, muddy and sandy bottoms, and a dense river network.

Physical Oceanography Waves

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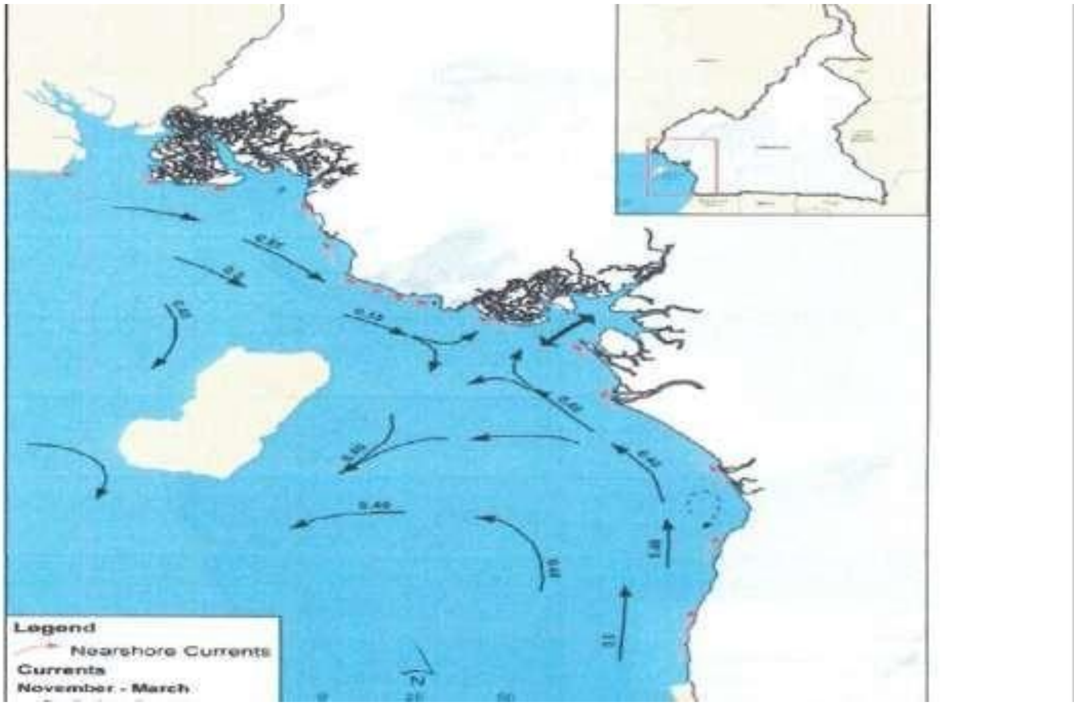

Figure 3: current movement off the coast of Guinea between March and November

The waves reaching the West African coast (Gulf of Guinea) are of two distinct origins namely, the sea generated waves by the weak local monsoon, and swells generated by storms in the southern Atlantic (**Allerman and Tilmans, 1993**).

Storms occur all-round the year but are most intense in the rainy season: (June to August). The frequency of the swells reaching the region and generated by these storms vary between 8 and 20s, with an average frequency of 12-13s. Their average height is approximately 1.0-1.5m, although wave heights of 2 to 3m or more can also occur (CSIR, 2002). These swells generally arrive from the South and Southwest. Long swells undergo considerable shoaling near the coast where they form breakers. Measurements in the south of the Cameroon coast indicate swells with higher wave heights during the rainy season. Maximum wave heights have been recorded between 2.65 and 3m (5 year storm) and between 2.8 to 3.25m.

The locally generated waves are small, short frequency waves from the SW that rarely exceed heights of 1.25m and have a minimum frequency of between 3 and 4 s (LCHF, in CSIR, 2002).

Tides.

Tides are semi-diurnal; mean tidal ranges being 1.8 and 2.8m, with spring tide attaining 2 to 4m on the open coast (Bird and Schwartz, cited in CSIR, 2002). These currents caused by tides are weak over the continental shelf; however, strong tidal streams occur in the various inlets and estuaries along the coast, especially those of the Cameroun Estuary. The following height differences have been recorded for tidal

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statistics along the Cameroon: MLWS (0.2m), MLWN (0.5m), MSL (+1.0m), MHWN (1.6m), MHWS (1.8m), and time differences: MHW (+5min) and MLW (no data). (CSIR, 2002).

Figure 4: Gulf of Guinea as seen on google map

During the 2017 international oil spill conference, (**Pu Li et Al, 2017**) outline the oil spills models established for the past decades. He made mentions of the following model:

- General National Oceanic and Atmospheric Administration (NOAA) Operational Modeling Environment (GNOME) first elaborated by (**Beegle-Krause, 1999, 2001**) [6]. GNOME is the modeling tool that responder uses to predict the possible route, or trajectory, a pollutant might follow in or on a body of water, such as in an oil spill.
- Oil spill contingency and response (OSCAR) model
- OILMAP™

Depending on the location of spill, oil product may reach the coast of any country according to the speed, waves and wind directions.

The main objective of the response team during an oil spill is to contain the product to avoid contaminating sensitive areas like sanctuaries, sandy beach and shore lines. The challenging issues is oil spilled in the marine environment will disperse and move based on the following factors: winds, surface currents, tides, air and water temperatures, and salinity. The type and amount of spilled oil, local shoreline and bottom features also influence movements of an oil slick.

A common impact associated with crude oil exploration and production is the possibility and occurrence of oil spills **(Percy Korsah et Al 2014**).

To protect contamination of sensitive areas, there is the need to predict the movement of oil and estimate the duration and timing when it will heat an area. To achieve this, there is need to understand the chemical composition of spilled oil, the oceans currents and the weather. These information will help us to predict oil movement also known as trajectory analysis.

Trajectory analyses is used to identify areas that are most vulnerable to oil contamination so that equipment to contain the oil spill can be dispatched to where it will be most effective. Forecasting the movement of oil spill is always a challenge in the early hours of occurrence due to the unavailability of data like quantity spilled, location, type of product as well as environmental condition of wind and currents. **Samuels et al. (2013**) point out that winds, ocean current, coastline boundary, tides and information on the oil spilled are key input parameters required to simulate oil spill trajectory in GNOME.

Behavior of crude oil in water

When oil is spilt on the surface of the sea, it undergoes many chemical and physical processes collectively termed as weathering

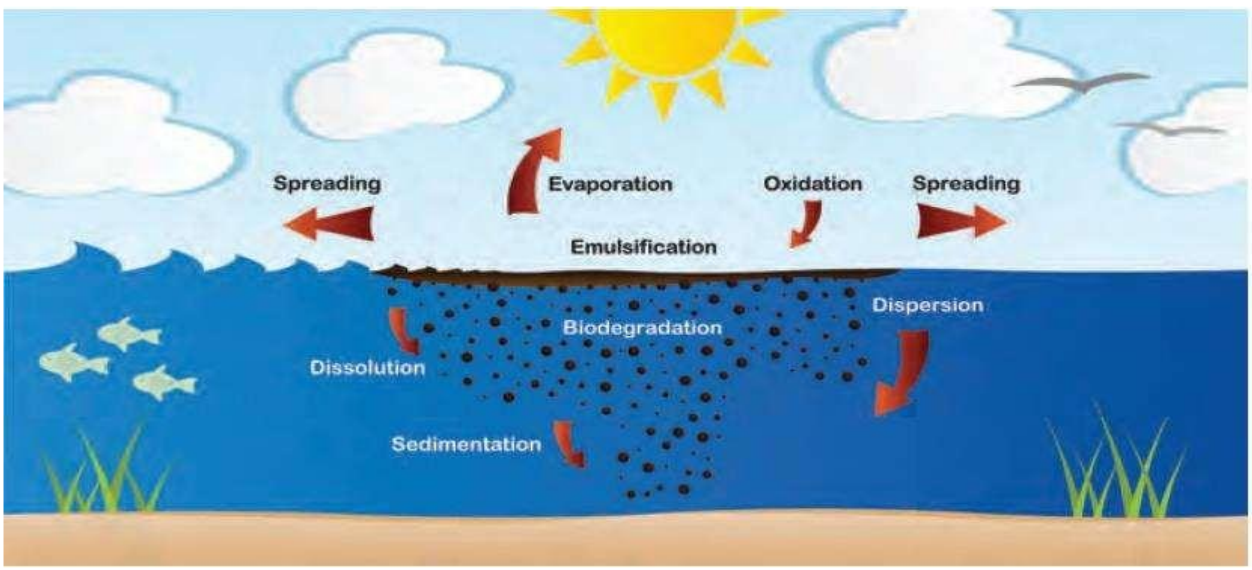

Figure 5: weathering process of crude oil in water. Source ITOPF hand book

The physical properties of crude oils are the quantitatively measurable characteristics of crude oils.

They vary according to the composition of the oil, the relative abundance of the groups of hydrocarbons, and essentially depend on reservoir temperatures and pressures. **(Madu Anthony et al 2017).**

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The chemical properties of crude oil deal with the chemical nature and the changes in composition in relation to temperature and pressure variations occurring at all times within the oil pool. Some of the chemical properties are related to the origin, migration, and accumulation of the crude oil.

Characteristics of spilled oil in water

Oil has macroscopic properties that help describe its initial behavior if spilled. These include its pour point, density, surface tension, and viscosity **(J. A. Galt, 2017)**. The density of oils vary from about 0.85 to 1.07 g/cc (***David Lord, 2014).*** This density is the major factor in determining whether the oil will float, or sink. The vast majority of oils are lighter than water and float (the density of freshwater is 1.0 g/cc, ocean water densities are about 1.02+ g/cc). Gravitational forces are initially4 responsible for the spreading of oil that is spilled.

Fate of spilt oil in the sea

Spilt oil in water will undergo the following: evaporation, photo-oxidation, spreading, dispersion, emulsification, stranding and sedimentation, fragmentation and finally biodegradation (**Fingas et al**). Each of this process is useful in tracking the trajectory of oil in water. The slick spreads over the water surface due to a balance between gravitational, inertial, viscous and interfacial tension forces, while composition of the oil changes from the initial time of the spill (**Fatai et al, 2006**)

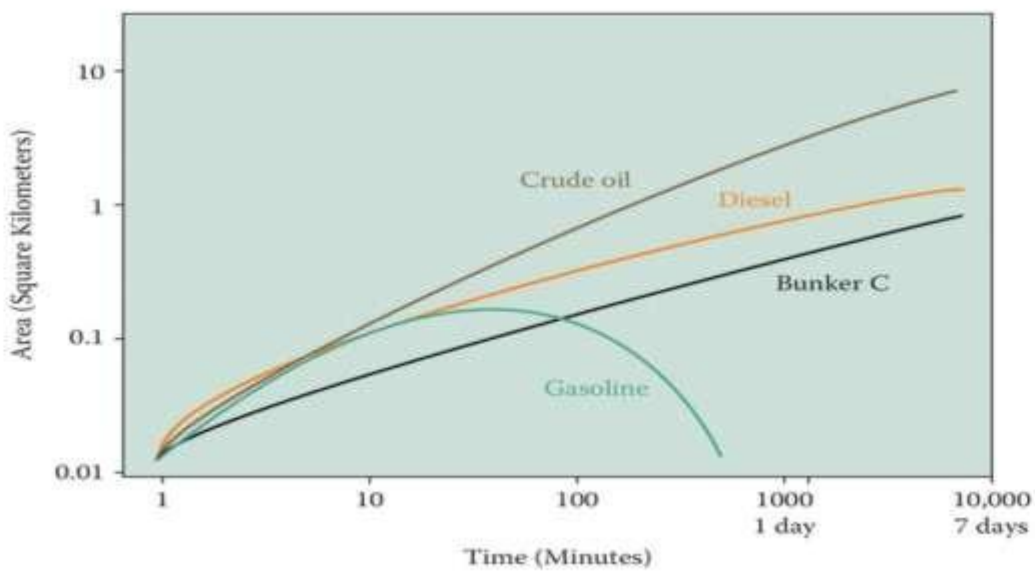

Figure 6: Comparison of the spreading rates of different oils and fuels.

The formation of oil-in-water or water-in-oil emulsion depends upon turbulence, but usually occurs within days after the initial spill. It forms thick pancakes on the water and intractable sticky masses if it comes ashore.

Winds

Wind affects oil trajectory in three major ways:

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- Oil weathering
- Surface effects on the water
- Direct transport

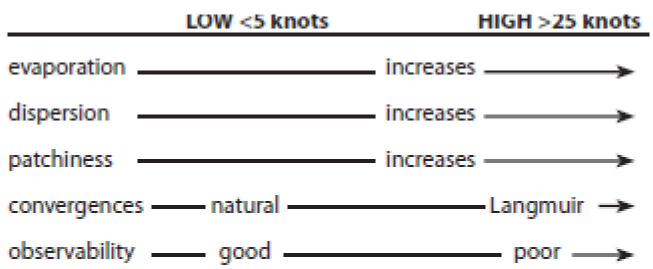

Figure 7 Wind effects on oil trajectory

Methodology

Two major processes transport oil spilled on water: spreading and advection. For small spills (<100 barrels), the spreading process is complete within the first hour of the release. Winds, currents,and large-scale turbulence (mixing) are advection mechanisms that can transport oil great distances. In general, the oil movement can be estimated as the vector sum of the wind drift (using 3% of the wind speed), the surface current, and spreading and larger-scale turbulence (diffusion).

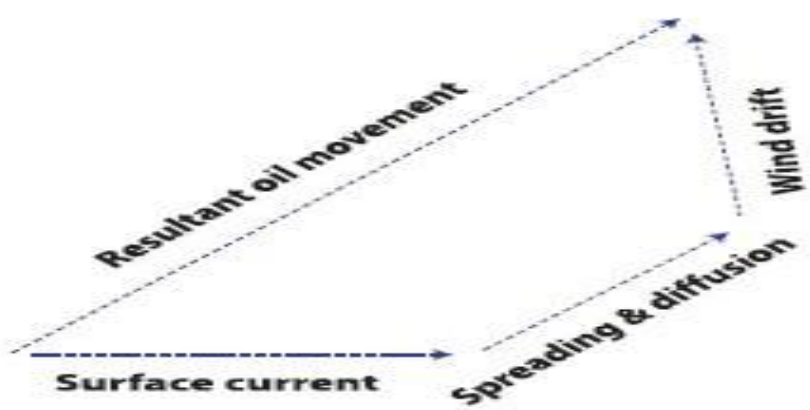

Figure 8: factors affecting oil movement in water

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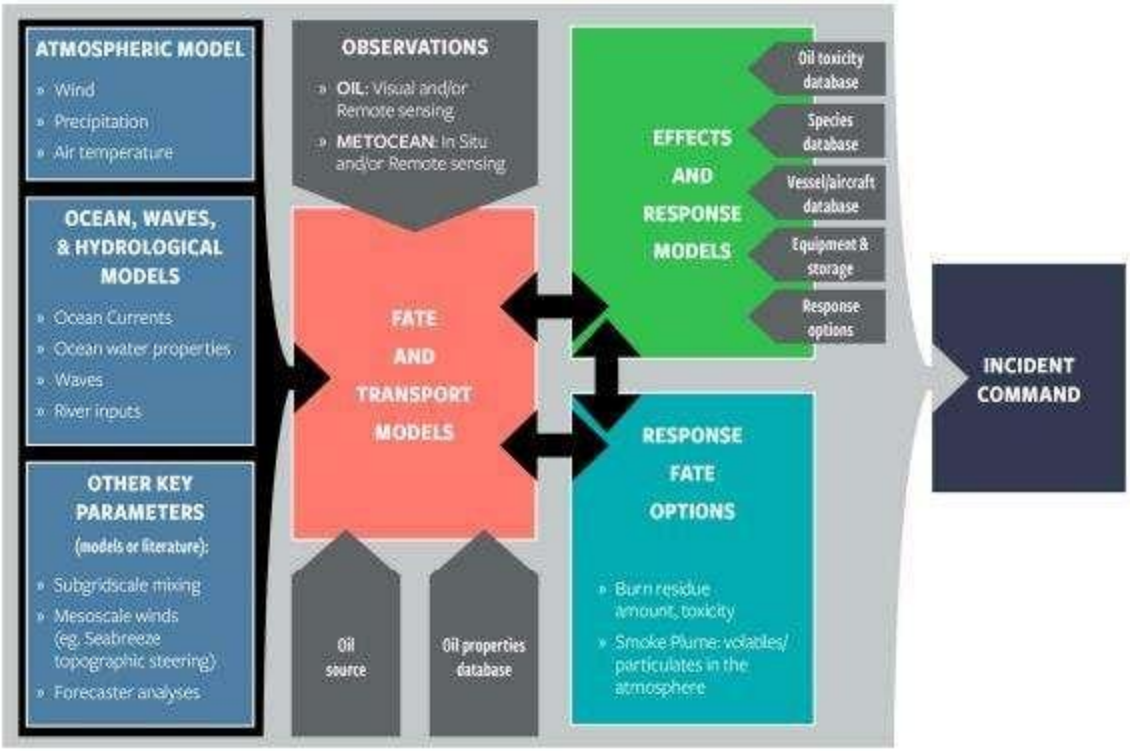

Figure 9: schematics of operational oil spill response methodology

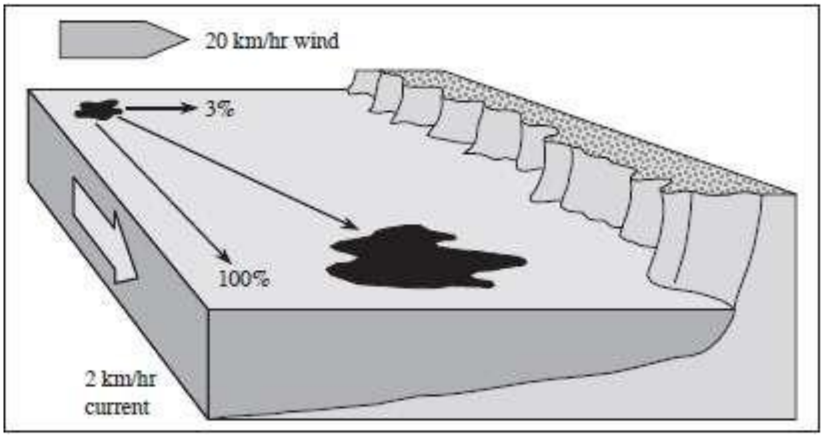

Figure 10: movement of oil in water (source: EM oil spill response handbook)

The surface current is caused by wind. In the GOG the winds speed varies from seasons to season and the trajectories taken by an oil spill to reach a particular location will depend on the period of the season. For the purpose of analysis, the period of November to March when there is high wind speed spreading up to 35 knots was considered.

Oil spill trajectory models is useful in forecasting oil slick movement. The wind plays an important role for oil coming ashore than the currents.

Oil spills models is applied to predict or forecast the movement of surface slicks and identify areas that are sensitive and to apply counter measures to avoid oil contamination of those zones.

To model an oil spill, three steps or modules are used namely: **(Sawsen Saad et al, 2016**)

1. Input values or modules provides information about initial condition of the model to use.

   Data about the wind speed, waves, temperature, ice etc and initial data about oil types, properties, locations and time of occurrences.

2. Transport and or oil trajectory

3. Fate of the oil (weathering) (**Alexander Kileso et al, 2014**) The various models commonly

used are the:

- GNOME: General National Oceanic and Atmospheric Administration (NOAA) Operational Modeling Environment
- Oilmap (***Delvigne and Hulsen (1994***).)
- Oil spill contingency and response (OSCAR) model

To model the movement of oil, the most important input parameters include the type and quantity of oil spilled, along with the rate of release. Key environmental input data include wind strength and direction, ocean currents, tides and air and sea temperatures. Accuracy and availability of this data can often be an issue (**AKA Aloysius**).

Although models cannot precisely predict the changes an oil undergoes, they can indicate whether an oil is likely to dissipate naturally or whether it is likely to reach the shoreline. This information can be used by spill responders to decide on the scope of initial aerial surveillance flights and/or the most effective spill response techniques to employ within the optimum timeframe.

In this article, the use of GNOME for trajectory analysis was done.

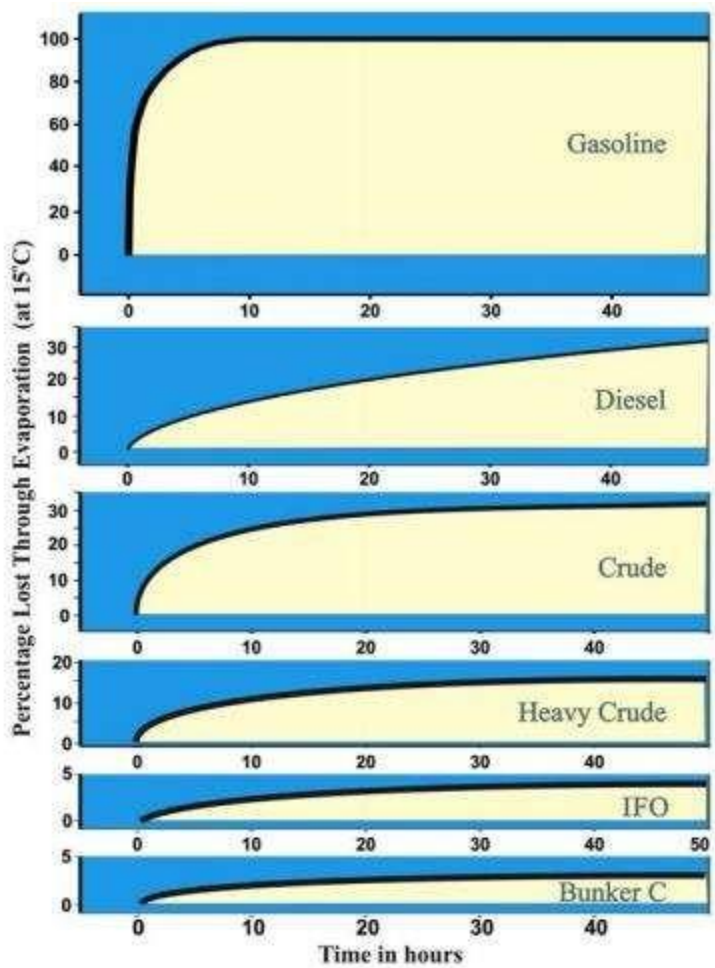

Figure 11 Oil evaporation curves for several typical oil data from experiments at 15 degree C [13]

Wind speed measurement at the Gulf Of Guinea Table 1: wind speed data in January off the coast of Guinea leading towards Kribi

Period	Time	Av Wind	Units	Direction towards kribi Beach (Degrees)
January 1st,2021	00h to 23h	10	knots	263
January 2nd,2021	00h to 23h	6	knots	220
January 3rd,2021	00h to 23h	8	knots	234
January 4th, 2021	00h to 23h	9	knots	214
January 5th, 2021	00h to 23h	7	knots	259
January 6,2021	00h to 23h	4	knots	245
January 7,2021	00h to 23h	5	knots	260
January 8,2021	00h to 23h	6	knots	234
January 9,2021	00h to 23h	4	knots	245
January 10,2021	00h to 23h	7	knots	256
January 11,2021	00h to 23h	8	knots	270
January 12,2021	00h to 23h	7	knots	243
January 13,2021	00h to 23h	5	knots	210

Oil spill trajectory consist of running model reports to estimate the time in which an oil spill will reach a certain area. In our case model will be ran to see how long oil can arrived the coast of kribi. Knowing the time in which oil spill can arrive a certain location is very critical for response team. It enables the team to be prepare and act accordingly to reduce contamination of sea shore and other estuaries or sensitive resources.

Figure 12: oil spill trajectory cycle questionnaire

Oil Trajectory and Fate Models for Oil Spill

In Oil spill response and contingency planning, models are simulated to know or estimate the exact location in which oil will reach at a particular time (**Fatai et al**). According to **(Tkalich et al**), oil slick spreads over the water surface due to a balance between gravitational, inertial, viscous and interfacial tension forces, while composition of the oil changes from the initial time of the spill. Light (low molecular weight) fractions evaporate, water-soluble components dissolve in the water column, and immiscible components become emulsified and dispersed in the water column as small droplets.

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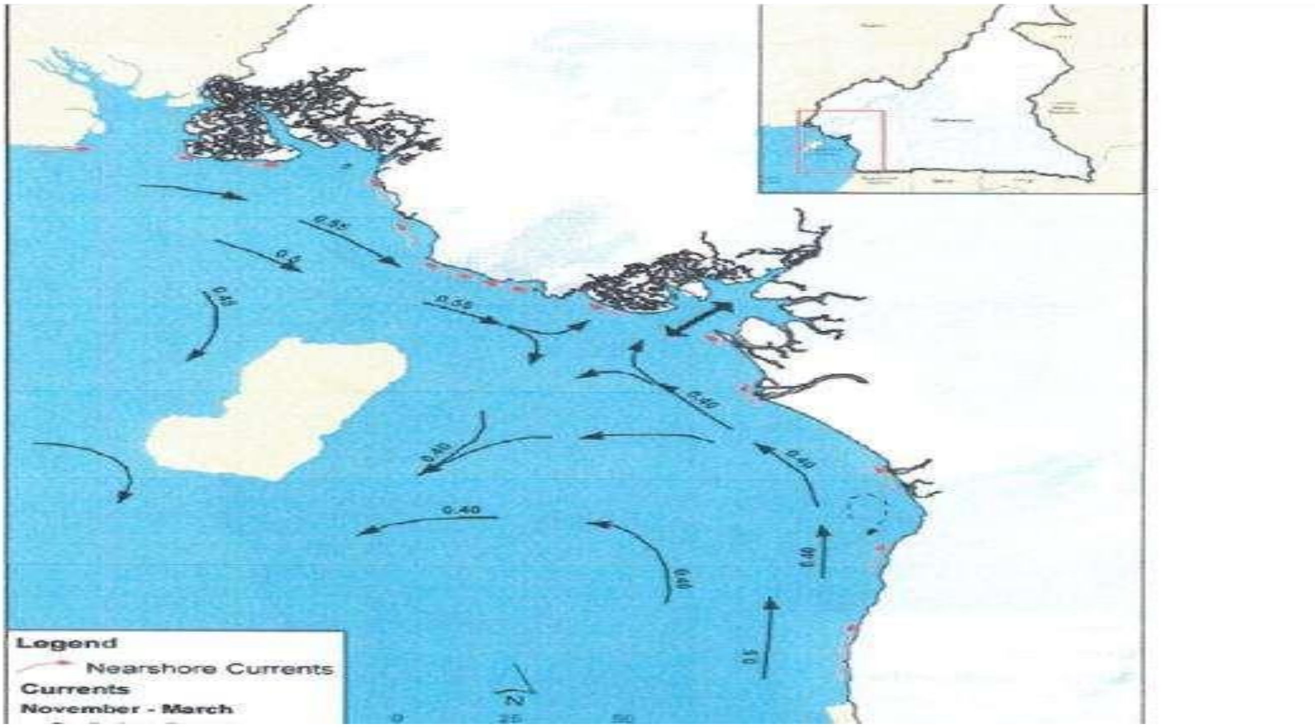

Figure 13: Wave and current behavior in kribi from March to November.

The GNOME Model.

The General NOAA Oil Modeling Environment (GNOME) is a two-dimensional model as stated by **(Beegle Krause)** that is designed for the rapid modeling of pollutant trajectories in the marine environment; it's used as a forecasting tool for both actual spill events and a planning tool to examine "what-if" scenarios. (**William, B et al).**

GNOME uses an Eulerian/Lagrangian spill-trajectory model in which the regional physics are simulated as Eulerian (continuous) fields within which the slick's Lagrangian Elements move (**Beegle Krause).**

Within GNOME the oil is divided into a large number of small particles which move under the influence of ocean currents, wind drift and turbulent motions. The fate and transport of oil spilled into the marine environment also depends on a suite of physical, chemical and biological processes "weathering".

GNOME model integrates simple algorithms for oil weathering (**Amy MACFADYEN et al**).

Ocean current responsible for moving oil as 100 percent of the speed of the ocean current. During the wet season, the Guinea Current and the Easterly Flowing North Equatorial Counter Current are responsible for moving oil spill. The Guinea Current has speeds of 30cms-1 and touches the sea bed at depths shallower than 50m. From time to time, the Guinea Current reverses it's easternly flow. (Reddy ***and al 1997***)

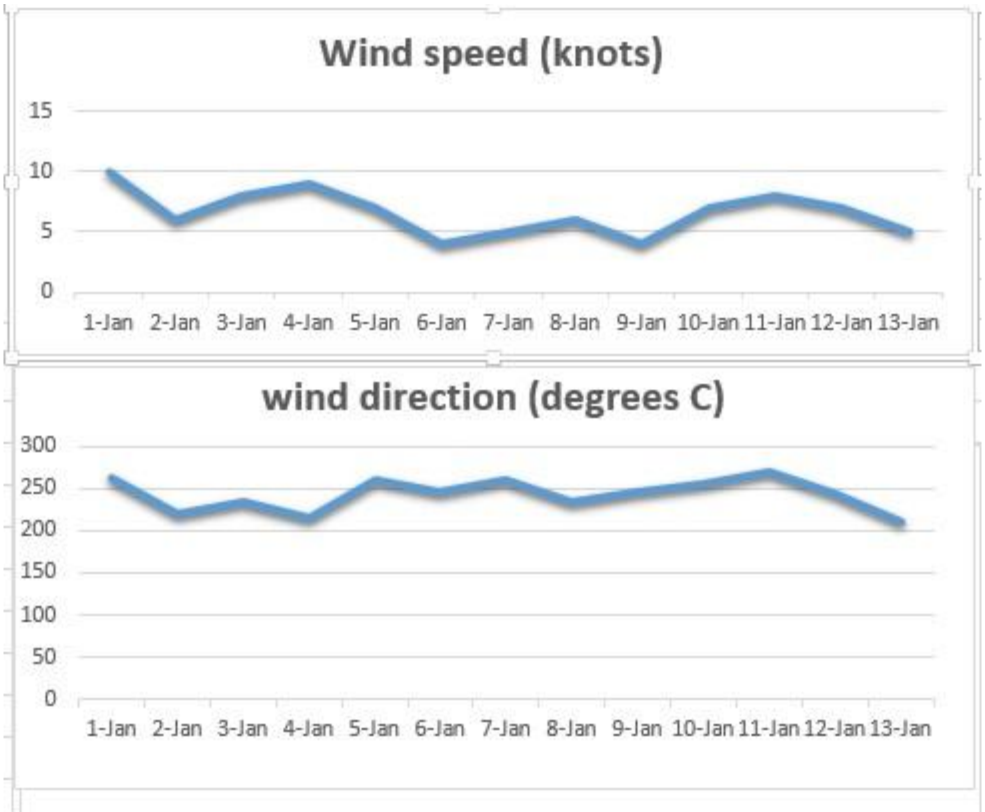

Figure 14: wind speed and direction towards kribi beach.

Simulation

GNOME run to find the trajectory of oil slick off the coast of Kribi for a 72 hrs period is done as below. Oil spill simulation model is used in oil response and contingency planning and as a tool in oil fate and impact assessment (***Rossouw, 1998***). In the event of an oil spill taking place, predictions of the slick can be supplied, provided that the necessary meteorological information is available.

As oil approaches the coastline it becomes a threat to the beach face or intertidal area. In many spills this threat and/or the actual oiling of the beach becomes a major issue and the focus of most of the spill response activities. As is often the case a number of different processes interact to control how, or if, the oil actually impacts the shoreline (***J. A. Galt 2017***).

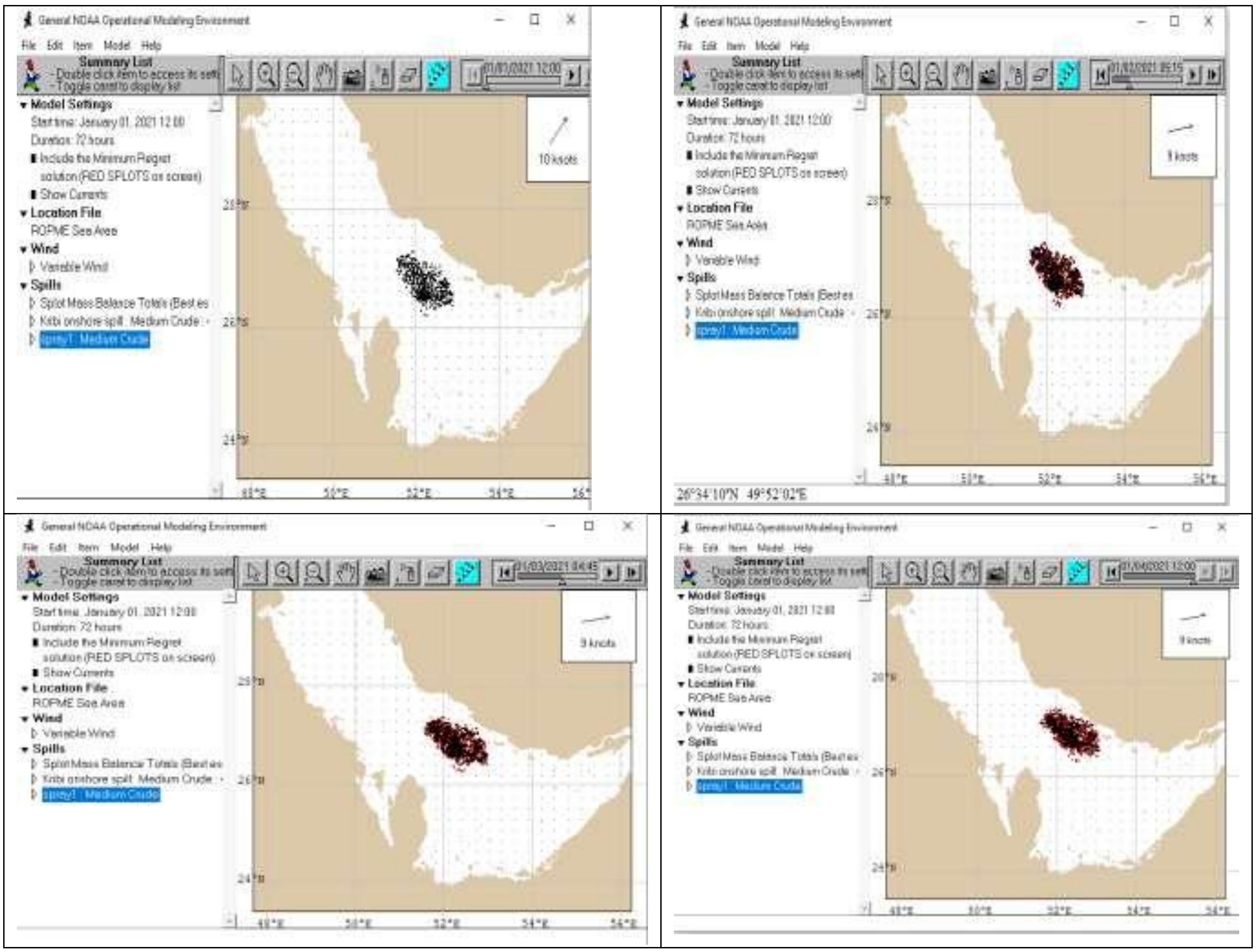

Figure 15: oil spill trajectory from day 1 of the release till day 4 as simulated using GNOME

ADIOS

ADIOS (Automated Data Inquiry for Oil Spills) is NOAA's oil weathering model. It's an oil spill response tool that models how different types of oil weather (undergo physical and chemical changes) in the marine environment. Working from database of more than a thousand different crude oils and refined products, ADIOS quickly estimates the expected characteristics and behavior of spilled oil.

Its predictions are designed to help decision-makers develop cleanup strategies based on estimates of how long spilled oil will remain in the environment. The ADIOS database includes estimates of the physical properties of oils and products. It then uses this information and mathematical equations to predict changes in those properties once the oil has been released. Such properties include the density, viscosity, and water content of an oil or refined product; and the rates at which it evaporates from the sea surface, disperses into the water column, and forms oil droplets that become emulsified, or suspended, in the water.

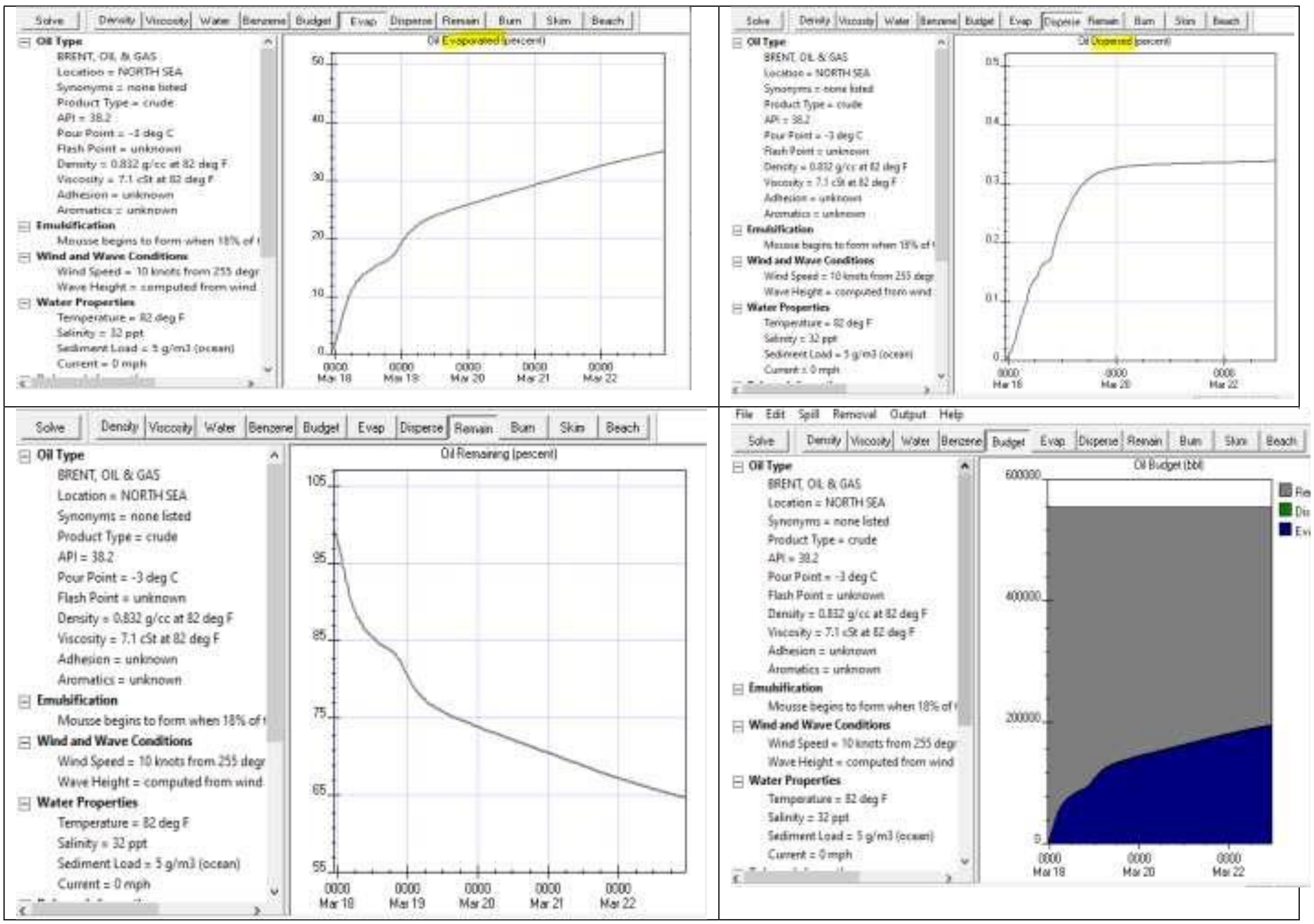

Figure 16: ADIOS simulator for spill progression and clean up estimated cost.

Interpretation of results

The oil slick moves according to the surface currents and wind towards the direction of flow. At speed of 10 knots, the oil spill situated about 14 miles from the coast of kribi will hit the shore after day three of the spill. As seen on figure 15 the GNOME model shows the oil slick movement according to durations and the ADIOS model in figure 16 above shows the comparative oil slick movement taking into account the amount evaporated, the quantity remaining, the cost estimate for cleanup and the amount of oil slick dispersed from the initial point of the spill.

Conclusion

The trajectory of the oil slick depends on the wind and the diffusion coefficient. The simulation using GNOME is just predictions and not reality, many other factor can affect the movement of oil in water. The transport and fate of spilled oil in water bodies are governed by physical, chemical, and biological processes that depend on the oil properties, hydrodynamics, meteorological and environmental conditions. Oil spilled into water is subjected to turbulent flow. Oceanic turbulence is generated by winds and current, and by heating and cooling. Flow in the upper layers of water becomes more turbulent as the wind and current increases.

Recommendations

Crude Oil is very adhesive, especially when it is moderately weathered, and binds to shorelines or other mineral material with which it comes in contact. It does not degrade significantly and can remain in the environment for decades. Oil production companies needs to put in place a rapid clean up response group with frequent drill exercise. This can help to contain the spilled oil in a timely manner to avoid spreading and further contamination of the sea and other sensitive area. Focus should be on their operating equipment, processes put in place for maintenance strategies and trained qualified personnel to operate their facility. If all these three barriers (equipment, Processes and people) are effective, the spill incident can be reduced to a minimum.

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