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Analytical Modelling Of Impacts Of Oil Spills In The Niger Delta Of Nigeria: A Case Study Of The Botokiri, Odeama And Santa Barbara Spills In Nembe LGA Of Bayelsa State

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ABSTRACT

This study aims to analyze the impact of oil spills in the Niger Delta of Nigeria, specifically in the Botokiri, Odeama, and Santa Barbara regions of Nembe LGA, Bayelsa State. Increased oil exploration and transport have led to higher risks of spills, which adversely affect marine environments and are challenging to manage. This research focuses on modeling oil weathering processes (OWP) to understand how oil slick properties such as viscosity and density change over time. Mathematical models, particularly the fourth order Runge-Kutta method, were used to simulate these changes in different types of crude oils. The study involved field sampling and laboratory analysis of the affected areas following three significant oil spills: a sabotage-induced spill in Santa Barbara, an equipment failure in Botokiri, and a corrosion-induced spill in Odeama. Results show that oil extracted from most affected areas matched the reference oil, except in Shellkiri. Environmental analysis revealed variations in water pH, salinity, and dissolved oxygen levels, with some parameters exceeding permissible limits. Sediment and soil samples indicated moderate levels of petroleum hydrocarbons and heavy metals, but these were generally below intervention values. Microbial analysis suggested ongoing biodegradation of hydrocarbons. The findings emphasize the importance of understanding initial oil properties and environmental conditions to plan effective spill response strategies. The study provides insights into the behavior of oil spills and suggests improvements for oil spill modeling and response measures.

Keywords: Analytical modelling**,** petroleum consumption, oil exploration, marine environment, crude oil, oil spill impacts, oil weathering processes (OWP), Botokiri, Odeama and Santa Barbara

INTRODUCTION

In recent years, increased petroleum consumption has promoted oil exploration and oil transport activities in the marine environment. The production and transport of crude oil on the sea surface always holds the risk of spills. In addition, man-made errors and mechanical failures result in incidents like collision of ships, bursting of pipelines, failure of oil rigs etc., that emit tons of crude oil in the marine environment. In the marine environment crude oil exhibit harmful and long-term effects. Oil in the sea water may enter the food chain of marine animal, sink to sea bed affecting marine vegetation, foul the harbour facilities and damage eco-sensitive near shore resources, when washed ashore. Furthermore, oil spills are difficult to recover from the sea surface due to unpredictable nature of the sea surface and weather conditions. Hence, oil spills are undesirable in marine ecology. Oil spill releases a large amount of crude oil on sea surface. Once the crude oil is spilled, it gradually starts decaying under the influence of concurrent processes collectively termed as oil weathering processes (OWP). Weathering of an oil slick modifies its behavior making it more persistent to marine waters and enduring its lifespan in marine biology. Hence in order to plan an effective response operation, it is vital to have advance knowledge of oil slick behavior. The mathematical representations of OWP are therefore used to predict critical slick properties such as viscosity and density *(Aditya Kumar Mishra and G. Suresh Kumar / Aquatic Procedia 4 (2015) 435 – 442).*

After the crude oils are spilled, on the sea surface they spread to form a thin layer called oil slick. The oil slicks are then acted upon by several natural processes together to degrade the oil slick. These processes are referred as oil weathering processes (OWP). The weathering processes significantly alter the slick properties especially density and viscosity of crude oils. Several researchers (*Sebastiao and Soares, 1995; ASCE, 1996; Reed et al., 1999; Lehr, 2001; Azevedo et al., 2014; Fingas, 2014)* had investigated oil weathering processes. They found that, temporal changes in characteristic slick properties endure slick lifespan on the sea surface. In addition, initial spill conditions and initial oil properties critically affect the evolution of oil slicks. When responding to oil spills or planning a counter measure, prior knowledge of oil properties is of paramount importance. As type and effectiveness of countermeasure selected, highly rely on slick properties. The mathematical models established over the years had been widely used to accomplish the task. Therefore, the focus of the present work was to model and assess the effect of initial oil characteristics on slick properties after spill. For this purpose, fourth order accurate Runge-Kutta was found appropriate and used. The set of time dependent equations were solved explicitly with three different crude oils namely light, intermediate and heavy crude oils.

The National Oil Spill Detection and Response Agency (NOSDRA), which is saddled with the responsibility of detecting and responding to all oil spillages in Nigeria, commissioned Thermosteel Nigeria Ltd (TNL) to carry out a Post Spill Impact Assessment (PSIA) of Aiteo Eastern Exploration & Production Company Limited (AEEPCo) spill impacted areas in Botokiri, Odeama and Santa-Barbra Communities of Opu-Nembe, Nembe Local Government Area of Bayelsa State.

Aiteo Eastern Exploration and Production Company Limited is the operator of OML29 and Nembe Creek Trunkline (NCTL) on behalf of itself and the Nigerian National Petroleum Corporation (NNPC) Joint Venture (JV). A Joint Investigation Visit (JIV) was conducted by a Joint Investigation Team (JIT) comprising of representatives of NOSDDRA, AEEPCO, Bayelsa State Ministry of Environment (BYSMENV) and the relevant communities at the different communities. On 1st October 2019, about 116 bbl of crude oil spilled from Santa Barbra well 1 and the JIV indicated that the cause of the spill was sabotage. A second spill was reported on 31st October 2019 at NCTL in Botokiri community, spilling about 1300 bbl of crude oil and the cause of the spill was equipment failure. A third spill occurred on the 11th of May 2020 releasing about 48.5 bbl of crude oil which was allegedly due to corrosion. Thermosteel Nigeria Limited was mobilized to field for sampling from 23/9/2020 -8/10/2020 and laboratory analysis followed thereafter. This report therefore contains the findings of the field sampling and laboratory analysis covering the locations of the three oil spill incidents.

LITERATURE REVIEW

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After the crude oils are spilled, on the sea surface they spread to form a thin layer called oil slick. The oil slicks are then acted upon by several natural processes together to degrade the oil slick. These processes are referred to as oil weathering processes (OWP). The weathering processes significantly alter the slick properties especially density and viscosity of crude oils. Several researchers (Sebastiao and Soares, 1995; ASCE, 1996; Reed et al., 1999; Lehr, 2001; Azevedo et al., 2014; Fingas, 2014) had investigated oil weathering processes. They found that, temporal changes in characteristic slick properties endure slick lifespan on the sea surface. In addition, initial spill conditions and initial oil properties critically affect the evolution of oil slicks. When responding to oil spills or planning a counter measure, prior knowledge of oil properties is of paramount importance. As type and effectiveness of countermeasure selected, highly rely on slick properties. The mathematical models established over the years had been widely used to accomplish the task. Therefore, the focus of the present work was to model and assess the effect of initial oil characteristics on slick properties after spill. For this purpose, fourth order accurate Runge-Kutta was found appropriate and used. The set of time dependent equations were solved explicitly with three different crude oils namely light, intermediate and heavy crude oils.

Oil Spill Modelling

Oil spill modelling is a tool used to support oil spill preparedness and response planning. It can also be used to support response operations in the event of an actual oil spill. There are a number of different approaches to modelling, which are generally used in combination to inform risk assessment, and response and preparedness planning. Two types of oil spill modelling often used are stochastic and deterministic modelling.

Stochastic modelling

Stochastic oil spill modelling is created by overlaying a great number (often hundreds) of individual, computer-simulated, hypothetical oil spills. The simulated oil spills for a stochastic model will all start from the same location (e.g. a drilling location or production platform) but each oil spill scenario will be subject to a different set of wind and weather conditions drawn from historical records. Sophisticated modelling software will count how often oil may be observed in each area of the environment in all of the discrete spill events. This is often presented as a probability of exposure and can be useful for informing preparedness and response arrangements as it shows which areas are more or less likely to be impacted in the remote chance as spill occurs. Considering many spill events and the different spill trajectories is an integral part of modern spill risk assessment and is often used to identify the range of environments that may be affected in various conditions and identify the priorities for protection. Stochastic modeling is generally used for risk assessment and preparedness planning. By overlaying hundreds of oil spills into a single map, stochastic modeling shows all the areas that could be affected rather than just assuming one spill scenario. It is misleading to imply that stochastic modelling represents what a single spill would look like or the area it would affect.

Deterministic modelling

Deterministic modelling creates a computer simulation of a single hypothetical oil spill subject to a single set of wind and weather conditions. Deterministic modelling is used to forecast the fate and behaviour of oil from a single model run. Deterministic modelling is commonly used to consider the fate and effects of representative ‘worst-case’ oil spill scenarios. Often, one or more model runs are generated and each run will be carefully selected in consideration of the nature and scale of the offshore petroleum activity and the local environment. The information produced by deterministic modelling is very useful for informing upper limits for oil spill preparedness and response arrangements, which assumes that no other action is taken, which can then be adapted and scaled to match the particulars of different oil spills. While it is impossible to prepare for an infinite number of possible oil spills it is also insufficient to only prepare to respond to a single representative worst-case oil spill, therefore, appropriate preparedness and response planning tends to be informed by both deterministic and stochastic modelling. (National Offshore Petroleum Safety and Environmental Management Authority)

Modeling weathering processes

Oil weathering processes (OWP) act naturally on oil slicks conceived after oil spills, on the sea surface. It includes spreading, evaporation, dissolution, dispersion, emulsification etc. These processes are complex, self-competing and act simultaneously. Although, the processes like evaporation removes major fraction of volatile parts, the residue still thrive on the sea surface as a result of emulsion formation with enhanced oil volume. But then, not all oils emulsify; some even break and separate into oil and water phases.

Spreading

Fay (1971) described spreading to evolve in three stages: inertia-gravity, gravity-viscous and viscous-surface tension. The oil slick was assumed to spread axi-symmetrically, with circular slick before and after spreading independent of wind, wave and currents. The first stage passes rather quickly and third stage is attained when slick gets broken. Hence, an oil slick spends most of lifespan in gravity-viscous regime. In order to model spreading in gravity-viscous stage, the time to end first stage and initial area at the end of the first stage were calculated (Berry et al., 2012). Later area for second stage was estimated using Eq. (4) (Sebastiao and Soares, 1995).

$$t_0 = \left(\frac{k_2}{k_1}\right)^4 \left(\frac{V_0}{\upsilon_w g \Delta}\right) \quad (1)$$

$$\Delta = \frac{\rho_{sw} - \rho_{oil}}{\rho_{sw}} \quad (2)$$

$$A_0 = \pi \left(\frac{k_2^4}{k_1^2}\right)\left(\frac{\Delta g V_0^5}{\upsilon_w}\right) \quad (3)$$

$$\frac{dA}{dt} = k_{sp} \frac{V^{\frac{4}{3}}}{A} \quad (4)$$

$$\frac{dF_e}{dt} = \frac{k_{evp} A}{V_0} \left\{ a - \frac{b\,(T_0 + T_g F_e)}{T_{oil}} \right\} \quad (5)$$

$$k_{evp} = 2.5x10^{-3} W_{s10}^{0.78} \quad (6)$$

$$T_0 = 532.98 - 3.125 API \quad (7)$$

$$T_g = 985.62 - 13.597 API \quad (8)$$

where, t0 is time to end stage one of spreading (s), V0 the volume of oil spilled (m^3), V is the volume of oil at any time instant t (m^3), k_2 and k_1 are empirical constants (1.14 and 1.45 respectively), g is the gravitational acceleration.(m^2/s), p_{sw} is the density of sea water (Kg/m^3), p_{oil} is the initial density of oil (Kg/m^3), uw is the kinematic viscosity of water(m^2/s), A_0 is the initial area for stage 2 of spreading(m^2) and k_{sp} is the evaporation constant (150 s^{-1}).

Evaporation

Evaporation is the primary mechanism of oil removal from the sea surface. It removes most of the volatile fractions of the crude oil within hours of spill. The density and viscosity of the oil slick is significantly modified by evaporation.

Therefore, estimating rate of evaporation is crucial. The rate of evaporation was calculated using analytical equation proposed by Stiver and Mackay (1984), assuming oil slick to be single component. The data unavailable on T_0 and Tg were evaluated using NOAA formulation as in Eq. (7) and Eq. (8) (Berry, 2011).Where, F_e is the volume fraction of oil evaporated (%), k_{evp} is the mass transfer coefficient of evaporation (m/s), a and b are evaporation constants (6.3 and 10.3 respectively), T_0 is initial boiling point temperature of oil (K), T_g is the gradient of oil distillation curve (K),

W_{s10} is the wind speed at height of 10 m from sea surface (m/s) and T_{oil} the temperature of the oil spilled (K) (assumed to be equal to sea surface temperature) and API refer to the American Petroleum Institute gravity scale.

Dissolution

Dissolution of crude oil into the sea increases the toxicity of sea water (Riazi and Roomi, 2008). The chemicals present in the oil and capable of dissolution are also easy to evaporate. Since, evaporation is a faster process compared to dissolution most of these chemicals evaporate quickly. The amount of crude oil dissolved in sea water, is therefore typically small (in ppm). The rate of dissolution may be estimated using following equations (Shen et al., 1993). The suitable changes were incorporated to obtained volume fraction of oil dissolved as follows:

$$\frac{dF_d}{dt} = K_{diss} A \left(\frac{S}{1000\rho_{oil}}\right) \quad (9)$$

$$S = S_0 \exp(-12.0 F_e) \quad (10)$$

Where, Fd is the volume fraction of oil dissolved in sea water (%), Kdiss is the mass transfer coefficient of dissolution (m/s), S the solubility of oil at time t (g/m^3) and S_0 is the initial solubility of oil in water (g/m^3).

Emulsification

Emulsification results due to wave breaking and sea surface turbulence. The sea surface disturbance entrains sea water into the oil slick. As slick viscosity increases with time, higher amount of water is trapped in the slick. Therefore, the formation of emulsion increases water content of oil. This further impedes the rate of evaporation. In addition, it increases density and viscosity of the slick particular. The water content of oil due to emulsion formation can be modeled using Mackay's formulation Eq. (11) (Sebastiao and Soares, 1995). The impact of emulsification on rate of evaporation was assimilated as per Lehr (1994).

$$\frac{dY}{dt} = k_{emul}(1+W_{s10}^{2})\left(1-\frac{Y}{Y_f}\right) \tag{11}$$

$$k_{evp\_cor} = k_{evp}(1-Y) \tag{12}$$

Where, Y is the water content of oil (vol %), K_{emul} is the mass transfer coefficient of emulsification (2.0 x10^{-6}, m/s), Yf is maximum water content of water in oil (vol %) and K_{evp_corr} is the corrected mass transfer coefficient of evaporation considering the effect of emulsion formation (m/s).

Density and viscosity

Density and viscosity of an oil slick on the sea surface are basically influenced by OWP. Evaporation and emulsification are the key processes that improve the viscosity of an oil slick. Effect of evaporation, however was reported more significant than the rate of evaporation. As emulsification causes rapid rise in slick viscosity, the effect of emulsion formation should essentially be encompassed while estimating slick viscosity. The difference in oil slick and sea surface temperature further improves the density and viscosity values. Thus, considering the effect of evaporation, emulsification and temperature difference the density and viscosity may be calculated using Eq. (13) and Eq. (14) (Berry et al., 2012). Owing to, lack of data on reference temperature at which density was measured. The effect of temperature difference on density was not considered.

$$\rho_{net} = Y\rho_{sw} + \rho_{ref}(1-Y)(1+0.18F_e) \tag{13}$$

$$\mu_{net} = \mu_0 \exp(c_{evpm}F_e)\exp\left(\frac{2.5\,Y}{1.0-0.654\,Y}\right)\exp\left(-63.16\frac{T_{ref}-T_{sl}}{T_{sl}T_{ref}}\right) \tag{14}$$

Where, p_{net} is the resultant density of oil at any time instant t (Kg/m^3), pref is the initial density of oil (Kg/m^3), $^{\wedge}{}_{net}$ is the resultant density of oil at any time instant t (cP), ^0 is the initial density of oil (cP) and Trfis the temperature at which viscosity was measured before spill (K).

Numerical strategy and details

The simulations were run for a hypothetical spill of volume 1000 m^3, with three different crude oils: Statfjord crude, Kuwait crude and Prudhoe Bay crude oils, respectively. The crude oils were categorized based on API values into light, intermediate or medium and heavy crude oil (Allen and Dale, 1997; Cormack, 1999; Boyed et al., 2001; API, 2011). The set of non-linear equations from Eq. (1) - (14) were solved simultaneously using Runge-Kutta fourth order method for period of 24 hours or one day. The time step of 10 seconds was selected. After each time step, changes in oil properties under the influence of OWP were calculated. The rate of spreading, evaporation, dissolution and emulsification were allowed to vary concurrently. The corresponding behavior of slick was then evaluated based on area of spread, volume remaining and considering the changes in the oil viscosity. The data unavailable in the literature on intermediate crude oil were obtained averaging the information on light and heavy oils.

OSCAR Model System

The OSCAR model system (Reed et al., 1995a; Aamo et al., 1996) has been developed to supply the public and private sectors with a tool for an objective analysis of alternative spill response strategies. Key components of the system, shown schematically in Figure 1, are **IKU's Data-Based Oil**

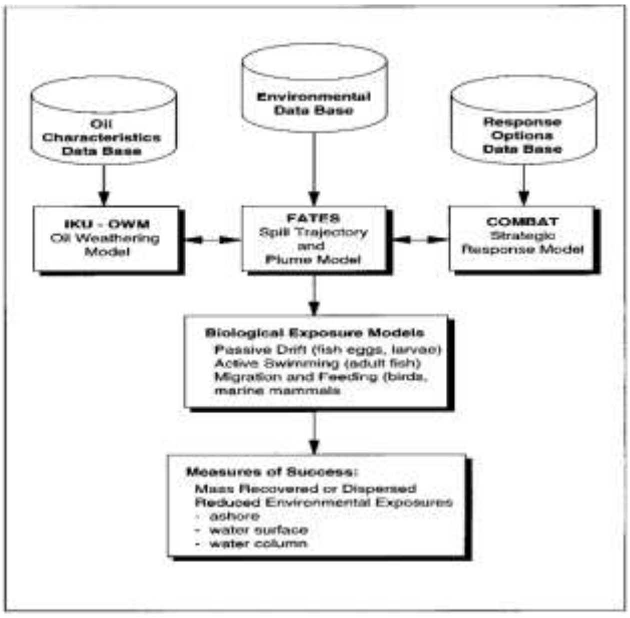

Figure 1. Schematic overview of OSCAR’s Model.

Weathering Model (Aamo et al., 1993; Daling et al., 1990, 1991), a three-dimensional oil trajectory and fates model (Reed et al., 1995b), and an oil spill combat model (Aamo et al., 1995, 1996). OSCAR model has been applied to the analysis of alternative oil spill response strategies for both offshore platforms (Aamo et al., 1995; Reed et al., 1995a) and coastal terminals (Reed et al., 1996b). In evaluating these analyses, the Norwegian State Pollution Authorities addressed the importance of a calibration, testing, and sensitivity study to establish model credibility. The work is reported in Reed et al. (1996a; calibration and testing) and in this paper (sensitivity studies).

Sensitivity analysis

A subset of the model’s system and user-defined parameters has been studied in respect to how variations in them affect the model results. The following scenario is used in the analysis: " Release of 200 tons of Troll crude " Constant wind speeds of 5 and 10 m/s " Constant temperature of 10°C " Mechanical clean-up based on minimum requirements given in “Regulations relating to emergency preparedness in the petroleum activities” (Norwegian Petroleum Directorate, 1994) " Dispersant application based on a recently developed helicopter bucket. Mechanical clean-up is used when the text does not state differently.

Tables 1 and 2 summarize the parameters for mechanical clean-up and dispersant application, respectively. The effectiveness given in the tables is defined as the percentage of treated oil (that is, oil that has entered the boom, or oil that has been treated with dispersants) that is actually recovered or dispersed.

Spreading

Most processes that take place in the model are dependent on the area of the oil slick. A slick covering a large area will be subject to a larger number of breaking waves, and thereby will disperse faster than a thicker slick containing the same amount of oil. Also, the process of evaporation will be more rapid when the oil is spread over a larger area.

The size of the slick also determines the effectiveness of oil spill response actions. In other words, the model that estimates the rate at which an oil slick spreads will influence the results given by most of the sub models. In OSCAR, spreading is calculated according to Mackay et al. (1980):

$dA = Kh^{133} A \, dt$

Where: A is the area of the slick (m^2)

h is the thickness of the slick (m)

t is time (s)

$K < 5780$ is an empirical constant (s^{21})

In the model, spreading stops when the slick has reached a minimum thickness, depending on the oil type in question. In this case, the minimum thickness is the following:

$h_{min} = 0.5\mu m$

In addition to the gravity-viscous spreading given in the preceding equation, natural dispersion will also affect the spreading of oil, in that oil is driven into the water column and resurfaces as blue sheen (with thickness equal to h_{min} in the model) behind the main slick after a certain period of time. For a given wind scheme, the spreading will typically be dominated by one of the effects: in calm weather, the gravity- viscous equation will govern the spreading, whereas in rough weather the process of natural dispersion will be the dominating factor.

Figures 2 and 3 show the total area covered by oil and the area cov- ered by thick oil (.20 µm), respectively, for 5 m/s wind and K 5 Korg/5, K 5 Korg, and K 5 2Korg, where Korg is the original value of K ø 5780s21.

The figures show that a change in K leads to large variations in both total area and area of thick oil. From this we can expect differences in evaporative loss, natural dispersion, and mass recovered. Computed mass balances show that the differences are considerable, with lifetimes for the surface slick of approximately 18 hours, 3.5 days, and 5 days, respectively. The mass balances show that the clean-up rate decreases, whereas the rate of evaporation and dispersion increases with increasing K. In 10-m/s wind, these considerations become less evident, in that natural dispersion now dominates areas and mass balances (Figures 4 and 5). An increasing K gives a considerable increase in dispersed oil, which in turn leads to large areas of sheen being formed.

Figures 6 and 7 show total area and area of thick oil, respectively, for 5-m/s wind and h_{min} 5 h_{min},org/5, h_{min} 5 h_{min},org, and h_{min} 5 2h_{min},org, where h_{min},org is the original value of h_{min} 5 0.5 mm. The figures show that, for the two thickest slicks, just small changes in area are recorded, whereas for the thinnest slick the value of h_{min} is approaching a limit for calculating surface area, where the combination of the number of particles used to represent the slick and the minimum thickness introduce considerable noise into the calculations. This effect is discussed in more detail in the next section. The mass balances show only small differences as a function of h_{min}. In 10-m/s wind, the difference in total area between the two thickest slicks is evident in the beginning of the simulation, and then decreases somewhat as the simulation proceeds. The thinnest slick, however, has a much larger total area than the others. The area of thick oil is practically equal in the three cases. As for the 5m/s case, the mass balances show only small variations.

2.2.3 Number of particles for representing the surface slick

In the model, an oil slick is represented by many small particles that all are subject to spreading, evaporation, and emulsification. Any given particle can either lie on the surface or be submerged in the water as droplets of certain sizes. In this way, natural dispersion is also simulated by the particle representation. To obtain a good representation of the oil slick as a whole, a great number of particles is needed. The number of particles is especially important for the dispersion process, since dispersion is discretized in a whole number of particles (a particle cannot be partly submerged and partly on the surface). Simulations were performed for three different numbers of particles (100, 500, and 1000). For 5-m/s wind and 100 particles, the total area calculations are noisy because of natural dispersion being discretized in a whole number of particles. However, this problem vanishes when 500 and 1000 particles are used. The differences between the 500 and 1000 particles cases are small, and are caused by clean-up being somewhat dependent on the number of particles (this problem is discussed in more detail in the section dealing with search criteria for mechanical clean-up equipment). It is worth noting that the noisy behaviour in the area calculations does not influence the mass balances much, since the noise is caused by sheen, which has a large area but a small mass. Sheen also has a relatively short lifetime.

As for the 5-m/s wind, the 10-m/s cases are relatively similar. However, the total area calculations are heavily affected by noise when 100 particles are used. Some noise can also be seen for the 500- and 1000- particle cases. The increased noise level is caused by the more dominating dispersion process at higher winds.

Effectiveness of response equipment.

The effectiveness of an oil spill response action in OSCAR depends on a set of parameters that the user has to specify. Most of the parameters are usually known, and they describe the physical characteristics of the equipment. Such parameters may be given by the manufacturer or may be based on tests performed by third parties. However, one particular parameter that must be specified, which often is difficult to estimate, is the instantaneous effectiveness of the equipment. In OSCAR, an effectiveness must be specified for both equipment for mechanical clean-up and equipment for the application of dispersants.

Table 1. Parameters for mechanical clean-up actions

Maximum recovery rate	50 tons/hour
Operational speed	1 knot
Cruise speed	8 knots
Boom opening	56 meters
sweep area	0.1 km2/hour
Effectiveness	60% at 10 m/s wind
→	80% at 5 m/s wind

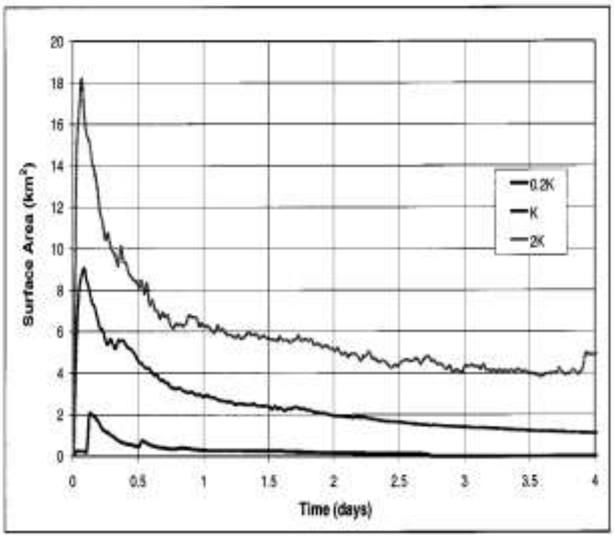

Figure 2. Change in total surface area over time for three values of the spreading coefficient, 0.2K, K, and 2K, in a 5m/s wind

Mechanical response.

In the model, the instantaneous effectiveness of mechanical clean-up equipment (skimmer/boom system) affects the rate of clean-up as follows:

$$r = \frac{e}{100\%} \min\begin{cases} r_{\max} \\ r_{\text{boom}} = bvh \end{cases}$$

Where: r is the rate at which emulsion is removed from the sea (m3/s) $r_{\max}$ is the maximum pump capacity, specified by the manufacturer (m3/s) r_{boom} is the rate at which emulsion enters the boom (m3/s) b is the width of the boom opening (m) v is the operational speed (m/s) h is the oil slick thickness at the boom opening (m) e is the instantaneous effectiveness (%) If the effectiveness is set to, for instance, 80%, the clean-up rate will be 80% of the rate at which emulsion enters the boom, but will be limited to 80% of the maximum pump capacity. In other words, the effectiveness specifies leakage from the boom when r_{boom} is the limiting factor, and overloading of the pump when $r_{\max}$ is the limiting factor. The effectiveness of the skimmer/boom system will typically vary with wind and sea state, the viscosity of the emulsion, and how well the operators are trained in using the equipment. These factors have to be taken into account when the instantaneous effectiveness is estimated.

Simulations over 5 days were performed for four different effectiveness values. Figure 8 shows the amount of oil recovered at 5-m/s wind.

Figure 9 shows the corresponding surface exposure. Surface exposure is calculated as follows:

$$E(t_n) = \sum_{i=1}^{n} w_i s_i \Delta t_i$$

Where: E(tn) is surface exposure at time tn (m2s)

wi is the width of the slick perpendicular to the direction of drift at time ti (m)
si is the distance the slick has drifted since last timestep (m)
Dti is the ith timestep (s)
tn is time (s)

Table 2. Parameters for chemical dispersion

Maximum application rate	450 L/min.
Onboard dispersant tankage	2.5 m3
Operational speed	58 knots
Cruise speed	100 knots
Application width	25 meters
Effectiveness	60% at 10 m/s wind
	80% at 5 m/s wind

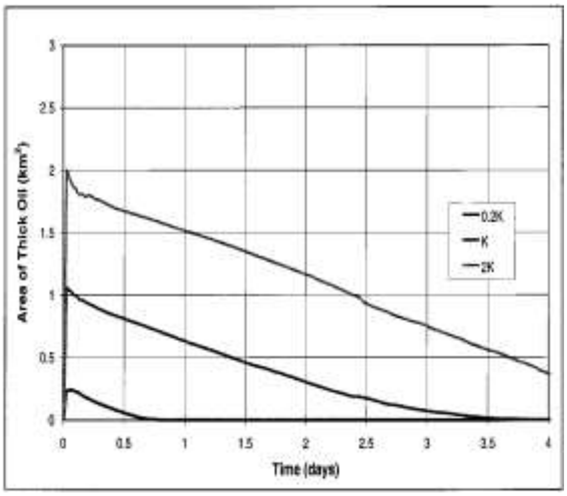

Figure 3. Change in area of thick oil (.20 µm) over time for three values of the spreading coefficient, 0.2K, K, and 2K, in a 5-m/s wind

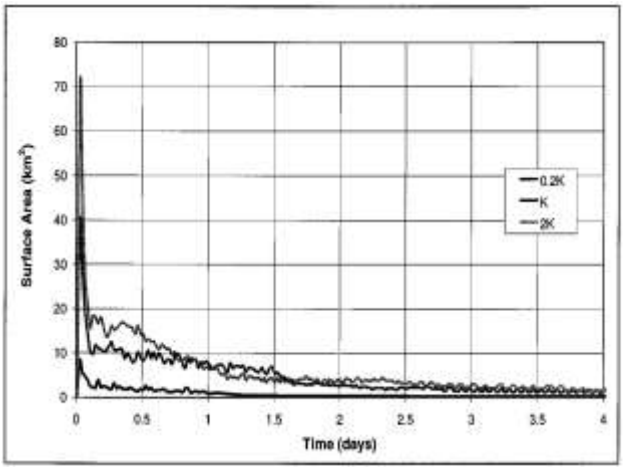

Figure 4. Change in total surface area over time for three values of the spreading coefficient, 0.2K, K, and 2K, with a 10-m/s wind

The surface exposure is assumed to be proportional to the number of birds that will be affected by the slick, assuming an even distribution of birds on the sea surface.

Figures 8 and 9 show that in calm weather, when the degree of natural dispersion is low, the lifetime of the oil and thereby the exposure will be strongly dependent on the effectiveness of the oil spill response action. However, the total amount of oil eventually recovered does not depend much on the effectiveness.

Figures 10 and 11 show the corresponding information at 10-m/s wind. In this case, the lifetime of the oil is less dependent on the effectiveness of the recovery units, since natural dispersion now makes an important contribution to the removal of oil from the sur- face. This leads to small differences in surface exposure (see the curves for 50%, 70%, and 90% in Figure 11). The amount of oil eventually recovered is more dependent on the effectiveness in this case.

2.2.6 Chemical response. The instantaneous effectiveness of dispersant application affects the rate of dispersion in the model as follows:

$$r = \frac{e}{100\%} \min\begin{cases} r_{\max} / \mathrm{DOR} \\ bvh \end{cases}$$

Where: r is the rate at which oil is successfully treated with dispersant (m3/s)
rmax is the application rate (m3/s), b is the application width (m)
v is operational speed (m/s), h is the oil slick thickness (m)
e is the instantaneous effectiveness, (%) DOR is the dispersant-to-oil ratio (typically 1:20)

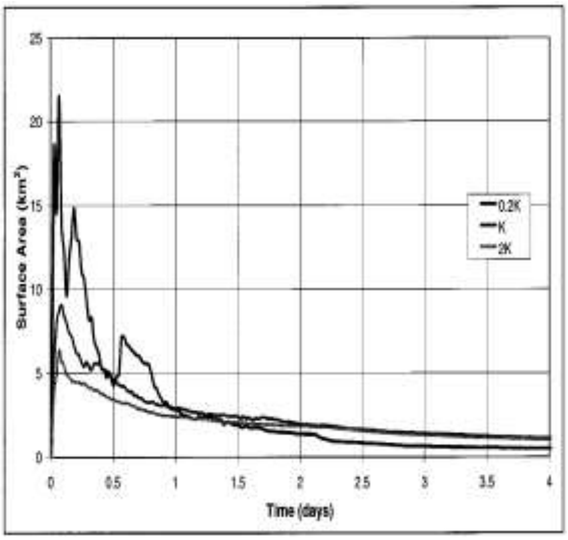

Figure 5. Change in area of thick oil (.20 µm) over time for three values of the spreading coefficient, 0.2K, K, and 2K, in a 10-m/s wind

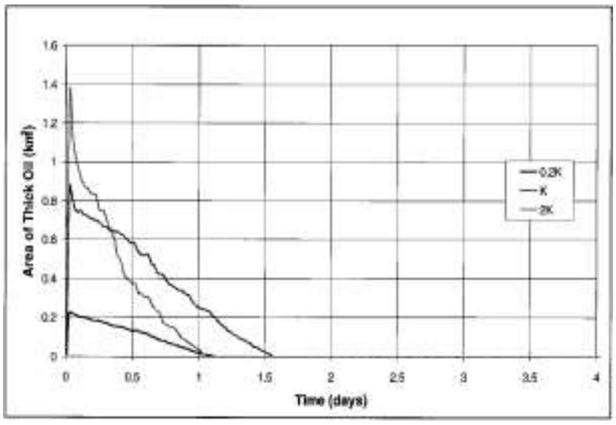

Figure 6. Change in total surface area over time for three values of the minimum oil film thickness, 0.2hmin, hmin, and 2hmin, in a 5-m/s wind

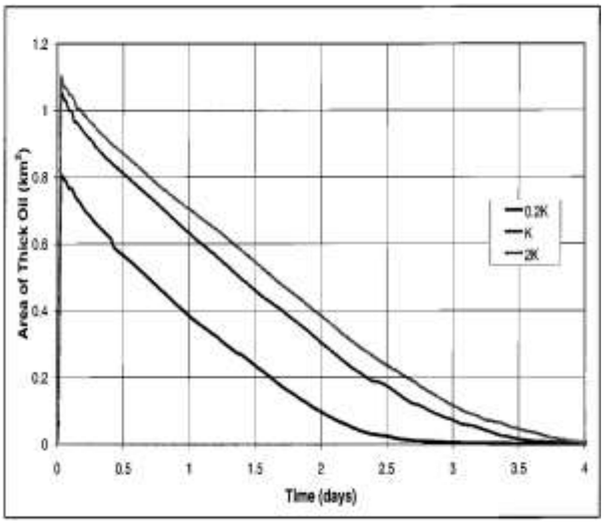

Figure 7. Change in area of thick oil (.20 µm) over time for three values of the minimum oil film thickness, 0.2hmin, hmin, and 2hmin, in a 5-m/s wind

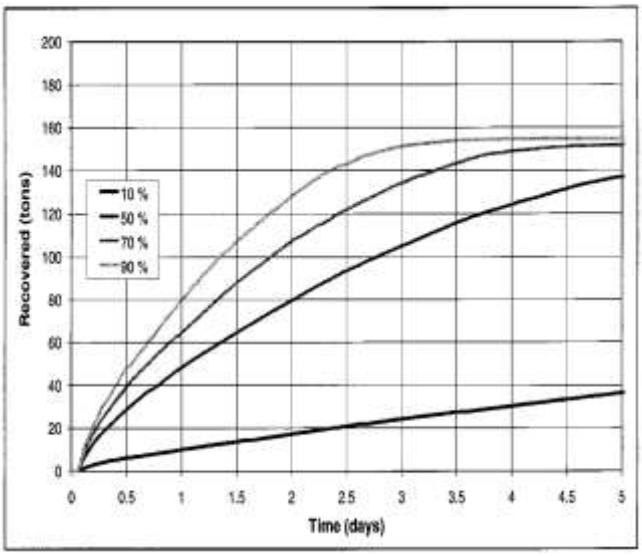

Figure 8. Oil recovered over time for four values of instantaneous effectiveness for mechanical response in a 5-m/s wind

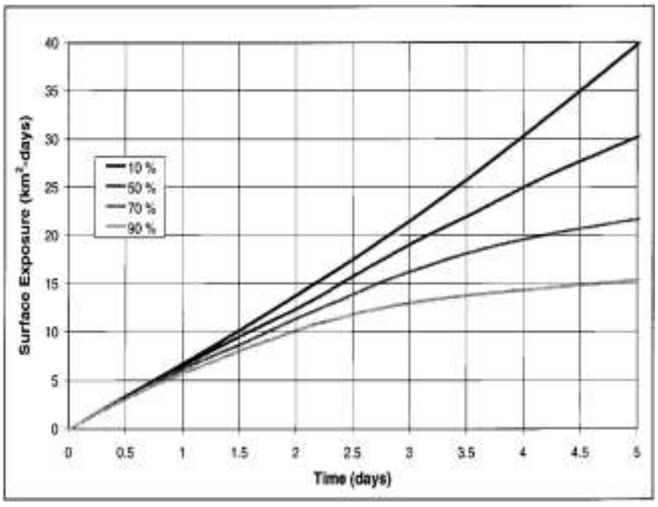

Figure 9. Surface exposure over time for four values of instantaneous effectiveness for mechanical response in a 5-m/s wind

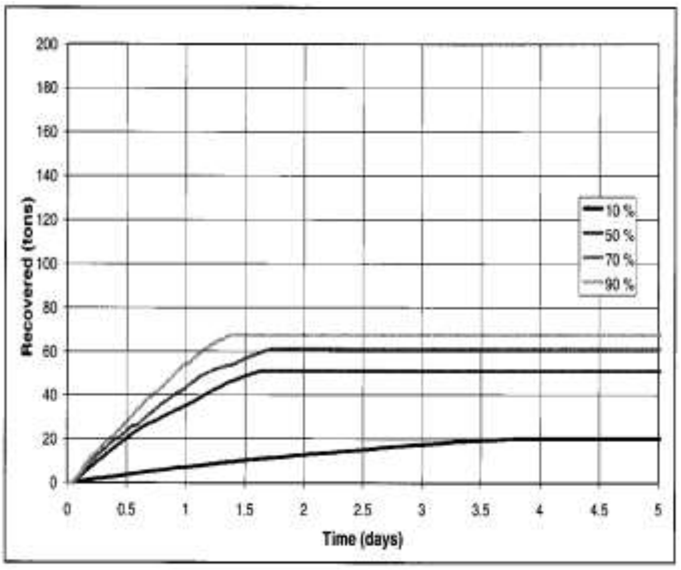

Figure 10. Recovered oil over time for four values of instantaneous effectiveness for mechanical response in a 10-m/s wind

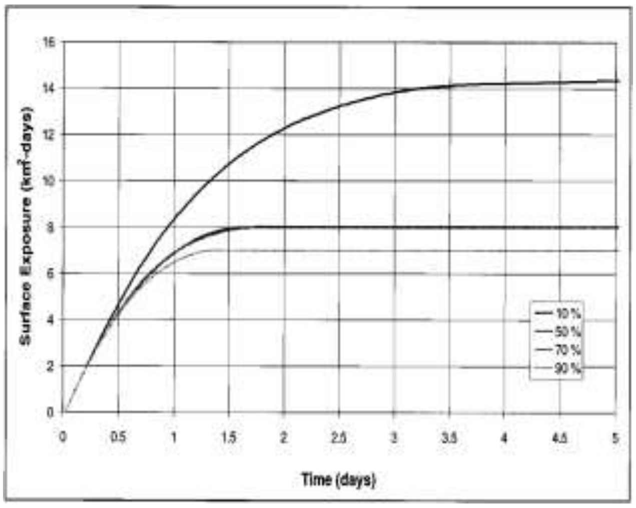

Figure 11. Surface exposure over time for four values of instantaneous effectiveness for mechanical response in a 10-m/s wind

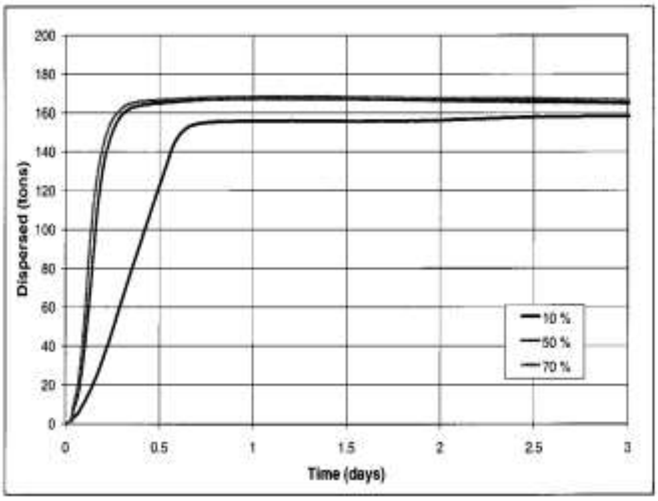

Figure 12. Dispersed oil over time for three values of instantaneous effectiveness for chemical response. Nearly no delay between application trips.

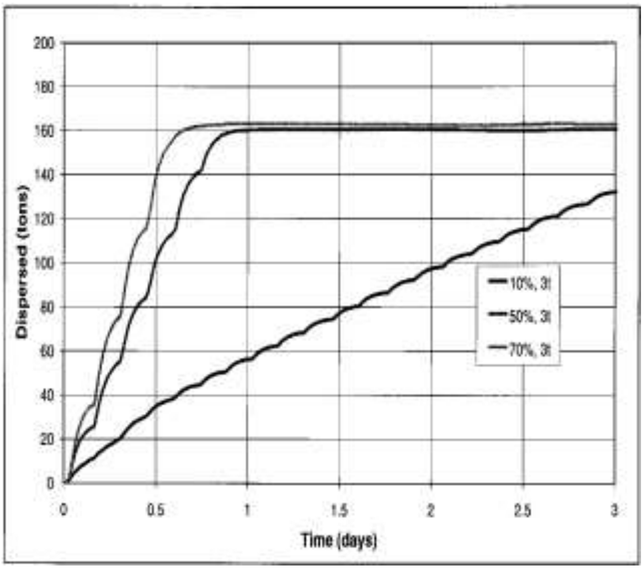

Figure 13. Dispersed oil over time for three values of instantaneous effectiveness for chemical response. Three-hour delay between application trips.

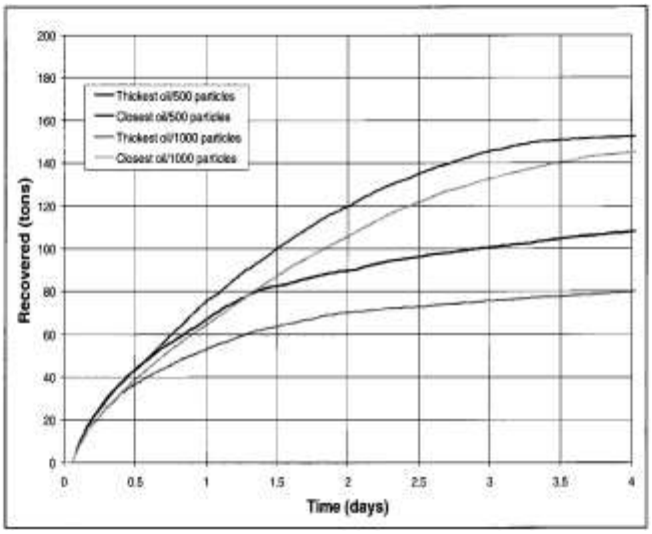

Figure 14. Recovered oil over time for two search criteria (closest and thickest oil) and two values for number of particles (500 and 1000)

- The spreading coefficient, K, is a key parameter in calculating areal coverage and mass balance. K is currently constant, but should vary with the viscosity of the oil (and thereby with the oil type and its emulsion formation properties).
- The minimum thickness for an oil slick has limited influence on areal coverage of thick oil and practically no influence on the mass balance. However, the total areal coverage, including sheen, is greatly affected by the minimum thickness.
- The number of particles used to represent an oil slick has a minor influence on the mass balance, to the extent that it has an influence on the simulation of response actions. Noise is introduced into the area calculations when too few particles are used. The noise is caused by natural dispersion being discretized in a whole number of particles, and increases with increasing wind speed (due to increasing natural dispersion).
- In calm weather, the effectiveness of mechanical clean-up only slightly affects the total amount of oil collected, but is decisive for the rate at which oil is collected. At higher wind speeds, the total amount of oil collected becomes a strong function of effectiveness, in that it competes with natural dispersion in removing oil from the surface.

- The effectiveness of mechanical clean-up strongly affects surface exposure in calm weather, but only slightly in rough weather.
- The amount of oil that is chemically dispersed by helicopter is more dependent on the delay due to refuelling and refilling than on the effectiveness of the dispersant. However, the amount of dispersant applied is directly dependent on the effectiveness.
- Oil spill response actions from boats may be sensitive to the number of particles used to represent the surface slick, depending on the search strategy specified.
- Oil spill response from aircraft, when the movement between different parts of the slick is very rapid, is not dependent on the number of particles used to represent the surface slick.
- In the simulations performed here, the threshold concentration for biological effects only influences the fraction of fish eggs and larvae in the interval of 0 to 40 ppb-hours, indicating that a higher fraction of the total population is affected with a decreasing threshold. For the fish eggs and larvae affected at a certain threshold, no shift toward higher exposures is seen when the threshold is lowered.

The sensitivity study has shown the model to be numerically robust.

The importance of specifying realistic search strategies for response vessels has also been made clear.

Description of the Facility

Preamble

Aiteo Eastern Exploration and Production Company Limited is the operator of OML29 and NCTL on behalf of itself and NNPC JV. The concession has an area extent of Circa 990sq km, while NCTL which carries products from the fields is 100km long, and is located in the heart of the Niger Delta in Bayelsa and Rivers States.

Development and Production History of OML 29 Fields

The concession consists of 9 fields including the iconic Oloibri field (1st Commercial Oil Discovery in Nigeria), which holds remaining reserves of over 1.5 billion bbls of oil and 2.5 Tcf of gas. It has 240mbpd and 50 MMscf/d of installed production capacity, most of which have been vandalized. Available data indicate that daily production from OML 29 peaked at over 100kbopd in 2002. Production from the OML and indeed most of the Niger Delta wetlands began to suffer from 2004, and was almost nil from 2008 to 2012 due to armed conflict, unrest, militancy and damage to oil facilities in the Niger Delta. Currently, Nembe Creek, Santa Barbara and Odeama Fields are producing oil and gas. AEEPCo records for February 29th 2016 show a collective production of about 75,733 bopd and 40.98million scf (MMscf)/d. Other fields in the concession include Oloibiri, Okoroba and Kugbo West, which are located in the fresh water forest north of the OML.

Causes of Oil Spills

The causes and circumstances of oil spills are varied, and their analyses provide valuable insights for managing risk. This information is, however, difficult to obtain as data is sometimes inconsistent or not available, particularly for small spills. For this analysis, the primary causes of oil spills greater than 7 tonnes have been grouped into Allisions/ Collisions, Groundings, Hull Failures, Equipment Failures, Fires and Explosions, Others and Unknown. Figure 15, below, provides an overview of the causes by size of spill. Events such as heavy weather damage and human error have been categorised as "Other" and spills where the relevant information is not available have been designated as Unknown and are reported but excluded from the analysis.

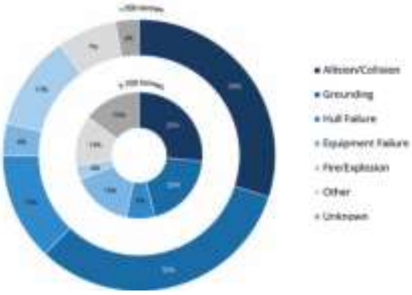

Figure 15. Oil Tanker Spill Statistics 2022

Figure 15, provides an overview of the causes by size of spill. Most oil spills (>7 tonnes) recorded between 1970 and 2022 were caused by Allisions/Collisions and Groundings. it is evident that whilst the overall number of spills has reduced over the decades, the proportion of those that arise from Allisions/Collisions has increased and those due to Groundings have decreased. It also demonstrates a decrease in the proportion of spills caused by Hull Failure, with a significant drop after the 1990s and none recorded so far this decade. The outlook for this decade is, however, uncertain, with only three years of data recorded. The most frequent causes of oil spills (>7 tonnes) from tankers are Allisions / Collisions and Groundings

Vessel Operation at Time of Spill

In the following analysis, the operation that the vessel was undertaking at the time of the incident is explored. Reporting of large spills (>700 tonnes) tends to provide more information and greater accuracy than smaller spills. Vessel operations have therefore been grouped into Loading/Discharging, Bunkering, At Anchor (Inland/ Restricted waters), At Anchor (Open water), Underway (Inland/Restricted waters), Underway (Open water), Other Operations and Unknown Operations.

Oil Spill Incidents

From 2004 to 2011 excluding minor leakages from 'tapped' joints from illegal bunkering, oil spills recorded in the area was over 110 bbl affecting of 10 ha of land, some of which have been remediated. No data spill is available until recently when three spills (Odeama Well 9, Santa Barbra Well 1 and NCTL at Botokiri) occurred resulting in the release of 1464.5 bbl into the environment. Which is the subject of this study.

Impacts of Oil Spills on Environments

The health hazards created by oil exploration and exploitation are covert and slow in action. They are not given the deserved attention in official documents in Nigeria, even as they can be major contributors to the disease burden in oil-bearing communities. This study would focus on interpretation of the data reported in several published studies on crude oil spills in the Niger delta region, Nigeria. An average of 240,000 barrels of crude oil are spilled in the Niger delta every year, mainly due to unknown causes (31.85%), third party activity (20.74%), and mechanical failure (17.04%). The spills contaminated the surface water, ground water, ambient air, and crops with hydrocarbons, including known carcinogens like polycyclic aromatic hydrocarbon and benxo (a) pyrene, naturally occurring radioactive materials, and trace metals that were further bioaccumulated in some food crops. The oil spills could lead to a 60% reduction in household food security and were capable of reducing the ascorbic acid content of vegetables by as much as 36% and the crude protein content of cassava by 40%. These could result in a 24% increase in the prevalence of childhood malnutrition. Animal studies indicate that contact with Nigerian crude oil could be hemotoxic and hepatotoxic, and could cause infertility and cancer. The oil spills in the Niger delta region have acute and long-term effects on human health. Material relief and immediate and long-term medical care are recommended, irrespective of the cause of the spill, to ensure that the potential health effects of exposures to the spills are properly addressed.

MATERIALS AND METHODS

Every time an oil spill occurs, the public loses faith in authorities and oil companies' capacity to implement preparedness and response decisions to mitigate impacts (Walker, A.H.; Pavia, R.; Bostrom, A.; Leschine, T.M.; Starbird, K.2015, 21, 667–690). The severity of impacts typically depends on the quantity and type of oil spill, the ambient conditions, and the sensitivity of organisms and their habitats to the oil. When crude oil is spilled on the sea, an oil slick is formed, i.e., a thin oily layer floating on the sea surface, affected by the large-scale advective processes dominated by currents, winds, and waves leading to centre of mass slick transport (order of tens to hundreds of meters per day), and the slow, low-scale, diffusive processes reshaping the slick (order of centimetres to meters per day) responsible for modifying contaminants' concentration. The time scales and relative importance of the processes depend on spill-specific and environmental factors such as the quantity of oil spilled, the oil's initial physico-chemical characteristics, and meteorological and sea state conditions. In parallel, a series of natural, complex, and self-competing processes, referred to as "oil weathering processes" (OWPs), tend to degrade the slick. As hydrocarbons are non-conservative pollutants, their physicochemical characteristics change over time as a result of OWPs. Spreading, evaporation, dispersion/diffusion, emulsification, and dissolution are the most crucial OWPs, acting at the early stages of the oil spill, while photo-oxidation, biodegradation, and sedimentation act in the longer term and determine the ultimate fate of the oil spilled. Oil density and viscosity are the parameters mostly altered by the OWPs after spillage.

Oil pollution may not only occur on the sea surface, but also in deeper waters, leading to even more extensive environmental impacts. The on-going exploitation of deep-water oil reserves and the installation of pipelines at high water depths increase the risks of accidental oil release from well blowouts and pipeline ruptures. Major deep-water oil spill accidents caused by such occurrences are the 2010 Deepwater Horizon oil spill in the Gulf of Mexico, discharging approximately 492,000 to 627,000 tons of oil, and the 2011 Penglai 19-3 oil field spill in the Bohai Sea, China, discharging ~200 tons.

Several oil spill models are extensively used at the global level to simulate the evolution of an oil spill. These models may range from simple vector-based calculations, such as the DHI oil spill model within MIKE, to the modern, new-generation, operational, three-dimensional (3D) numerical models, coupled to meteorological, hydrodynamic, and wave models, forecasting in high-resolution and with high precision the transport and fate of oil. The simulation of the transport and fate of an oil spill at sea, appraising the physicochemical processes that occur between the oil phase and the water column, forms the basis for the evaluation of the engendered environmental, social, and economic impacts. Thus, this study presents a state-of-the-art review on oil spill processes and their parameterization, and offers a critical comparison among the widely used oil spill models, in terms of their capacity to simulate the oil released from surface or submerged sources, the capacity to assimilate real-time field data to initiate model execution and correct the modelled forecasts in space and time, and the evaluation of uncertainty in the produced predictions. All of the above are crucial for the timely, efficient, and cost- effective response to oil spills and should be considered in the real-time management of such incidents. Finally, this work will provide technical recommendations and will propose potential advancements and improvements in oil spill modelling.

Oil Physical Transport and Weathering Processes The behaviour of an oil spill in the marine environment depends on a series of physical, chemical, and biological processes that are largely determined by both the properties of leaked oil and the environmental, hydro-meteorological conditions (wave, winds, currents, solar radiation, etc.), and discharge characteristics (instantaneous/continuous, surface/deep-water). The fate and behaviour of an oil spill can be influenced by the physicochemical oil weathering processes: oil spreading, evaporation, emulsification, dissolution, photo-oxidation, biodegradation, and sedimentation, and the physical transport processes, like transport and turbulent mixing, dispersion, and resurfacing (see Figure 15).

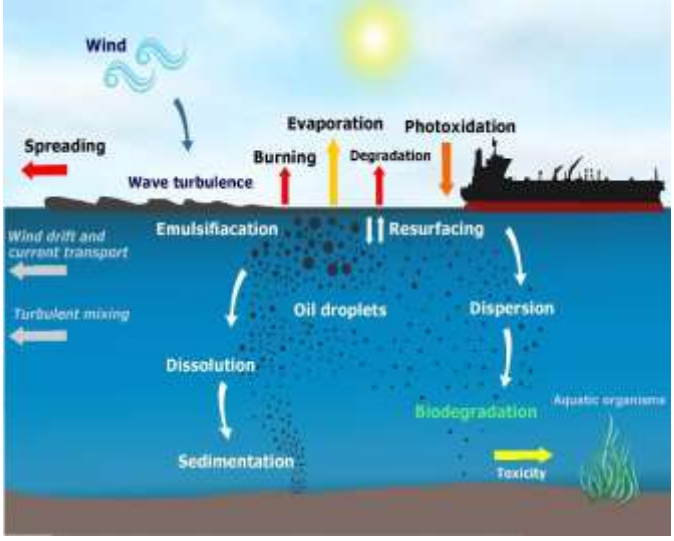

Figure 16. Main transport and weathering processes (OWPs) affecting the oil spill.

Oil Weathering Processes

Spreading Algorithms

Spreading refers to the creation of a thin film, expanding over the sea surface, as soon as oil is being released. Spreading algorithms in oil spill models provide an estimate of the spill thickness or surface area, used for modelling of many transport and fate processes such as evaporation, dispersion, and emulsification. Spreading rate and oil spill thickness depend on the sea surface temperature, oil viscosity, and density.

The most widely-used spreading algorithms have been developed by Fay and Hoult. The theory of gravitational spreading against viscous resistance is also followed in the Mackay’s fate algorithms, modified versions of which are widely used in operational oil spill models (e.g., MEDSLIK, MEDSLIK-II). Advanced oil spreading algorithms consider processes such as wind shear stresses, turbulent mixing and wave

Field sampling Activities

Thermosteel Nigeria Limited was mobilized to field for sampling from 23/9/2020 – 8/10/2020 and laboratory analysis followed thereafter. Sampling involved collection of samples from the various environmental matrices including surface water, sediment, ground water, soil, vegetation, plankton, benthos and fisheries. A total of

Three Hundred and Eighty-Four (384) samples of soil, sediment, surface water, plankton, benthos and vegetation were collected. Socioeconomic and health studies were also carried out through interviews, questionnaire administration, literature and walk through surveys.

RESULTS AND DISCUSSIONS

Crude Oil Characterization and Fingerprinting

The chemical fingerprinting analyses of the reference crude oil taken from Santa Barbara Well-1, were compared with oil extracted from the alleged contamination soil samples from the four communities, namely Owukubu, Amgbakiri, Shellkiri and Diepreye. The diagnostic ratios recorded for the samples were compared to those of reference oil with the sole aim of determining the source of the spilled crude oil. Result show that the oil extracted from these communities were similar to the reference oil except that of Shellkiri that was of a different origin.

Climate and Meteorology

Climate and meteorological parameters including rainfall and humidity, sunlight radiation and temperature, wind speed, turbulence and direction etc., influence the impact and fate of oil spills. The study area lies within the humid tropical zone with defined dry (November – March) and wet (April – October) seasons. The wet season is brought about by the South-West trade wind blowing across the Atlantic Ocean. This begins around April and stretches to October. September and October are the peak months of flood in the area. The flood gradually recedes from November. The dry, dusty and often cold North-East trade blowing across the Sahara Desert dominates the dry season and brings a short period of harmattan. This starts around November and terminates in March. In general, the weather regime in the area is determined primarily by geographical location in relation to the fluctuating position of the Inter-Tropical Convergence Zone.

Surface Water

Odeama Well-9

Surface water reaction values varied with sampling points. Its pH values ranged from 6.77 to 7.42, with an average value of 7.18. These values fall within the FMEnv set maximum allowable limit of 40.00mg/l for surface water. Also, salinity (determined as chloric) ranged between 2419.00mg/l and 7705.00mg/l with an average value of 4060.13mg/l – indicating the water bodies in this area are brackish as the chloride levels across the sample stations exceeded 2000mg/l. The dissolved oxygen, biological oxygen demand and chemical oxygen demand values recorded mean values of 5.64mg/l, 5.91mg/l and 15.93mg/l respectively. Total suspended solids' concentrations varied from 20.00mg/l – 440.00mg/l with mean value of 138.75mg/l, which is higher than the FMEnv set limit of 40.00mg/l for surface water bodies in Nigeria. The water bodies recorded low concentration levels of Total Petroleum Hydrocarbon (TPH) across the study area with values ranging from 0.22mg/l to 18.58mg/l with a mean value of 2.63mg/l, except at two points close to the spill point, SW1 – 18.58mg/l and SW2 – 10.88mg/l. Polynuclear aromatic hydrocarbon and BTEX were below the detection limit (0.001mg/l) of the analytical instruments. Heavy metal ions were obtained in traces and compare favourably with the control sample with mean levels of 0.93mg/l and 0.13mmg/l for Fe2+, Fe3+ and Zn2+ respectively. Other metals (Pb2+, Hg2+, V2+ and Ba2+) were below their respective detection limits. Cd2+ and Ni2+ had concentration lower than the regulatory limits. Total heterotrophic bacteria and total fungi were of mean population loads of 1.77 x 104cfu/ml and 1.07 x 104 cfu/ml respectively. The HUB and HUF loads were low, indicating low petroleum hydrocarbon level in the surface water matrix and vis a vis effective degradation of petroleum hydrocarbon in the water bodies of the oil contaminated area.

Santa Barbara Well-1

The water bodies at and surrounding vicinity of Santa Barbara well-1 were fairly acidic with pH values ranging from 6.2 – 6.8 (mean value = 6.5). The dissolved oxygen demand (COD) mean values were 5.69mg/l, 6.44mg/l and 13.14mg/l respectively. Total Suspended Solids varied from 20.00mg/l – 320.00mg/l with mean concentration of 16.33mg/l – a value which exceeded 40m/l maximum limit set for an aquatic environment. Exchangeable cations recorded mean value of 244.86mg/, 83.85mg/l, 161.66mg/l and 1188.35mg/l for Ca2+, Mg2+, K+ and Na+ respectively. Also, total petroleum hydrocarbon levels ranged from 0.22mg/l to 12.58mg/l (mean = 1.78mg/l) while Polynuclear Aromatic Hydrocarbon (PAHs) and BTEX were below the detection limit (0.001mg/l) of the laboratory analytical instruments. Heavy metal ions were also obtained in traces and compared favourably with the control sample, with mean levels of 0.66mg/l and 0.11mg/l for Fe2+, Fe3+ and Zn2+ respectively. Other metals (Ni2+, Hg2+, V2+ and Ba2+) were below their respective detection limits. Cd2+ and Pb2+ had concentrations lower than the regulatory limits. Total heterotrophic bacteria load ranged from 1.03 – 2.09 x 104 cfu/ml with an average value of 1.67 x 104 cfu/ml while total fungi load ranged from 1.00 – 1.25 x 104 cfu/ml with an average population load of 1.04 x 104 cfu/ml.

GROUNDWATER QUALITY

Groundwater potability tests were carried out on the borehole water samples collected from Okioku Tweni, Owukubu and Ikensi communities. The pH of the groundwater ranged from 6.4 – 7.6 (mean = 6.9). The mean pH value of 6.9 indicates that the groundwater from the region is within the WHO/FMEnv permissible values of 6.5 – 8.5 for drinking water. The conductivities ranged from 95.40µS/cm - 1066µS/cm with a mean value of 461.44µS/cm. Similarly, total dissolved solids varied from 50.56mg/l to 564.98mg/l with a mean value of 244.56mg/l. The dissolved oxygen, TSS, COD and Salinity varied from 4.50mg/l – 5.10mg/l, 40.00mg/l – 240.00mg/l (mean = 136.00mg/l), 7.90mg/l – 9.15mg/l (mean = 8.49mg/l) and 8.83mg/l – 318.00mg/l (mean = 105.92mg/l) respectively. The TPH, BTEX and PAHs level were below the analytical instruments' detection limit of 0.001mg/l. Hence there was no problem hydrocarbon contamination of the groundwater.

The first approach deals with the mass and momentum conservation equations applied to the oil slick or with a convection-diffusion equation. In this latter, the diffusive part of the equation illustrates the spreading of oil and the convective terms describe the advection of oil through currents and wind. On the other hand, the Lagrangian models discretize oil slicks as a large number of particles advected by the merged result of winds, waves, and currents, but also being transported via dispersion. Researchers have shown that Lagrangian models are more appropriate for prompt simulations, when oil spill accidents occur, and consequently are easier, more efficient, and computationally more cost-effective than the Eulerian approaches.

SEDIMENT

Odeama Well-9 Spill Site

Sediment acidity ranged between pH values of 2.7 and 6.3, with a mean value of 4.2. The inorganic nutrients were in moderate concentrations sufficient to suppor aquatic plants and benthic organisms. The anions namely; sulphate, nitrate and phosphate were in mean concentration levels of 161.88mg/kg, 9.85mg/kg and 2.13mg/kg respectively. Total petroleum hydrocarbon levels varied from 15.48mg/kg at Okpokiri community to 2512mg/kg the spill site. Relatively high levels of petroleum hydrocarbon were recorded in the sediment sample collected from close vicinity of the spill site, but were below the intervention value (5000mg/kg). BTEX was practically absent (<0.001mg/kg) across all the sampling stations, including the affected communities while PAHs ranged from <0.01mg/kg – 0.02mg/kg. The PAHs concentration levels were far below the set Target value of 1.0mg/kg for soil and sediment. Heavy metals concentrations were below their respective DPR intervention values and are also comparable with the control values. Microbiological analysis revealed that total heterotrophic bacteria loads ranged from 1.40 – 3.55 x 104cfu/g with an average of 2.30 x 104cfu/g while total fungi load ranged from 1.15 – 1.34 x 104cfu/g with an average population load of 1.34 x 104cfu/g. These microbial loads compare favourably with population loads recorded at the control points.

Santa Barbara Well-1

The sediment samples were acidic across the sampling stations, including the control point. Its values ranged from 3.1 – 6.0 with an average value of 4.5. Total organic carbon and total nitrogen contents were of mean values of 0.74% and 1.28% respectively. Also, nitrate ranged from 0.86mg/kg – 18.12mg/kg, phosphate; 0.72mg/kg – 4.62mg/kg while sulphate varied from 173mg/kg – 278.00mg/kg. Total petroleum hydrocarbon and PAHs were recorded in concentrations range of 1.57mg/kg (Tweni community) – 1523mg/kg (Spill Point) with a mean value of 413.09mg/kg and 0.02mg/kg – 0.85mg/kg (mean = 0.74mg/kg) respectively. BTEX were, however, below the detection limit (0.001mg/kg) of the analytical equipment. TPH and PAHs were obtained in concentration levels below their intervention values. Heavy metals' level (mg/kg) were in mean values of 17437, 47.38, 23.14, 18.63, 1.04, 15.48 and 13.38 for Iron, Zinc, Chromium, Lead, Cadmium, Nickel and Copper respectively. However, Barium, Arsenic, Vanadium and Mercury were practically absent in the sediment across all the sample stations, even as other metals' concentrations were below the respective Intervention values. Microbiological analysis revealed that TBH, TF, HUB and HUF were in average population loads of 2.20 x 104cfu/g, 1.41 x 104cfu/g, 1.01 x 102cfu/g and 0.67 x 102cfu/g respectively. Hydrocarbon utilizers are considered present in moderate population loads capable of further degradation of petroleum hydrocarbon in the bottom sediment across the study area.

NCTL Sediment Properties

The pH values of the sediment and control stations were within acidic scale, with values ranging from 2.2 – 5.3. The percent total organic carbon ranged from 0.62% - 1.40% with a mean value 0.95%. Nitrate ranged from 2.16mg/kg to 32.79mg/kg while phosphate levels varied from 0.46mg/kg – 5.13mg/kg with a mean value of 2.20mg/kg. Total petroleum hydrocarbon levels were low across the study area, including the communities, with values ranging from 10.06mg/kg to 154.20mg/kg. Lowest concentration (10.06mg/kg) of TPH was recorded in sediment taken from Dasaba community while Borokiri and Seriakiri had 125.80mg/kg and 10.27mg/kg respectively. The recorded TPH levels in sediment samples with the spill impact zone were, summarily, far below it set Intervention limit of 5000mg/kg. The BTEX and PAHs were practically absent across the sampling station. The most abundant metal was Fe with concentration levels ranging from 12690mg/kg – 22150mg/kg, followed by Zinc (16.80mg/kg- 40.20mg/kg); Chromium (7.40mg/kg – 14.80mg/kg), Lead (7.70mg/kg – 13.80mg/kg); Nickel (3.8 – 8.70mg/kg) and Copper (2.20mg/kg) and Nickel (Ni) 3.80mg/kg – 7.40mg/kg. Recorded concentrations of heavy metals in the sediment samples taken across the study area were below their respective intervention values. Microbiological examination of sediment revealed TBH population loads that ranged from 2.00 – 4.00 x 104cfu/g, with an average population load of 2.91 x 104cfu/g while TF ranged from 1.00 – 3.00 x 104cfu/g with a mean value of 1.80 x 104cfu/g. Presence of hydrocarbon degraders (HUB and HUF) in sediment shows possibility of furtr biodegradation process of petroleum hydrocarbon in the study area.

SOIL

Odeama Well-9 Oil spill

The pH of the soil varied from strongly acidic to alkaline with values that ranged from 2.5 – 8.3 for the topsoil and 2. – 7.7 for bottom soil. Total organic carbon and total nitrogen levels varied from 0.06 – 1.26% and 0.02 – 1.75% respectively in the topsoil and from 0.01 – 1.36% and 0.02 – 2.39% respectively in the bottom soil. Furthermore, inorganic soil nutrients in topsoil recorded average concentrations levels of 201.85mg/kg for sulphate, 28.66mg/kg for nitrate and 1.73mg/kg for phosphate while the bottom soil had 186.27mg/kg, 23.41mg/kg and 2.94mg/kg respectively. The topsoil and bottom soil recorded total petroleum hydrocarbons (TPH) which ranged from 15.48mg/kg and 4804mg/kg and 19.76mg/kg to 5922mg/kg respectively, while polynuclear aromatic hydrocarbons (PAHs) concentrations ranged from 0.02mg/kg – 1.20mg/kg in the topsoil and 0.15mg/kg – 1.80mg/kg in the bottom soil. The levels of BTEX across the sample stations were below the equipment detection limit of <0.01mg/kg. Total hydrocarbon concentrations in the topsoil and bottom soil at each of the sample stations were below the Intervention value of 5000mg/kg. Heavy metals levels in the topsoil ranged from 7520mg/kg – 28120mg/kg, 3.20mg/kg – 66.00mg/kg, 6.70mg/kg – 34.40mg/kg, 0.10mg/kg – 1.10mg/kg, <0.001 – 0.60mg/kg, 2.20mg – 34.90mg/kg and 4.70mg/kg – 33.80mg/kg for Fe, Zn, Cr, Pb, Cd, Ni and Cu respectively. Similarly, bottom soil contained metals in various concentrations ranging from 8970 – 19340mg/kg for Fe, 9.40 – 61.20mg/kg for Zn, 3.20 – 33.60mg/kg for Cr, 1.60 – 18.50mg/kg, 0.10mg/kg – 1.80mg/kg, 2.40mg/kg – 32.20mg/kg for Ni and 2.50mg/kg – 31.80mg/kg for Cu. However, Mercury (Hg), Barium (Be) and Arsenic (As) levels were below the detection limit (0.001mg/kg) of the analytical equipment. All metals were in concentrations far below their respective Intervention values across the sample stations indicating that the spill site and even the affected communities' soils were not polluted with heavy metals resulting from the spill incident. Microbiological analysis revealed moderate population densities of the total heterotrophic bacteria (TPH), total fungi (TF), Hydrocarbon Utilizing Bacteria, and Hydrocarbon Utilizing Fungi. Presence of hydrocarbon utilizers in the study area reflects continuous degradation process and inturn cleansing of petroleum hydrocarbon in the affected oilspill soil strata.

Santa Barbara Well-1 Oil spill

The pH values of the topsoil in the hydrocarbon contaminated area varied between 2.08 and 6.80 with a mean level of 4.45 showing a slightly acidic property of the soils. This value was slightly higher than the pH of the soil from the control area which was 4.19. Extremely acidic conditions were recorded in the topsoil near the spill site and at the Amgbakiri community. Similar condition was also recorded for the bottom soil with pH values ranging from 2.70 – 7.90. The total organic contents (TOC) varied from 0.18 – 2.00 with a mean value of 0.79% in the topsoil while a range of 0.40 – 1.26% with a mean value of 0.88% was recorded in the bottom soil. Total nitrogen in the spill affected area varied from 0.02 – 2.48% (mean = 0.66%) and 0.03 – 2.45% (mean = 0.71%) for the topsoil and bottom soil respectively. Petroleum hydrocarbon levels varied from 19.76mg/kg (Tweni community) to 5922mg/kg (near the spill site) in the topsoil while it ranged from 18.24mg/kg – 4508mg/kg in the bottom soil. Mean TPH values were below the intervention value were below the PAHs

Intervention value of 40.0mg/kg. BTEX were however absent in the soil as its concentration was below the detection limit (0.001mg/kg) of the analytical instrument. Heavy metal concentration levels varied from 8659mg/kg – 2030mg/kg for Fe, 19.70mg/kg – 180.24mg/kg for Zn; 3.80mg/kg – 29.00mg/kg for Cr, 0.60mg/kg – 29.30mg/kg for Pb; 1.90mg/kg – 18.80mg/kg for Cu; 0.10mg/kg – 12.20mg/kg for Cd. Similarly, metals concentrations in the bottom soil varied from 8124mg/kg – 21250mg/kg, 23.30mg/kg – 239.64mg/kg, 9.70 -24.10mg/kg, 0.60 – 32.90mg/kg, 0.10mg/kg – 15.30mg/kg, 2.90mg/kg – 12.20mg/kg and 2.20mg/kg – 13.10mg/kg for Fe, Zn, Cr, Pb, Cd, Ni and Cu respectively. Mercury, Barium and Vanadium were below their minimum detection limit of 0.001mg/kg in both topsoil and bottom soil. Metals concentrations were below their respective Intervention values and compared well with the respective mean values recorded at the control site. The total heterotrophic bacteria (THB) and TF were of population densities across the ample station in the oil spill affected area. This is an indication of a visible community with capacity to mineralize organic matter, particularly the petroleum and petrogenic hydrocarbon in soil at various Depths.

24th Nembe – Cawthorne Channel Trunk Line (NCTL)

The pH values of soil samples varied from 3.0 – 7.8 (mean = 4.6) and 3.1 – 7.7 (mean = 4.4) for the topsoil and bottom soil respectively. The observed acidic conditions at the spill site could be due to produced organic acids specifically fluvic and humic acids from microbial degrading processes of the petroleum hydrocarbon. Total organic carbon (TOC) levels varied from 0.05 – 4.95% and 0.04 – 4.94% in the topsoil and bottom soil respectively. On the other hand, total nitrogen levels avenged 0.39% in the topsoil and 0.37% for the bottom soil. Total petroleum hydrocarbon levels in the topsoil ranged from 24.53mg/kg at Agneskiri, to 5201mg/kg at Botokiri. Furthermore, TPH concentrations in the bottom soil varied between 1.16mg/kg – 4801mg/kg with a mean value of 2035mg/kg. The TPH levels across the sampling stations, including the spill site, were below the Intervention value of 5000mg/kg. Polynuclear Aromatic Hydrocarbon concentration levels ranged between 0.01 – 8.56mg/kg (mean 0.96mg/kg) and 0.01 – 3.14mg/kg (mean 0.64mg/kg) in the topsoil and bottom soil respectively. As reported at the control station, BTEX concentration levels were absent across the sampling stations. Metals were recorded in concentrations below their respective Intervention values, across the sampling stations and compared favourably with values recorded at the control sites. The concentration abundance of heavy metals followed the same order, as Fe>Zn>Cr>Pb>Cu>Ni and Cd, in both top and bottom soils. Relatively high population densities of heterotrophs recorded in the soil is an indication of a viable community with capacity to mineralize organic matter. The hydrocarbon degrades (HUF and HUB) population densities were moderate and the ratios of HUF/TF and HUB/THB population percentage were below 10% indicating low degree petroleum hydrocarbon contamination in the soil layers of the study area.

Vegetation

Four (4) habitat types i.e., freshwater, mangrove swamp, secondary forest and modified grassland were identified in the study area. The vegetation in the area appears generally healthy, apart from the ones that were directly impacted by the spill, which are showing signs of stress.

Fisheries

The spills did not seem to negatively affect the counts and diversity of phytoplankton, zooplankton and benthic invertebrates. The counts were higher at the alleged spill site compared to the background. Total petroleum hydrocarbon levels recorded were 0.589mg/kg, 2.548mg/kg and 4.238mg/kg in the muscular tissue of dead fishes in Santa Barbara, Botokiri and Odeama respectively. On the other hand, polynuclear aromatic hydrocarbons and BTEX were below the detection limit of 0.001mg/kg. Heavy metals were within background levels.

Socio-Economics

The socio-economic measurement framework formed was developed to determine the impacts of the Santa Barbra Well 1, Odeama Well 9 and Botokiri pipeline spill incidents. The framework included both direct and indirect indicators, which were reviewed with AITEO prior to initiating the socio-economic post impact report. The study identified socioeconomic impacts of the Santa Barbra Well 1, Odeama Well 9 and Botokiri pipeline spill incidents on employment, economy, occupation/source of livelihood, local employment, political impact, socio impact, impact on cultural properties and increase in social vices etc.

CONCLUSION

Surface water, sediment, soil, fish and vegetation within the vicinity of the oil spill sites, contained higher than background levels of TPH and therefore adjudged to the negatively impacted by the oil. But the average concentration of hydrocarbons in the environment was lower than the intervention levels.

RECOMMENDATIONS

Increase security surveillance and protection of oil installations

Carry out frequent inspections and maintenance of oil installations

Discourage illegal crude oil bunkering and artisanal refineries through awareness campaigns, sensitization and enforcement

Carry out site delineation studies to determine the spatial extent of impact (Depth and spread), classify the scale of the spill into different categories (none, light, medium and heavy)

Carry out site remediation and restoration of the medium and heavily impacted areas and/or monitor since the concentration of TPH in the soil and sediment is below the intervention limit of 5000mg/kg

The Niger Delta region in South-South Nigeria, on Africa's West Coast, is densely populated. The region, which contains a substantial stock of crude oil and natural gas, has been nicknamed "the engine room" for Nigeria's economic development and progress. It is responsible for up to 90% of the country's economic growth (or gross domestic product/GDP). The region has multiple ecosystems, such as the aquatic environment, that are critical to the survival of the area's various habitats and living species. However, the same region has witnessed unjustifiable environmental pollution arising from oil activities over the years of exploration and production which has orchestrated negative consequences on the Niger Delta ecosystem. This has led to extended negative consequences on natural resources, which also have detrimental repercussions psychologically, ecologically, socially, economically, and physically which, in turn, impacts the overall health of the affected individuals. This write-up provides an overview of the major drivers of the oil leakage in Nigeria's Niger Delta ecosystem as well as the major impacts on the environment. It will also analyze numerous means of remediation in use and extend such for a more inclusive and productive option. Moreover, this review offers key measures that may help to maintain long-term policies for reducing adverse implications and increasing the living standard for the Niger Delta area's affected communities.

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