Oil Spill Disaster Monitoring Along Nigerian Coastline

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Key words: oil spill, disaster, monitoring

SUMMARY

In 1956, Royal Dutch Shell discovered crude oil at Oloibiri, a village in the Niger Delta, and commercial production began in 1958. Today, there are 606 oil fields in the Niger Delta, of which 360 are on-shore and 246 offshore. Nigeria is now the largest oil producer in Africa and the eleventh largest in the world, averaging 2.5 million barrels per day (bbl/d) in 2004. Nigeria's proven oil reserved is 35.2 billion barrels. Since the discovery of oil in Nigeria in the 1956, the country has been suffering the negative environmental consequences of oil development.

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. These processes include advection, turbulent diffusion, surface spreading, evaporation, dissolution, emulsification, hydrolysis, photo-oxidation, biodegradation and particulation. Oil spill models have the capability of predicting the three-dimensional evolution of oil, including entrainment, subsurface transport, sedimentation, and refloating of spilled oil.

A new oil spill trajectory model has been developed. The results from a hypothetical simulation from a point around OPL 250 located about 150km off the Nigerian coastline shows that the simulated oil spill for wet season reached the shore (around Penington River) after 104hours (about 4.5 days). Also during the dry season, the results from the model indicate that the oil spill reached the shore (at the entrance of Benin River) after 162hours (6.5days).

The Nigerian Sat 1 Satellite has joined the Disaster Monitoring Constellation. The Nigeria Sat-1, would help in monitoring oil spill by providing the spill position which would serve as input data into the oil spill model. A successful combating operation to a marine oil spill is dependent on a rapid response from the time the oil spill is reported until it has been fully combated. Information on the exact position and size of the oil spill can be plotted on maps in GIS and a priority of the combat efforts and means according to the identified coastal sensitive areas can be carried out. The creation of regional spill response centres along coastlines will help in managing oil spill. In order to assist the decision-makers in choosing the areas of priority, coastal sensitivity maps of Nigeria including areas of ecological and socio-economic interest must be produced at small scales.

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1. NIGERIAN COASTLINE

Nigeria is a maritime state with a coastline of approximately 853 km. Nigeria is located between Latitude 4^o and 14 ^{o} N and Longitude 2^o 45 and 14^o 30E. Nigeria is bordered to the North by the Republics of Niger and Chad, to the West by the Republic of Benin, to the East by the Republic of Cameroon and to the South by the Atlantic Ocean (Dublin Green et al, 1999).

Nigeria's total land and water area is 923,768 sq km, with the area of the land being 910,768 sq km while that of water is 13,000 sq km (CIA World Fact Book, 2005). Nigeria exercise sovereignty over its territorial sea which has its breadth up to a limit of 12 nautical miles; Nigeria has sovereign rights in a 200-nautical mile exclusive economic zone (EEZ) with respect to natural resources and certain economic activities, and exercise jurisdiction over marine science research and environmental protection (UNCLOS, 1982). Nigeria's continental shelve extends from the shore to the 200m depth (CIA World Fact Book, 2005).

The Nigerian climate is tropical, characterized by high temperatures and humidity as well as marked wet and dry seasons. The coastal areas has an annual rainfall ranging between 1, 500 and 4,000 mm (Kuruk, 2004).

The surface water of the Nigerian coast is basically warm with temperature generally greater than 24^oC. Sea surface temperatures show double peaked cycles which match quantitatively the cycle of solar heights. Between October and May, Sea surface temperatures range from 27^o-28^oC, while during the rainy season of June to October, the range is between 24^o and 25^oC. (Dublin Green et al, 1999)

The surface water is typically Oceanic surface water of the Gulf of Guinea with salinity generally less than 35.00% . In the Niger Delta, salinity range between 27-30% in January to March and 28 - 30% in June to September. This low salinity values are due to the influx of fresh water from the numerous estuaries of the Niger Delta. . (Dublin Green et al, 1999)

1.1 Hydrology of Nigeria

The hydrology of Nigeria is dominated by two great river systems, the Niger-Benue and the Chad systems. With the exception of a few rivers that empty directly into the Atlantic Ocean, all other flowing waters ultimately find their way into the Chad basin or down the lower Niger to the sea. The two river systems are separated by a primary watershed extending northeast and north-west from the Bauchi Plateau which is the main source of their principal tributaries. North-west of the plateau lie the elevated, drift-covered plains of central Hausa-land which is drained by numerous streams all flowing outwards to join the major tributaries (Kuruk, 2004).

Nigeria is blessed with a vast expanse of inland freshwater and brackish ecosystems. Their full extent cannot be accurately stated as it varies with season and from year to year depending on rainfall. However, the water resources are spread all over the country from the coastal region to the arid zone of the Lake Chad Basin. The country's extensive mangrove ecosystem, a great proportion of which lies within the Niger Delta and found mainly in the Rivers, Delta, Cross River, Akwa lbom, Lagos and Ondo States, is estimated to cover between 500,000 and 885,000 hectares. Freshwaters start at the northern limit of the mangrove ecosystems and extend to the Sahelian region (Kuruk, 2004).

The inland water system includes thirteen lakes and reservoirs with a surface area of between 4000 hectares and 550,000 hectares have a total surface area of 853,600 hectares which represents about one percent of the total area of Nigeria. They include lakes Chad, Kainji, Jebba, Shiroro, Goronyo, Tiga, Chalawa Gorge, Dadin Kowa, Kiri, Bakolori, Lower Anambra, Zobe and Oyan. With the exception of Lake Chad, all the lakes are man-made (Kuruk, 2004).

Deltas and estuaries, with their saline wetlands have a total surface area of 858,000 hectares, while freshwaters cover about 3,221,500 hectares. Other water bodies, including small reservoirs, fish ponds and miscellaneous wetlands suitable for rice cultivation cover about 4,108,000 hectares (Kuruk, 2004).

The entire Gulf of Guinea is highly stratified with a thin surface layer of warm fresh tropical water (Longhurst 1964). The stratification of the upper water column along the Gulf of Guinea is generally very strong except in areas subject to upwelling events.

In the Nigerian coastal waters, the upper limit of the thermocline is generally shallow about 12-15 m. The depth of the thermocline tends to increase with increasing distance offshore over the continental shelf (Dublin Green et al, 1999).

2. OIL EXPLORATION AND EXPLOITATION

Nations all over the world depend on oil and gas for fuelling of cars, generation of electricity and other domestic purposes. As the world population increases, the demand for oil and gas has also been increasing. In order to meet the pressing need for oil and gas, oil exploitation and exploration has been increasing at alarming rates.

In 1956, Shell British Petroleum (now Royal Dutch Shell) discovered crude oil at Oloibiri, a village in the Niger Delta, and commercial production began in 1958. Today, there are 606 oil fields in the Niger Delta, of which 360 are on-shore and 246 off-shore. These have been parceled out to the oil multinationals for extraction. Also, over 3,000 kilometers of pipeline lie across the landscape of the Delta, linking 275 flow stations to various export facilities (Adebanwi, 2001).

Nigeria is now the largest oil producer in Africa and the eleventh largest in the world, averaging 2.5 million barrels per day (bbl/d) in 2004. The Nigerian government plans to increase oil production to 3 million bb/d in 2006 and 4 million bbl/d in 2010.The country is also a major oil supplier to both Western Europe and the United States, with Asia and Latin America becoming increasingly important as well. In 2004, Nigerian crude exports to the United States averaged 1.1 bbl/d (Nigeria Country Analysis Brief, 2005).

Nigeria's economy is heavily dependent on earnings from the oil sector, which provides 20% of GDP, 95% of foreign exchange earnings, and about 65% of budgetary revenues (CIA World Fact Book, 2005).

Nigeria's state-held refineries (Port Harcourt I and II, Warri, and Kaduna) have a combined nameplate capacity of 438,750 bbl/d, but problems including sabotage, fire, poor management and lack of regular maintenance contribute to a low current capacity of around 214,000 bbl/d, according to World Markets Research Center. Plans for several small, independently-owned refineries are also being developed, with the Nigerian government planning for three new refineries to come onstream by 2008. The $1.5-billion Tonwei refinery in Bayelsa State appears set to be the first private refinery in Nigeria, with a planned initial capacity of 100,000 bbl/d. In October 2004, the government issued 13 licenses for the construction of additional private refineries. *(*Nigeria Country Analysis Brief, 2005*)*

Nigeria has six export terminals including Forcados and Bonny (operated by Shell), Escravos and Pennington (ChevronTexaco), Qua Iboe (ExxonMobil), Brass (Agip), and Bonny Island LNG (Nigeria LNG). Shell's Bonny terminal is currently undergoing a $600 million expansion and will export 1.5 million bbl/d after its completion in 2006. (Nigeria Country Analysis Brief, 2005)

2.1 Oil and Gas Reserves in Nigerian Coastal Areas

Oil and Gas Journal (2005) estimates Nigeria's proven oil reserved at 35.2 billion barrels. The Nigerian government plans to expand its proven reserves to 40 billion barrels by 2010. In February 2005, Nigeria announced the award of five oil blocks in the Joint Development Zone (JDZ), shared by Nigeria and neighboring Sao Tome and Principe (STP). The JDZ reportedly holds reserves of 11 billion barrels and could potentially yield up to 3 million bbl/d in the next 2-3 years. Development is also occurring in the waters surrounding the JDZ. *(Nigeria Country Analysis Brief, 2005)*

The majority of Nigerian reserves are found along the country's coastal Niger River Delta, with the majority of oil located in approximately 250 small (i.e., less than 50 million barrels each) fields. At least 200 other fields contain undisclosed reserves. Nigeria's crude oil reserves have gravities ranging from 21^{o} API (American Petroleum Institute) to 45^{o} API. Its main export crude blends are Bonny Light (37^{o} API) and Forcados (31^{o} API). Approximately 65 percent of Nigerian crude oil production is light (35^{o} API or higher) and sweet (low sulfur content) (Oil and Gas Journal, 2005).

According to (Oil and Gas Journal, 2005), Nigeria has an estimated 176 trillion cubic feet (Tcf) of proven natural gas reserves, giving the country one of the top ten natural gas endowments in the world and the largest endowment in Africa. In October 2004, Nigeria announced that its natural gas reserves could be as high as 660 Tcf. The government plans to raise earnings from natural gas exports to 50 percent of oil revenues by 2010. The World Bank estimated in November 2004 that Nigeria flares approximately 75 percent of the natural gas it produces due to a lack of infrastructure. Nigeria is the world's highest natural gas flaring country with 42.6 percent of its total annual natural gas production being flared. NNPC estimates that Nigerian flared natural gas accounts for approximately 20 percent of the world total. Official Nigerian policy is to end natural gas flaring completely by 2008 by collecting associated natural gas and processing it into liquefied natural gas (LNG) (Nigeria Country Analysis Brief, 2005).

2.2 Oil Spill Incidents in Nigeria

Oil spillage is categorized into four groups: minor, medium, major and disaster. The minor spill takes place when the oil discharge is less than 25 barrels in inland waters or less than 250 barrels on land, offshore or coastal waters that does not pose a threat to the public health or welfare. In the case of the medium, the spill must be 250 barrels or less in the inland water or 250 to 2,500 barrels on land, offshore and coastal water while for the major spill, the discharge to the inland waters is in excess of 250 barrels on land, offshore or coastal waters. The disaster refers to any uncontrolled well blowout, pipeline rupture or storage tank failure which poses an imminent threat to the public health or welfare (Ntukekpo, 1996).

Oil spill incidents have occurred in various parts and at different times along our coast. Some major spills in the coastal zone are the GOCON's Escravos spill in 1978 of about 300,000 barrels, SPDC's Forcados Terminal tank failure in 1978 of about 580,000 barrels and texaco Funiwa-5 blow out in 1980 of about 400,000 barrels. Other oil spill incidents are those of the Abudu pipe line in 1982 of about 18,818 barrels, The Jesse Fire Incident which claimed about a thousand lives and the Idoho Oil Spill of January 1998, of about 40,000 barrels. The most publicised of all oil spills in Nigeria occurred on January 17 1980 when a total of 37.0 million litres of crude oil got spilled into the environment. This spill occurred as a result of a blow out at Funiwa 5 offshore station. Nigeria's largest spill was an offshore well-blow out in January 1980 when an estimated 200,000 barrels of oil (8.4million US gallons) spilled into the Atlantic Ocean from an oil industry facility and that damaged 340 hectares of mangrove (Nwilo and Badejo 2005).

According to the Department of Petroleum Resources (DPR), between 1976 and 1996 a total of 4647 incidents resulted in the spill of approximately 2,369,470 barrels of oil into the environment. Of this quantity, an estimated 1,820,410.5 barrels (77%) were lost to the environment. A total of 549,060 barrels of oil representing 23.17% of the total oil spilt into the environment was recovered. The heaviest recorded spill so far occurred in 1979 and 1980 with a net volume of 694,117.13 barrels and 600,511.02 barrels respectively.

Available records for the period 1976 to 1996 indicate that approximately 6%, 25%, and 69% respectively, of total oil spilled in the Niger Delta area, were in land, swamp and offshore environments. Also, between 1997 and 2001, Nigeria recorded a total number of 2,097 oil spill incidents.

Thousands of barrels of oil have been spilt into the environment through our oil pipelines and tanks in the country. This spillage is as a result of our lack of regular maintenance of the pipelines and storage tanks. Some of these facilities have been in use for decades without replacement. About 40,000 barrels of oil spilled into the environment through the offshore pipeline in Idoho.

Sabotage is another major cause of oil spillage in the country. Some of the citizens of this country in collaboration with people from other countries engage in oil bunkering. They damage and destroy oil pipelines in their effort to steal oil from them. Pirates are stealing Nigeria's crude oil at a phenomenal rate, funneling nearly 300,000 barrels per day from our oil and selling it illegally on the international trade market. Nigeria lost about N7.7 billion in 2002 as a result of vandalisation of pipelines carrying petroleum products. The amount, according to the PPMC, a subsidiary of NNPC, represents the estimated value of the products lost in the process.

Illegal fuel siphoning as a result of the thriving black market for fuel products has increased the number of oil pipeline explosions in recent years. In July 2000, a pipeline explosion outside the city of Warri caused the death of 250 people. An explosion in Lagos in December 2000 killed at least 60 people. The NNPC reported 800 cases of pipeline vandalization from January through October 2000. In January 2001, Nigeria lost about $4 billion in oil revenues in 2000 due to the activities of vandals on our oil installations. The government estimates that as much as 300,000 bbl/d of Nigerian crude is illegally bunkered (freighted) out of the country.

In Nigeria, fifty percent (50%) of oil spills is due to corrosion, twenty eight percent (28%) to sabotage and twenty one percent (21%) to oil production operations. One percent (1%) of oil spills is due to engineering drills, inability to effectively control oil wells, failure of machines, and inadequate care in loading and unloading oil vessels.

3. TRANSPORTS AND FATE OF OIL SPILL

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. These processes include advection, turbulent diffusion, surface spreading, evaporation, dissolution, emulsification, hydrolysis, photo-oxidation, biodegradation and particulation. When liquid oil is spilled on the sea surface, it spreads to form a thin film – an oil slick. The movement of the slick is governed by the advection and turbulent diffusion due to current and wind action. 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. 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 (Tkalich et *al*, 2003).

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. After a long time, this mousse may disintegrate into lumps of tar. Heavy oil fractions may attach to suspended sediments and be deposited to the seabed, where the bacterial degradation is much slower. Tar balls and mousse present a small surface area compared with their volume and degrade extremely slowly for this reason. Given enough time, the combined actions of weathering and biodegradation can eliminate most of the spilled oil. Unfortunately, nature does not always have enough time. The result is that oil may wash up on beaches or into biologically sensitive tidal areas or estuaries, causing severe damage (Tkalich et *al*, 2003).

3.1 Oil Trajectory and Fate Models for Oil Spill Disaster Monitoring

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 (Rossouw, 1998).

Two approaches for computing oil spills trajectories are commonly encountered in the literature; Lagrangian models and Eulerian models. The Lagrangian models consist basically in representing the oil slick by an ensemble of a large number of small parcels which are advected by a velocity which results from a combination of the action of winds and currents. Then, the slick is divided into pie shaped segments or strips, depending if the form of the slick is nearly circular or elongated. Fay (1969) spreading formulas are then applied to each segment. For the Eulerian approach, two model are usually encountered, those based on the mass and momentum equations applied to the oil slick (Hess and Kerr (1979), Benqué et. al . (1982)), and those based on a convection-diffusion equation (Venkatesh (1988) among others), in which the diffusive part of the equation represents the spreading of oil by itself and the convective terms represents the advection of oil by currents and winds (Paladino and Maliska, 2000).

It is common practice to use Eulerian coordinates for solution of the partial differential equations in environmental hydraulics, in contrast to the tracking of the oil slick drifting that traditionally employs the Lagrangian approach. The Eulerian method appears to be used more frequently in future, because of the increasing need to couple the pollutant transport and chemical kinetics equations with (Eulerian) hydrodynamic models (Tkalich et *al*, 2003).

Many models have been developed to predict the motion of marine oil spills. In these models the external inputs for each time step include factors such as:

i. Amount of oil spilled.
ii. Type of oil spilled.

iii. Location of oil spill source.
iv. Wind magnitude and direction at each location.
v. Current magnitude and direction at each location.

Given these data, the model can predict future world states, that is the distribution of oil on water at each time step (Jungfun & Jan, 1995).

There are few models available for managing oil spill incidents. Some of these models are developed abroad whereas a handful of them are developed locally. The major features of these models are:
i. to predict the weathering of spilled oil.
ii. to model the sub-surface transport of spilled oil.
iii. to predict the probability of various areas being imparted by a spill from a given site.
iv. to asses the vulnerability of sites to oiling
v. to model the effects of different oil clean-up scenarios.
vi. to perform risk assessments for the important resources.
vii. to assist in search and rescue operations.

Some of the software developed and in use for oil spill management are those developed by Hang et al (1989), Kung et al (1997), OILMAP, SIMAP, Coastal Zone Oil Spill model (COZOIL), Computer Model at S.L. Ross, Canada, Multiphase Oil Spill Model (MOSM), and Nigerian Oil Spill Model (NOSM).

The physical, chemical, and biological processes governing the transport and fate of oil spill are described below. Advection is the mechanism for transporting oil while the fate of oil spill is governed by spreading, evaporation, dissolution, entrainment, emulsification, biodegradation, photosynthesis, sedimentation and shoreline deposition.

3.2 Advection

Advection is the main mechanism that governs the drifting of suspended oil and surface oil slick. The advection of suspended oil is the movement of oil droplets entrained in the water column due to the water current (Reddy and Brunet, 1997).

Some models include two mechanisms to advect or move the oil; these mechanisms are wind drift and currents. Some of these models specify a fixed percentage of the wind speed directly downwind for advection of oil on water.

3.3 Spreading

Spreading determines the area extent of the surface oil, which in turn affects the weathering of the oil. Spreading results from turbulent diffusion and the balance of gravity, inertia, viscosity and surface tension forces.

In most models, Fay's spreading theory of 1971 is used. In Fay's theory oil spill is considered to pass through three phases. In the first phase, only gravity and inertial forces are important. In the second phase, the gravity and viscous forces dominate. The last phase is governed by the balance between surface tension and viscous forces. To apply this theory, the geometry for the oil slick is simplified into either one-dimensional or radial form. The criteria to determine the geometry of the oil slick is through the calculation of the aspect ratio. When the Aspect Ratio is less than 3, the radial spreading will be used. Formulas for spreading laws and rates of these two forms are given by the model.

3.4 Evaporation

Evaporation can be the largest contribution to oil weather removal, and depends on the type of oil, spill area, oil slick thickness, vapour pressure and mass transport coefficient. These in turn are composition of the oil, wind speed and temperature. Mackay Evaporative Exposure formula developed by (Mackay, 1980) is mostly used to calculate the evaporate rate of the oil.

3.5 Dissolution

This is the process in which soluble hydrocarbons enter the water column from the surface slick or entrained oil droplets. Dissolution accounts for much less of the mass balance than evaporation, except perhaps under ice. NOSM uses the Mackay and Leinonen algorithm for dissolution of oil. The method of (Cohen *et al*, 1980) and (Juang and Monastero, 1982) is used by (Hang et al, 1989).

3.6 Entrainment

This is a physical process in which oil particles are transported from the sea surface into the water column due to breaking waves. The entrained oil is broken down into droplets of varying sizes which spread and diffuse into water column. Entrained oil is subject to enhanced dissolution and biodegration. Entrainment is greater during periods of higher wave energy. The Mackay expression is used by NOSM.

OILMAP modeled entrainment or natural dispersion by using Delvigne and Sweeney's (1988) formulation. The entrainment coefficient is a strong function of oil viscosity and is based on a curve fit to data given in Delvigne and Hulsen (1994).

Two options are available in COZOIL for simulating entrainment: one developed by Mackay *et al*. (1980a,b) and a second developed by Audunson (1979) and modified by Spaulding *et al*. (1982).

3.7 Emulsification

This is the process by which water is mixed with oil, forming a "chocolate mousse" type compound that dramatically increases the oil/water mixture volume and increases viscosity. Formation of water-in-oil emulsions depends on oil composition and sea state. The emulsified oil can contain as much as 80% water, with water droplets dispersed within a continuous phase of oil. NOSM, OILMAP and COZOIL formulation on emulsification are based on a function of evaporative losses and changes in water content, which is based on Mackay et al (1980, 1982).

3.8 Biodegradation

This is slow oil loss due to the ingesting and metabolizing of oil by various marine organisms. The amount of oil that can be biodegraded ranges from 11% to 90%. The variability is due to the variations in organisms for different locations, and the variation in oil components. NOSM includes a first order decay process in which the rate of oil biodegraded is proportional to the initial mass and an empirical decay coefficient.

3.9 Photosynthesis

This is the decay of oil through photon excitement of the oil. Typically it is not an important process but can be included in oil trajectory and fate models.

3.10 Sedimentation

This process occurs when the specific gravity of oil increases over that of sea water. Several processes ca cause this to occur, including weathering (evaporation, dissolution and emulsification), zooplankton ingestion, adhesion or sorption onto suspended particles, or interaction with the shoreline. Sedimentation is usually not important for mass balance calculations unless the concentration of suspended matter is high (>100mg/l). NOSM can model sedimentation as a “constant-rate” process.

The oil sedimentation algorithm by OILMAP is described in French et al (1994), ASA(1996) and Kirstein et al (1985). The rate of change of the volume of oiled sediments is expressed in terms of the product of the oil concentration, the suspended sediment concentration and an empirical reaction rate constant. If suspended particulate concentrations are below 100mg/l, no sedimentation occurs. Suspended sediment concentrates above 100mg/l are typical of highly turbid riverine and coastal waters and rarely occurs in shelf or oceanic flows. The settling velocity of the oil sediment is estimated using a modified Stokes law, which is dependent on the oil-sediment droplet size and density.

3.11 Shoreline Deposition

Oil shoreline interaction formulation by OILMAP is modeled based on a simplified version of Reed et al (1989) which formulates the process in terms of a shore type dependent holding capacity and exponential removal rate. The holding capacity and removal rates are also dependent on oil viscosity. The shoreline is specified in terms of eleven separate type classes: rocky, wave cut platforms, four classes of beach (fine and coarse sand, mixed sand and gravel, gravel, cobble),tidal flats, sheltered coastal areas (rocky, tidal flat, marsh), and glaciers.

The fate of spilled oil that reaches the shoreline depends on characteristics of the oil, the type of shoreline, and the energy environment. Even when beached, oil will continue to weather. However, several additional processes become important: reflotation, penetration into the substrate, and retention/transport in the beach-groundwater system. Erosion of oiled substrate from the beach may also occur.

The amount of oil which can be deposited onshore is a function of the area of the shore exposed to tide and wave action. COZOIL defines a beach width and angle (slope) for each type of shoreline which is then used in the calculation of exposed area.

NOSM simulates the shoreline deposition through an exponential decay function. The movement of oil slick in the model actually represents the movement of the centroid of the slick.

3.12 New Oil Spill Model

We developed a new oil spill trajectory mathematical model capable of simulating oil transport along our coastal waters. In developing this new mathematical model, we considered the major factors responsible for transporting and advecting oil on water. The assumption made in our work is that oil will not mix with water, and that the density of oil spill is less than that of water, thus the oil spill will move on water and not sink. The work is also limited to oil spill on open coastal water or deep sea. We made no attempt to model the movement of oil spill on land or on swamps.

Advection is the main mechanism that governs the transportation of suspended and surface oil slick. The combined effects of the following factors advect oil on water:

1. Wind drift current
2. Waves
3. Tides
4. Ocean Current
5. Longshore Current

The advection factors used in the model are described in the following subsections.

3.12.1 Wind Drift Current

The equation for the wind drift current is based on hyberbolic equations given by Officer (1976). The direction of the wind drift current is the sum of the wind direction and a deflection angle. The deflection angle of the wind drift current depends on latitude (Buranapratheprat and Tanjaaitrong, 2000).

3.12.2 Eulerian Surface Waves Drift

Sobey and Barker (1996) gave reliable estimates of surface kinematics. Higher order theory for stokes waves predicts that the water particle subject to uniform periodic waves will be transported in the direction of the wave advance. Since the water particle speed (u) given by stokes is the same as the horizontal water particle speed (u), stokes water particle speed was integrated into the Eulerian surface wave drift velocity equation given by Sobey and Barker (1996) to get the speed of the Eulerian surface wave.

3.12.3 Tides

The tidal amplitude and phase for this work is based on the results of Schwiderski's global ocean tidal model and contained in Splaudling et al (1987). The tidal amplitudes and tides were input data into the equations for the speed of tide given by Nelkon and Parker (1982).

In a tide wave the horizontal motion, i.e. the particle velocity, is called the *tidal stream*. The vertical tide is said to *rise* and *fall*, and the tidal stream is said to *flood* and *ebb*. If the tide is progressive, the flood direction is that of the wave propagation. If the tide is a standing wave, the flood direction is inland or toward the coast (Canadian Hydrographic Service, 2005).

3.12.4 Ocean Currents

The ocean currents affecting the Nigerian coastal area include the following:

(a.) Surface eastward flowing Guinea Current.
(b.) Subsurface westward and northward flowing Benguela Current.
(c.) Easterly flowing surface North Equatorial Counter Current.

Reddy and Brunnet (1997) gave the 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. The reversal is believed to be due to effects of the Benguela Current. The mean eastward velocity for the NECC is 15 cm s^{-1}. This increases to speeds of more than 30 cm s^{-1} in the Guinea Current (Arnault, 1987). The greatest flow for the NECC occurs in the boreal summer with eastward speeds of up to 29 cm s^{-1}, which are reduced during the spring. There is a reversal of a majority of the current's flow in the western part of the basin during the early months of the year (Arnault, 1987).

During the Dry season, the Benguela current moves the oil spill. Shannon (1985) gathered all available information about surface speed from previous studies and calculated the mean speed of the Benguela Current to be 17 cm s^{-1}. (Wedepohl et al. 2000) found that the mean speeds of the current vary from <11 cm s^{-1} to a maximum of 23 cm s^{-1}.

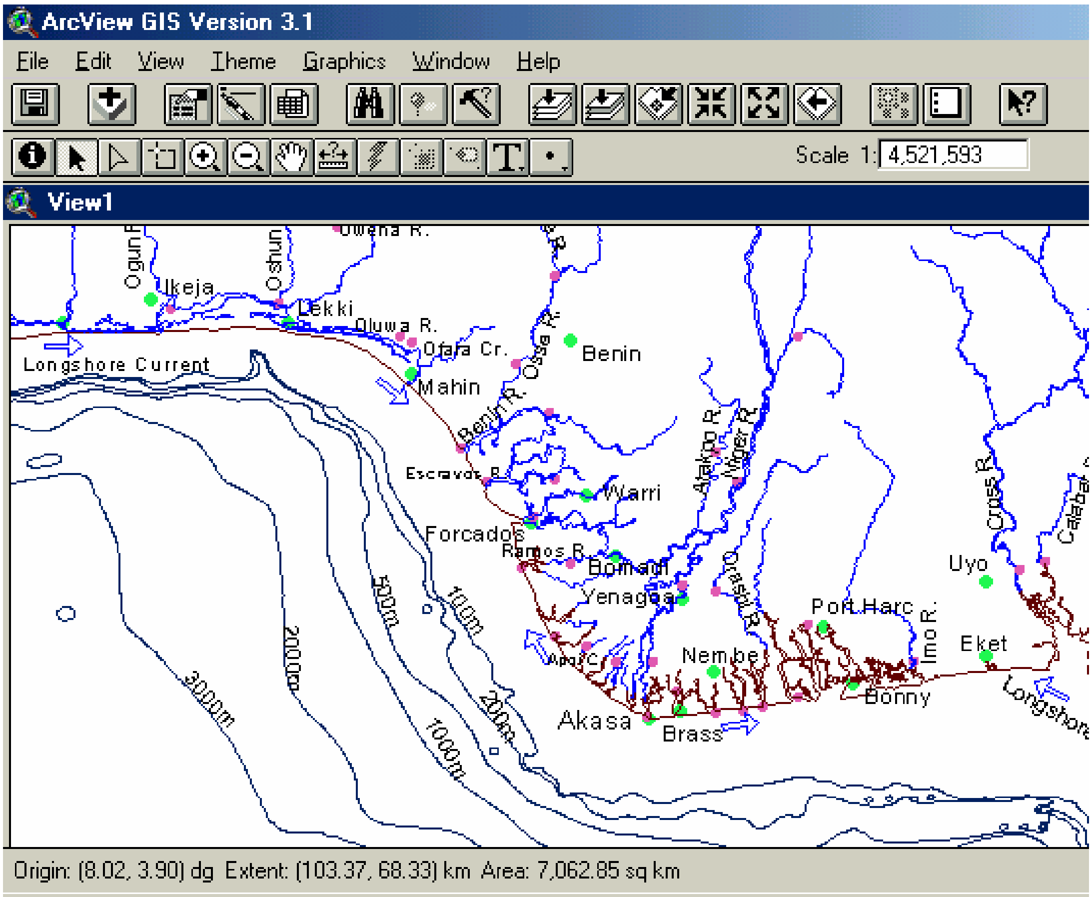
3.12.5 Longshore Currents

The longshore current speed for the work is based on Ibe and Antia, (1983). The longshore current direction for the model is based on Dublin Green et al (1997). Three main longshore drift directions along the Nigerian Coastline were specified by Dublin Green et al (1997). These directions are:

i. The west-east littoral drift along the western coastline.
ii. The littoral drift off the north western flank of the Niger Delta.
iii. The west-east littoral drift between Akasa point and the Calabar estuary.

The Longshore current directions are given in Figure 3.0 below.

Figure 3.0: Longshore Current Directions Along Nigerian Coastline



3.12.6 New Oil Spill Advection Model

The vector sums of the speed and directions of wind drift current, Eulerian surface wave drift, tides, ocean current and longshore current considered above will move the oil along our coastal waters. These vector sums is the model's advection speed and direction, and are given by the equations below.

$$S_{NM} = \sqrt{((S_{WDC} \text{Cos } \theta_{WDC} + S_{SWD} \text{Cos } \theta_{SWD} + S_{TIDE} \text{Cos } \theta_{TIDE} + S_{OC} \text{Cos } \theta_{OC} + S_{LC} \text{Cos } \theta_{LC})^2 + (S_{WDC} \text{Sin } \theta_{WDC} + S_{SWD} \text{Sin } \theta_{SWD} + S_{TIDE} \text{Sin } \theta_{TIDE} + S_{OC} \text{Sin } \theta_{OC} + S_{LC} \text{Sin } \theta_{LC})^2)} \quad \ldots\ldots.3.1$$

$$\theta_{NM} = \text{Tan}^{-1} (S_{WDC} \text{Sin } \theta_{WDC} + S_{SWD} \text{Sin } \theta_{SWD} + S_{TIDE} \text{Sin } \theta_{TIDE} + S_{OC} \text{Sin } \theta_{OC} + S_{LC} \text{Sin } \theta_{LC})/(S_{WDC} \text{Cos } \theta_{WDC} + S_{SWD} \text{Cos } \theta_{SWD} + S_{TIDE} \text{Cos } \theta_{TIDE} + S_{OC} \text{Cos } \theta_{OC} + S_{LC} \text{Cos } \theta_{LC}) \quad \ldots\ldots.3.2$$

Where

S_{WDC} = Speed of wind drift current
θ_{WDC} = Direction of wind drift current
S_{SWD} = Speed of Eulerian surface wave drift current
θ_{SWD} = Direction of Eulerian surface wave drift current
S_{TIDE} = Speed of tide
θ_{TIDE} = Direction of tide.
S_{OC} = Speed of ocean current.
θ_{OC} = Direction of ocean current.
S_{LC} = Speed of longshore current
θ_{LC} = Direction of longshore current

In addition to the new model developed, we also looked into existing equations governing the fate of oil on water. We incorporated equations for the rate of spreading and evaporation of oil spill on water to our model. These equations are the most important factors in the determination of the fate of oil spill. Fay's (1971) spreading theory is used in the model. In the model, oil spill is assumed to spread radially under steady gravity and viscous forces, thus Fay's radial spreading formula for gravity and inertial forces is used. The formula developed by Mackay (1980) is used to calculate the evaporate rate of oil in the model.

The new trajectory model and the existing fate model was written in the Visual Basic Environment (Windows based). This was done so as to make the model user friendly, by making use of its powerful graphical user interface. Programming in the visual basic environment also enables us to link the model with a base map of the Nigerian coastal areas in a MapInfo GIS environment.

3.12.7 Study Area and Hypothetical Simulations of Oil Spill Position with the Model

An hypothetical spill site around OPL 250 located about 150km off the Nigerian coastline was chosen as the study area. The actual spill position is longitude 4^o 30' 46.20" E and latitude 4^o 25' 39.80" N.

Simulations were made for wet and dry seasons for the study area above. The simulations for the wet and dry seasons were done in four phases for each season. For phase one, simulations were made from the spill point up to a point around the 100m isobath. In phase two, simulations were made from the point around the 100m isobath to a point about 20km to the coastline. Simulations for phase three were made from the point about 20km to the coastline up to another point about 10km to the coastline. Simulations for the last phase were made from the point about 10km to the coastline up to the coastline. The reason for making the simulations in four phases is that the effect of tides is negligible for the deep sea, while the tidal effect increases as one moves closer to the coastline. We have to vary the amplitudes and phases of tides along the coastal waters.

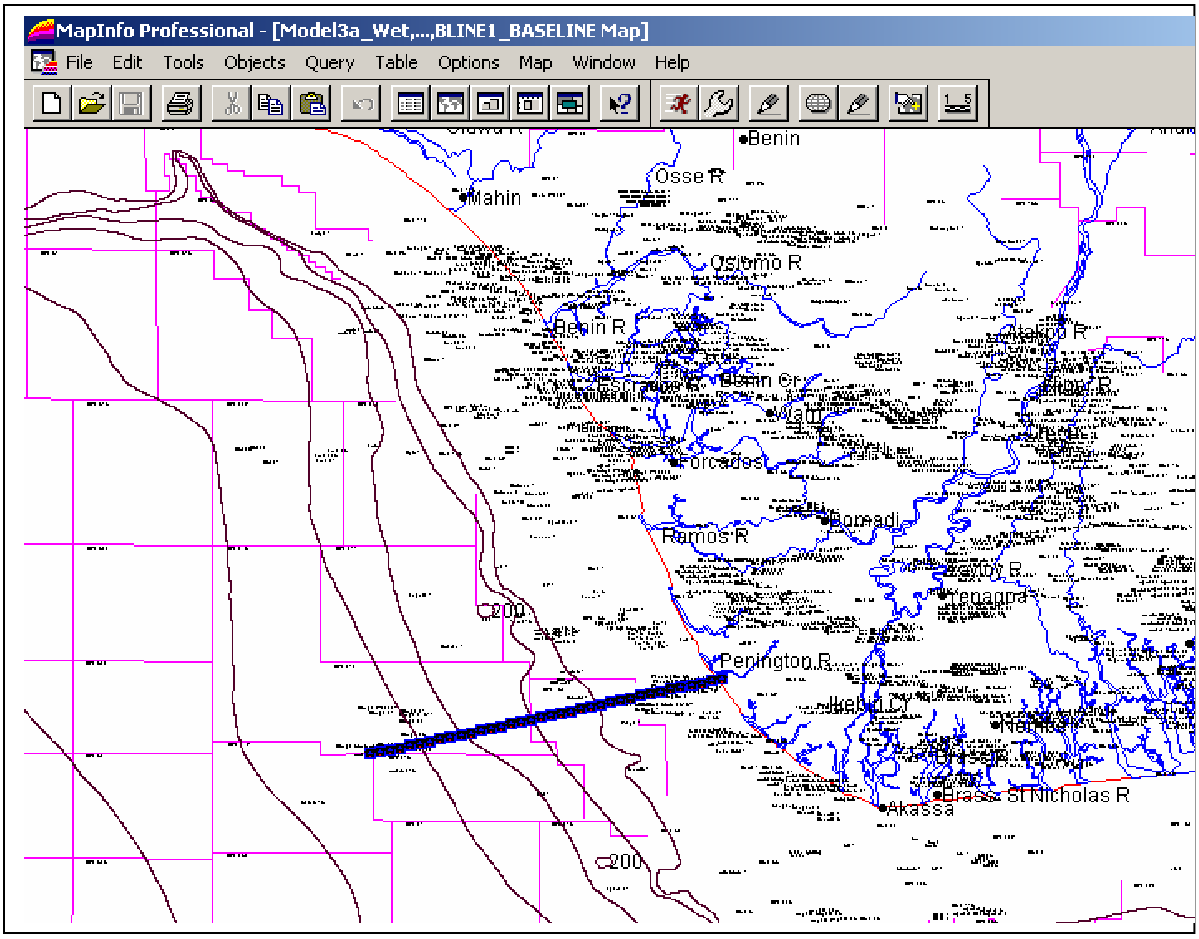
The simulated oil spill points for all the four phases for the wet season were plotted in MapInfo GIS software which is linked with the model in Visual Basic environment. The Oil Spill Trajectory for the wet season is shown in Figure 3.1 below.

The result of the simulation for wet season shows that the oil spill moves slower in deep sea and faster between the distance of 10km to 20km from the shoreline. The reason for this is that in the deep sea, there is no tidal effect while the tidal effect is prevalent in the 10km to 20km region. Also, the net effect of the longshore current and tides increased the speed of the oil spill near the shoreline.

Tides and ocean currents are the major factors responsible for oil spill movement along our coastline during the wet season. For the study location above, the magnitude of effective current velocity and directions remained the same throughout the four phases. The magnitudes of these are .223m/s and 90^o respectively.

Wind drift current and waves are secondary factors for moving oil spill during the wet season. The wind drift current remained constant for the four phases. The wind drift current is 1.94% of the wind speed in deep water, 0.81% of wind speed in shallow water. The wind drift velocity tends to zero along the coastline. The wave velocity increases as one moves towards the shoreline. The magnitude of the wave velocity is lower than that of the wind drift in the first three phases, but higher than that of the wind drift current in the fourth phase. The effect of waves is negligible in deep sea (1000m+) but cannot be dispensed with in shallow sea or near the coastline.

Figure 3.1: Oil Spill Trajectory for the Wet Season

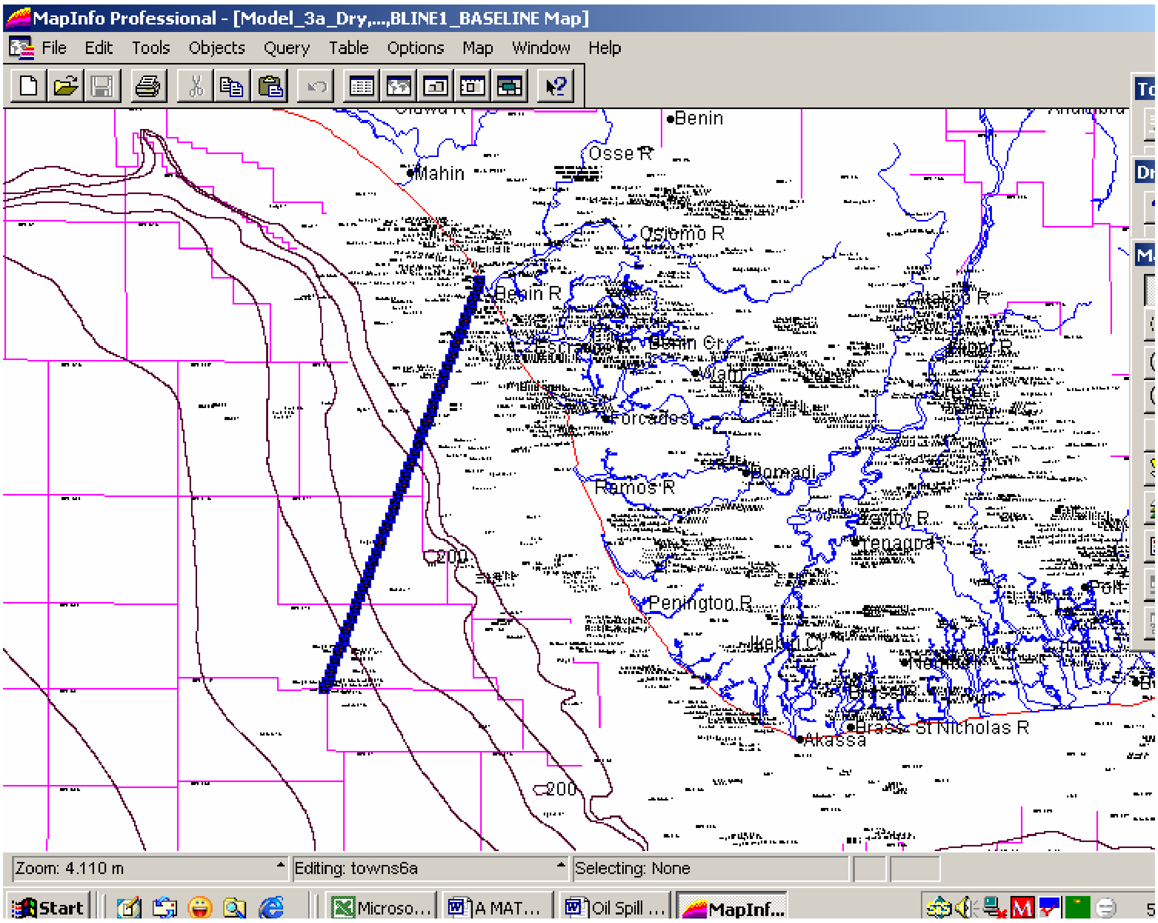


The simulated oil spill for wet season reached the shore (around Penington River) after 104hours (about 4.5 days). The oil spill will continue to move along the shoreline towards Escravos (i.e. in the direction of the longshore current). When the tide is high, the oil spill will move into the coastal lands and negatively impact the ecosystem.

By the end of the 104 hours a total of 94,525.660barrels of oil would have evaporated. This amount represents 16.88% of the 560,000 barrels of oil spilt. In addition the Slick area at the end of the 104hours would be 1782.058km^2.

The simulated oil spill points for all the four phases for the dry season were plotted in MapInfo GIS software which is linked with the model in Visual Basic environment. The Oil Spill Trajectory for the dry season is shown in Figure 3.2 below.

Figure: 3.2: Oil Spill Trajectory for the Dry Season



The result of the simulation for dry season shows that the oil spill moves also moves slower in deep sea and faster between the distance of 10km to 20km from the shore line during the dry season. The reason for this is that in the deep sea, there is no tidal effect while the tidal effect is prevailent in the 10km to 20km boundary. Also, the net effect of the longshore current and tides increased the speed of the oil spill near the shoreline.

Tides and ocean currents are also the major factors responsible for oil spill movement along our coastline during the dry season. For the study location above, the magnitude of effective current velocity and directions remained the same throughout the four phases. The magnitudes of these are .17m/s and 0^o respectively. Oil spill moves slower during the dry season. The reason for this is that the magnitude of the ocean current is lesser during the dry season.

Wind drift current and waves are also secondary factors for moving oil spill during the dry season. The wind drift current remained constant for the four phases. The wind drift current is about 2.% of the wind speed during the dry season. The wave velocity increases as one moves towards the shoreline. The magnitude of the wave velocity is lower than that of the wind drift in the first three phases, but higher than that of the wind drift current in the fourth phase. The effect of waves is negligible in deep sea (1000m+) but cannot be dispensed with in shallow sea or near the coastline. The oil spill trajectory for the dry season is shown in Figure 4.1.

The results from the model for dry season indicate that the oil spill reached the shore (at the entrance of Benin River) after 162hours (6.5days). The oil spill would then move towards Forcados (i.e. in the direction of the longshore current) around where its flow would be affected by the longshore current coming from Penington end. The oil spill would be stationary at this point, and move into the coastlands during high waters.

By the end of the 162 hours a total of 147241.894barrels of oil would have evaporated. This amount represents 26.293% of the 560,000 barrels of oil spilt. In addition the slick area at the end of the 162hours would be 1628.440km^2.

4. OIL SPILL DISASTER MANAGEMENT

The Federal Government, oil companies and non-governmental agencies have made several efforts to manage oil spill disaster along our coastline. These efforts are discussed in the following sections

4.1 Nigerian Government Action

To reduce the rate of oil incidents along the Nigerian Coast particularly as a result of vandalisation, the Federal Government through an act of the National Assembly created the Niger Delta Development Commission (NDDC). Part of the responsibilities of the Commission is to develop a master plan for the development of the Niger Delta, provide infrastructure and create an enabling environment for industrialisation and employment. There are also several other laws dealing with issues related to oil pollution in the environment. Furthermore, standards for the development of the environmental sensitivity index maps for the coast of Nigeria have been developed by the Environmental Systems Research Institute (ESRI). These standards are to be used by all the oil companies to prepare ESI maps for their areas of operations in Nigeria.

A number of Federal and state agencies deal with the problems of oil spill in Nigeria. The agencies include: the Department of Petroleum Resources (DPR), the Federal Ministry of Environment, the State Ministries of Environment and the National Maritime Authority.

A National Oil Spill Detection and Response Agency (NOSDRA) has been formed and approved by the Federal Executive Council of Nigeria. The Ministry of environment, which initiated the Agency, has also forwarded to the federal executive council for approval, the reviewed draft National Oil Spill Contingency Plan (NOSCP) which the Agency would manage (Alexandra Gas and Oil Connections, 2006)

The establishment of the contingency plan and the agency was in compliance with the International Convention on Oil Pollution Preparedness, Response and Cooperation (OPRC90) to which Nigeria is a signatory. According to the ministry's sources, the draft bill on the NOSDRA was being put together and would be forwarded to the National Assembly to be enacted into law (Alexandra Gas and Oil Connections, 2006).

Apart from intensifying efforts towards compliance monitoring and enforcement of oil and gas regulations and standards, the ministry is also mounting pressure on the oil and gas operators for a gas flare-out. Effort is also being made, according to the sources, to ensure the use of environmental-friendly drilling fluid and mud systems (Alexandra Gas and Oil Connections, 2006)

There is a need to create serious awareness among the populace on the implications of oil spill incidents on the environment. Governments must assist the rural communities in claiming their rights on oil spills and ensure that digital ESI maps are readily available for managing oil spill maps. Government should have strict rules for local oil tankers that would ply our coastal and inland waters as a result of the new cabotage law that is just being passed into law in the country (Nwilo & Badejo, 2005).

4.2 Efforts of the Oil Companies and Non Governmental Agencies

Due to increasing awareness in preventing and controlling spills in Nigeria, the Clean Nigeria Associates (C.N.A.) was formed in November 1981. The C.N.A. is a consortium of eleven oil companies operating in Nigeria, including N.N.P.C. The primary purpose of establishing the C.N.A is to maintain a capability to combat spills of liquid hydrocarbons or pollutants in general (Nwilo & Badejo, 2005).

Oil spillage can also be treated or removed by natural means, mechanical systems, absorbents, burning, gelling, sinking and dispersion. Oil spillage can be removed by natural means through the process of evaporation, photochemical oxidation and dispersions (Wardley-Smith, 1977). Bioremediation can also be used for managing oil spill problems (Hoff, 1993; Prince, 1993; Atlas, 1995). In addition, apart from the mechanical and chemical oil spill cleaning methods that have been used in managing oil spill problems, oil spill models have on several occasions being used to manage oil spills on the Nigerian Coast (Nwilo & Badejo, 2005).

4.3 Nigerian Sat 1

The Nigerian Sat 1 Satellite has joined the Disaster Monitoring Constellation, an international early-warning satellite network transmitting real-time information about droughts, earthquakes, deforestation and man-made disasters observable from space. The Nigeria Sat-1, an Orbit Satellite for geographical mapping, would also help to check the perennial problem of oil pipeline vandalisation, and assist in combating and managing oil spill incidents. The Nigeria Sat-1, would help in monitoring oil spill by providing the spill position which would serve as input data into the oil spill model. It would also give the extent of coastal water and coastal areas polluted. These information are vital for quick clean up of oil impacted areas.

4.4 International Co-operation

Cracking down on smugglers has proved difficult. To shore up the fight against oil smugglers in Nigeria, the US has donated three 56 metre (180ft) refitted World War two-era patrol oats to the navy. United Nations has also said that United States would donate additional four vessels. The Pentagon is funding each boat's refurbishment to the tune of $3.5m. The efforts of the Federal Government with the assistance of the US are already yielding fruits. The Nigerian Navy has intercepted several tankers.

4.5 Geographic Information System for Managing Oil Spill Incidents

A successful combating operation to a marine oil spill is dependent on a rapid response from the time the oil spill is reported until it has been fully combated. In order to reduce the response time and qualify the decision-making process, application of Geographic Information Systems (GIS) as an operational tool has been suggested. Information on the exact position and size of the oil spill can be plotted on maps in GIS and a priority of the combat efforts and means according to the identified coastal sensitive areas can be carried out. GIS offers opportunities for integration of oil drift forecast models (prediction of wind and current influence on the oil spill) in the computer program framework (Milaka,1995).

Required information for oil spill sensitivity mapping can be depicted on a set of thematic maps using GIS even though they can in theory be depicted onto a single sheet. With the use of a GIS, however, all the relevant information or themes can be stored in the system and produced onto maps in a format that befits the needs of the day. Alternatively, modeling exercises using the GIS can be conducted to assess the adequacy of any given oil spill contingency plan (Parthiphan, 1994).

The creation of regional spill response centres along coastlines will help in managing oil spill problems (Smith and Loza, 1994). The centres will use oil spill models for combating oil spill problems. Using data collected with an airborne system to input one or several new starting point(s) into the model, will improve the accuracy of the further predictions (Sandberg, 1996).

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In 1956, Royal Dutch Shell discovered crude oil at Oloibiri, a village in the Niger Delta, and commercial production began in 1958. Today, there are 606 oil fields in the Niger Delta, of which 360 are on-shore and 246 offshore. Since the discovery of oil in Nigeria in the 1956, the country has been suffering the negative environmental consequences of oil development. Sabotage is another major cause of oil spillage in the country.

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. These processes include advection, turbulent diffusion, surface spreading, evaporation, dissolution, emulsification, hydrolysis, photo-oxidation, biodegradation and particulation. Oil spill models have the capability of predicting the three-dimensional evolution of oil, including entrainment, subsurface transport, sedimentation, and refloating of spilled oil.

A new oil spill trajectory model has been developed. The results from an hypothetical simulation from a point around OPL 250 located about 150km off the Nigerian coastline shows that the simulated oil spill for wet season reached the shore (around Penington River) after 104hours (about 4.5 days). The oil spill will continue to move along the shoreline towards Escravos (i.e. in the direction of the longshore current). When the tide is high, the oil spill will move into the coastal lands and negatively impact the ecosystem.

By the end of the 104 hours a total of 94,525.660barrels of oil would have evaporated. This amount represents 16.88% of the 560,000 barrels of oil spilt. In addition the Slick area at the end of the 104hours would be 1782.058km^2.

Also during the dry season, the results from the model indicate that the oil spill reached the shore (at the entrance of Benin River) after 162hours (6.5days). The oil spill would then move towards Forcados (i.e. in the direction of the longshore current) around where its flow would be affected by the longshore current coming from Penington end. The oil spill would be stationary at this point, and move into the coastlands during high waters.

By the end of the 162 hours a total of 147241.894barrels of oil would have evaporated. This amount represents 26.293% of the 560,000 barrels of oil spilt. In addition the slick area at the end of the 162hours would be 1628.440km^2.

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 (Rossouw, 1998).

To reduce the rate of oil incidents along the Nigerian Coast particularly as a result of vandalisation, the Federal Government through an act of the National Assembly created the Niger Delta Development Commission (NDDC). Part of the responsibilities of the commission is to develop a master plan for the development of the Niger Delta, provide infrastructure and create an enabling environment for industrialisation and employment. There are also several other laws dealing with issues related to oil pollution in the environment. Also, standards for the development of the environmental sensitivity index maps for the coast of Nigeria have been developed by the Environmental Systems Research Institute (ESRI). These standards are to be used by all the oil companies to prepare ESI maps for their areas of operations in Nigeria.

5.2 Recommendations

The Nigeria Sat-1, would help in monitoring oil spill by providing the spill position which would serve as input data into the oil spill model. It would also give the extent of coastal water and coastal areas polluted. These information are vital for quick clean up of oil impacted areas.

In order to reduce the response time and qualify the decision-making process, application of Geographic Information Systems (GIS) as an operational tool has been suggested. Information on the exact position and size of the oil spill can be plotted on maps in GIS and a priority of the combat efforts and means according to the identified coastal sensitive areas can be carried out.

The creation of regional spill response centres along coastlines would help in managing oil spill problems (Smith and Loza, 1994). The centres will use oil spill models for combating oil spill problems. Using data collected with an airborne system to input one or several new starting point(s) into the model, will improve the accuracy of the further predictions

REFERENCES

Adebanwi Wale, (2001): Nigeria: Shell of a State. Dollars and Sense Magazine. http://www.thirdworldtraveler.com/Africa/Nigeria_Shell_State.html

Alexandra Gas and Oil Connections, (2006): Nigeria Forms Oil Spill Detection Agency. http://www.gasandoil.com/goc/news/nta40213.htm

Applied Science Associates, Inc.(ASA), (1996): Technical Manual for Spill Impact Modeling (SIMAP), Version W 1.0, Applied Science Associates, Inc, Narragansett, Rl.

Arnault, S., (1987): Tropical Atlantic geostrophic currents and ship drifts, Journal of Physical Oceanography, 18, 1050-1060.

Atlas, R.M., (1995): Petroleum Biodegradation and Oil Spill Bioremediation. Marine Pollution Bulletin 31, 178-182.

Audunson, T., (1979): Fate of oil spills on the Norwegian continental shelf. In: Proceedings of the 1979 Oil Spill Conference. API Publ. No. 4308, American Petroleum Institute, Washington, D.C.

Benque, J.P., A. Hauguel and P.L. Viollet, (1982): Engineering Application of Computational Hydraulics II. Pitman Advanced Publishing Program, London, pp. 57-63.

Buranapratheprat A. and S. Tanjaaitrong, (2000): Hydrodynamic Model for Oil Spill Trajectory Prediction. Chulanlongkorn University, Bangkok, Thailand.

Canadian Hydrographic Service, (2005)**:** Tides, Currents and Water Levels. Canadian Hydrographic Service. Canada.

CIA, (2005): The World Fact book -- Nigeria.htm

Cohen, Y., D. Mackay and W.Y. Shiu, (1980): Mass Transfer Rates Between Oil Slicks and Water. The Canadian Journal of Chemical Engineering. Vol. 58.

Delvigne, G.A. and L.J.M. Hulsen, (1994): Simplified Laboratory Measurement of Oil Dispersion Coefficient – Application in Computations of Natural Oil Dispersion. 17th Arctic and Marine Oil Spill Technical Program, June 8-10, 10, 1994, Vancouver, British Colombia, Canada, p. 767-784.

Delvigne, G.A and C.E Sweeney, (1988): Natural Dispersion of Oil, Oil and Chemical Pollution, Vol.4, p.281-310

Dublin-Green C.O., L.F. Awosika and R. Folorunsho, (1999): Climate Variability Research Activities In Nigeria. Nigerian Institute for Oceanography and Marine Research, Victoria Island, Lagos, Nigeria.

Dublin-Green C.O., A. Awobamise and E.A.Ajao , (1997): Large Marine Ecosystem Project For the Gulf Of Guinea (Coastal Profile Of Nigeria), Nigeria Institute of Oceanography Encyclopaedia Americana, 1994: International Edition, Grolier Incorporated.

Fay, J.A., (1969): The Spread of Oil Slicks on a Calm Sea. In Oil on the Sea. David P. Hoult ed., Plenum Press, New York, 53-63.

French, D. Howlett and D. Mendolsohn, (1994): Oil and Chemical Spill Impact Model System Description and Application. p 815-835 ln: Seventeenth Arctic and Marine Oilspill Program Technical Seminar ,Volume 2 June 8-10, 1994 , Coast Plaza Hotel, Vancouver, BC, Sponsored by Technology Development Directorate, Environmental Production Service, Environment Canada.

Hang, O., P. Evensen, and E.A. Martinsen, (1989): Oil Models for the South China Sea. Technical Report No. 70. Det Norslse Meteorologiske Institutt.

Hess, R.W. and C.L. Kerr, (1979): A Model to Forecast the Motion of Oil on the Sea. Proceedings of the Oil Spill Conference, pp 653-663.

Hoff, R., (1993): Bioremediation: An Overview of its Development and use for Oil Spill Clean up. Mar. POLLUT. Bull. 26, 476-481.

Ibe, A.C. and E.E. Antia, (1983): Preliminary Assessment of the Impact of Erosion Along the Nigerian Shoreline. Nigerian Institute for Oceanography and Marine Research, Technical Paper No. 13. Lagos.

Juang, J.C. and F.C. Monastero, (1982): Review of the State - of - the - Art of Oil Spill Simulation Models. Final Report Submitted to the American Petroleum Institute.

Jungfun,T. & Jan, W., (1995): Automatic Data Fudging and oil Spill Tracking. Department of Computer Science, Texas A&M University College Station.

Kirstein, B., J.R. Clayton, C. Clary, J.R. Payne, D. McNabb, G. Fauna, and R. Redding, (1985): Integration of Suspended Particulate Matter and Oil Transportation Study, Mineral Management Service, Anchorage, Alaska.

Kuruk, P., (2004): Customary Water Laws and Practices: Nigeria http://www.fao.org/legal/advserv/FAOIUCNcs/Nigeria.pdf.

Longhurst, A.R. (1964): The Coastal Oceanography of Western Africa. Bull. Inst. Afr. Noire. Ser. No. 2, p.337 - 402.

Mackay, D., W.Y. Shiu, K. Hossain, W. Stiver, D. McCurdy and S. Peterson, (1982): Development And Calibration Of An Oil Spill Behavior Model, Report No. CG-D-27-83, U.S. Coast Guard, Research and Development Center, Groton, CT.

Mackay, D., S. Peterson and K. Trudel, (1980): A Mathematical Model of Oil Spill Behavior, Department of Chemical Engineering, University of Toronto, Canada, 39pp.

Mackay, D.,S. Paterson and S. Madeau, (1980): Calculation of the evaporation rate of volatile liquids. In Proceedings, National Conference on Control of Hazardous Material Spills, Louisville, Kentucky, p. 361-368.

Mackay, D., I. Buist, R. Mascarenhas and S. Paterson, (1980a): *Oil Spill Processes And Models*, Report EE-8, Environment Protection Service, Canada.

Mackay, D., S. Paterson and K. Trudel, (1980b): A Mathematical Model Of Oil Spill Behavior, Department of Chemical and Applied Chemistry, University of Toronto, Canada.

Mikala K., (1995): Use of GIS as a Tool for Operational Decision Making, Implementation of a National Marine Oil Spill Contingency Plan for Estonia.Carl Bro International a/s, Glostrup, Denmark.

Nigeria Country Analysis Brief, (2005): Nigeria Country Analysis Brief.htm

Ntukekpo D.S., (1996): Spillage: Bane of Petroleum, Ultimate Water Technology & Environment.

Nwilo, P.C. & Badejo O.T., (2005): Oil Spill Problems and Management in the Niger Delta. International Oil Spill Conference, Miami, Florida, USA.

Officers, C.B., (1976): Physical Oceanography of Estuaries (and Associated Coaster Waters). John Wiley and Sons, Inc., UK.

Paladino, E.E. and C.R. Maliska, (2000): Mathematical Modeling and Numerical Simulation of Oil Spill Trajectories on the Sea. Federal University of Santa Catarina Brazil.

Parthiphan, K., (1994): Oil Spill Sensitivity Mapping Using a Geographical Information System. Department of Geography, University of Aberdeen. EGIS Foundation.

Prince R., (1993): Petroleum Spill Nioremediation in Marine Environments. Critical Rev. Micobiol. 19(4), 217-242.

Reddy, G. S. and Brunet M., (1997): Numerical Prediction of Oil Slick Movement in Gabes Estuary. Transoft International, EPINAY/SEINE, Cedex, FRANCE

Reed, M., E., Gundlach, and T., Kana, (1989): A Coastal Zone Oil Spill Model. Development and Sensitivity Studies. Oil and Chemical Pollution, 5, 411-449.

Rossouw, M., (1998): Oil Spill Simulation: Reducing the Impact. START/IOC/LOICZ Workshop on Climate Change and Coastal Process in Cotonou, Benin, West Africa.

Sandberg, E.C., (1996): Development of Remote Sensing for Coast Guard Applications.Remote Sensing. No. 28, pp 12.

Shannon, L.V., (1985): The Benguela Ecosystem, I., Evolution of the Benguela, physical Features and processes. *Oceanography and Marine Biology*, 23, 105-182.

Smith, L.A. & L. Loza, (1994): Texas Turns to GIS For Oil Spill Management. Geo Info Systems. pp 48.

Sobey, R.J., & C.H. Barker, (1996): Wave- driven Transport of Surface Oil. Journal of Coastal Research, 13(2), 490-496. Fort Lauderdale (Florida).

Splaulding, M.L., Anderson, E., Isaji, T., Gundlach, E.R. and Murdat, M. (1987): Application of an Oil Spill Trajectory Model to Nigerian Coastal Waters. The Petroleum Industry and the Nigerian Environment.

Spaulding, M.L., K. Jayko and E. Anderson, (1982): Hindcast Of The *Argo Merchant* Spill Using The URI Oil Spill Fates Model. *Journal of Ocean Engineering*, 9(5): 455-482.

Tkalich P., M.K. Huda, and K.H. Gin, (2003): A Multiphase Oil Spill Model. *Journal of Hydraulic Research* Vol. 41, No. 2 (2003), pp. 115–125 http://www.iahr.org/publications/assets/JHR41-2/p2171.pdf

Venkatesh S., (1988); The Oil Spill Behaviour Model of the Canadian Atmospheric Environment Service, Part I, Atmosphere-Ocean, Vol. 26, pp 93-108.

Wardley-Smith J, (1977): The Control of Oil Pollution on the Sea and Inland Waters. Graham and Trotman Ltd, United Kingdom.
Wedepohl, P.M., J.R.E. Lurjeharms, and J.M. Meeuwis, (2000): Surface drift in the south-east Atlantic Ocean. South African Journal of Marine Science, 22, 71-79.

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