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A GIS Based Cost Distance Modeling for Oil Spill Hazard Assessment in the Coastal Areas of South Eastern Nigeria

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Abstract: As long as petroleum oil is exists, it will be discharged (accidentally or incidentally) in the environment especially in the area where the oil is found. As a hazard, oil spill puts the people and environment that it occurs in danger. Hence, it is better to better to prepare for a spill than to be caught unawares by it. Hazard assessment conveys information on the likelihood of future hazardous events in the specific environment concerned. It involves two main components temporal and spatial analysis. The objective of this study is to assess oil spill hazard using spatial analysis modeling techniques in South Eastern Nigeria; an environment plagued with lack of appropriate *in situ* oil spill historical data that can be used for the probabilistic modeling. Hazard sources and impedance surfaces are the two main components needed to model oil spill hazard in this study. The modeling environment was provided by cost distance tool in arcmap spatial analyst extension. Using each of the identified hazard sources, hazard surfaces were created to reflect the movement of oil over each impedance surface. The final hazard surface was created by prioritizing and weighting the hazard surfaces and finally zoning the resultant surface into hazard classes. The matrix of the final hazard surface shows the very high and high zones together with the high hazard zone form 63.75% of the study area while the moderate and marginal zone constitutes 36.25%. The information provided by the study is very effective in oil spill contingency planning.

Key words: Hazard assessment, impedance surface, cost distance, contigency planning, information, South Eastern Nigeria

INTRODUCTION

Oil spill which is the discharge of oil (intentionally or unintentionally) in the environment with the area of operation being the most directly affected. Records show that a lot of petroleum products that are spilled in Nigeria end up lost to the environment, thereby bringing negative consequences as they are never recovered (Ifeadi and Nwankwo, 1987).

Although, it may be impossible to know when the next spill is going to happen and the amount that is likely to be spilled, it is however possible to identify where oil is stored, the corridor through which it travels and the industries that uses quantities of it in order to monitor and reduce the likelihood of a spill. Oil spill is a hazard as it puts the people and surrounding areas in an unsafe position.

Wadge *et al*. (1993) identifying the purpose of hazard assessment and its main components which can be describes as follows: hazard assessment is concerned with conveying information on the likelihood of future hazardous events in the specific environment concerned. It involves two main components temporal and spatial analysis. While the former is based on the catalogue of past hazardous events from which the probability of a recurrent event can be determined; the later is based on a map based model showing derived boundaries and relative categories of hazards. Geographic Information System (GIS) is well suited for hazard modeling as it has the capabilities of analyzing spatial patterns using a wide variety of input thematic data files.

The objective of this study is to assess oil spill hazard using cost distance spatial analysis modeling techniques in South Eastern Nigeria; an environment where temporal may not be feasible due to lack of appropriate *in situ* oil spill historical data that can be used for the probabilistic modeling.

MATERIALS AND METHODS

Study area: South East Coast of Nigeria (specifically, the coastal local government areas of Akwa Ibom State) is located in the Niger Delta within latitudes 4°33' and 4°29' North and longitudes 7°35' and 8°25' East (Fig. 1). With a total land area of 3421.55 km^{-2} and a total population of 1.40 million people, the study area has population density of 408.66 persons km^2 based on the 2005 population census (National Population Commission, 2006).

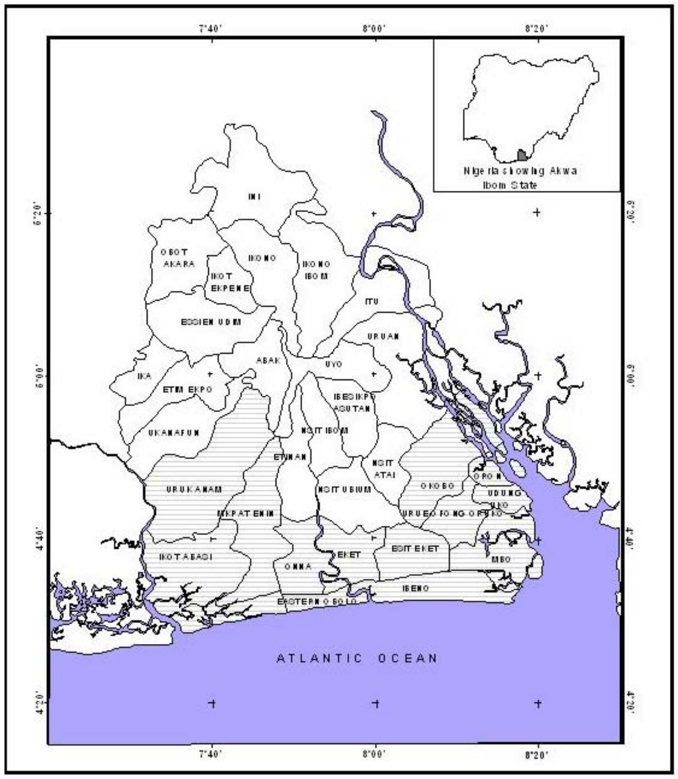

Fig. 1: Akwa Ibom State showing study area

Hazard components-identification and modeling: As suggested by Miller and Onwuuteaka (1999), Hazard sources and impedance surfaces are the two main components needed to model oil spill hazard in this study. The modeling environment was provided by cost distance tool in arcmap spatial analyst extension. Oil spill hazard sources shown in Fig. 1 were identified, grouped and ranked in the study area as follows: flow station and tank farm oil wells, oil pipelines, water bodies rivers and water bodies ocean. The locations of the hazard sources in the study area are shown in Fig. 2.

The rate of movement of oil spill over the land surface is a function of the nature of the surface. The characteristics of these surfaces act on the moving oil either impeding or assisting the movement. In this study, the following thematic map layers were used to model the impedance surfaces soil association, physiographic and geomorphic units, hydrologic units and slope. Arcmap has a cost distance spatial analyst extension module that allows the modeling of movement of liquid from a source across impedance/cost surfaces.

Hence, using each of the identified hazard sources, hazard surfaces were created to reflect the movement of oil over each impedance surface. The cost distance tool identifies for each raster cell, the weighted accumulating cost of transport of oil across the landscape from the nearest hazard source. Altogether, 20 cost distance surfaces were produced to reflect the interaction between the 5 hazard sources and 4 impedance surfaces modeled as shown in Table 1.

Hazard surface 1A is generated from the modeling of the cost distance of flow station and tank farm Hazard Source (HS1) over Soil Association as the impedance surface (A). Equally, hazard surface 5D is generated from the modeling of the cost distance of ocean Hazard source over slope impedance surface (D).

The 20 surfaces were combined/reduced to 5 based on the hazard sources, Hence, we have hazard surfaces based on flow station and tank farm, oil wells, oil pipelines, water bodies rivers and water bodies ocean. Figure 3 shows the oil well based hazard zones of the study area. The final hazard surface was created by prioritizing, weighting the 5 Hazard surfaces and finally zoning the resultant surface into Hazard classes.

Prioritizing and weighting: Each component of a model may not contribute equally to the final output. Hence, in modeling hazard the various components were ranked and weighted based on their perceived contributions to the

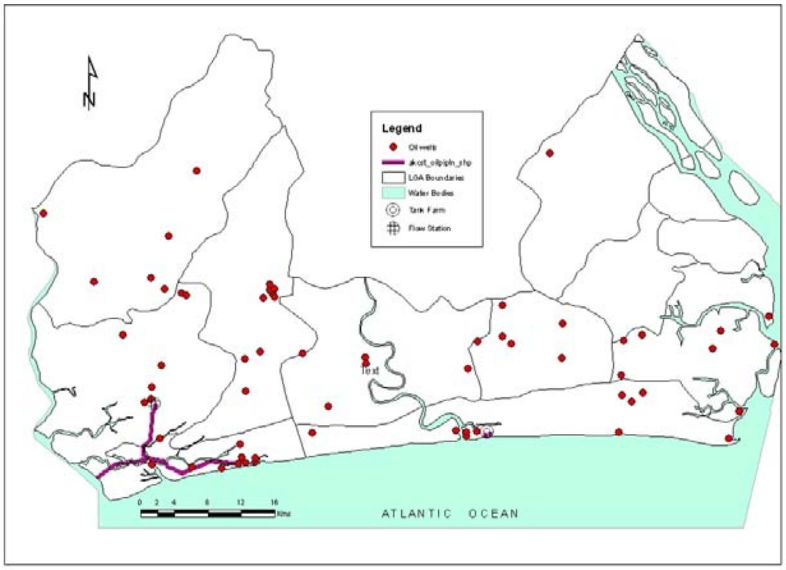

Fig. 2: Study area, Hazard source

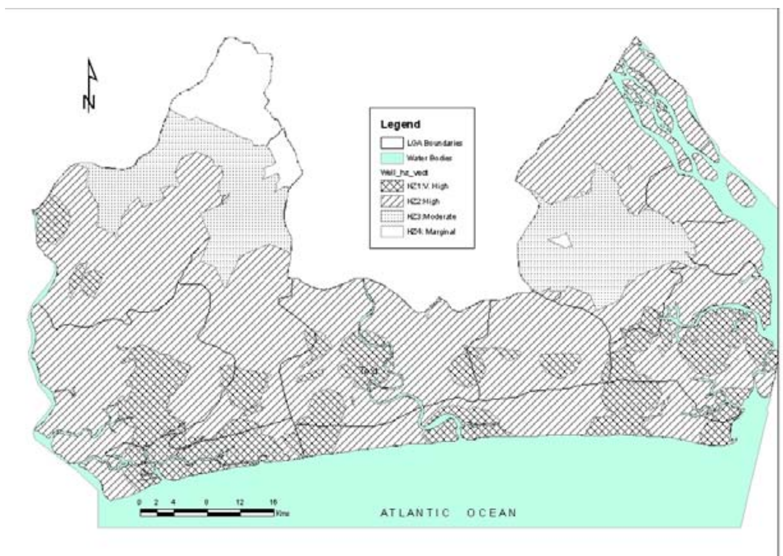

Fig. 3: Oil well based hazard zones

final Hazard surface as recommendations from literature (Miller and Onwuuteaka, 1999) and also as deducted from their known characteristics. As shown in Table 1, soil association is ranked and weighted highest as an impedance surface (30%) than slope (20%). Same argument also explains why tank farm and flow station is ranked and weighted highest (35%) and Ocean lowest (5%).

Combination of the hazard layers: The tool used for the combination of hazard layers was the Single Output Map Algebra Module of Arcmap 9.1. To create a given output layer (in this case hazard layer), Map Algebra as a Spatial Analyst tool, combines the component raster layers based on the formulae:

$$\text{Output} = \Sigma i = 1\text{-}N\ (\text{No. } P * Wj = 1\text{-}r)$$

Where:

p = No. of Pixels
I = The no. of pixels for each raster layer
J = The weightings of each layer

A map algebra is an analysis language based on a simple syntax similar to algebra, resulting in an output

Table 1: Hazard surfaces

Impedance surface	Hazard surfaces (HS) HS 1: Tank farm and oil flow station (35%)	HS 2: Oil wells (20%)	HS 3: Pipeline (30%)	HS 4: Rivers (5%)	HS 5: Ocean (10%)
A: Soil Association (30%)	Hazard surface 1A	Hazard surface 2A	Hazard surface 3A	Hazard surface 4A	Hazard surface 5A
B: Phy. and georm. units (25%)	Hazard surface 1B	Hazard surface 2B	Hazard surface 3B	Hazard surface 4B	Hazard surface 5B
C: Hydrologic units (25%)	Hazard surface 1C	Hazard surface 2C	Hazard surface 3C	Hazard surface 4C	Hazard surface 5C
D: Slope (20%)	Hazard surface 1D	Hazard surface 2D	Hazard surface 3D	Hazard surface 4D	Hazard surface 5D

Analysis by researcher

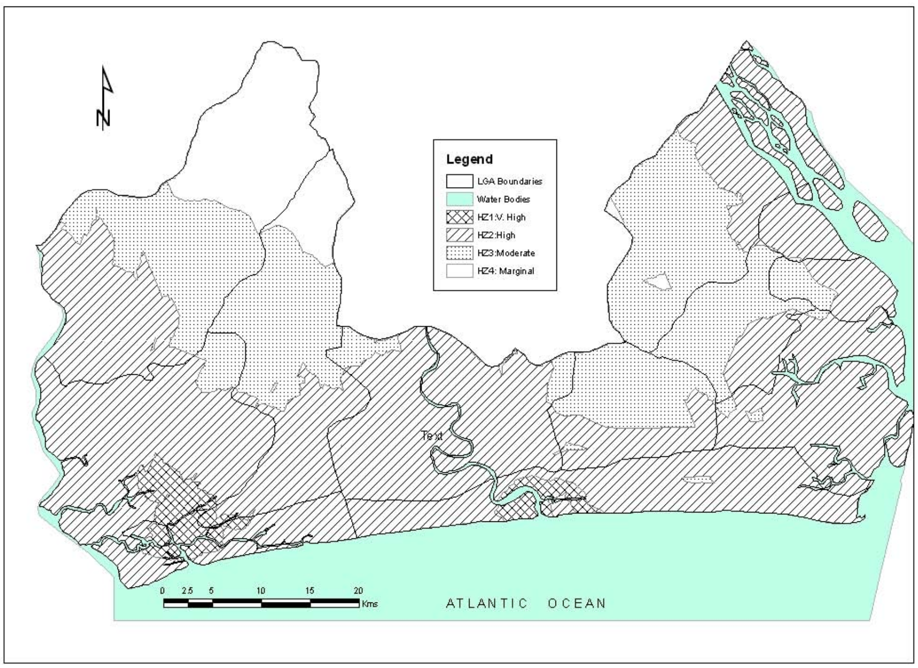

Fig. 4: The final hazard surface

raster dataset from some manipulation of the input. It allows one build complex expressions and process them as a single command.

The single output tool processes a map algebra expression and provides the capability to link other data as well as expose the input and output datasets in the Model builder (ESRI, 2005).

For this study, the combination of the component raster layers to create the output hazard surface was performed in two stages:

- Firstly, the 20 component layers were combined to form 5 separate Hazard layers (HS1, HS2, HS3, HS4 and HS5) each representing the product of the cost distance analysis from the 5 Hazard sources
- Secondly, the 5 Hazard layers were then combined to form the final single Hazard layer that is used to represent and explain the Hazard surface of the study area shown in Fig. 4

RESULTS AND DISCUSSION

The matrix of the final Hazard classes is showed in Table 2 showing that 3.02% of the study is made up of very high zone; 60.73% (the largest) constitute the high zone; 28.00% is made up of the moderate zone while 8.25% is the marginal hazard zone.

The very high and high zones together with the high hazard zone form 63.75% of the study area while the moderate and marginal zone constitutes 36.25%. As an indicator of the probability of experiencing an hazardous event, the hazard zones prioritizes hazards of different severity in the study area.

It shows at a glance the spatial spread of oil spill based hazard. In terms of the areal coverage, the analysis has revealed that the areas prone to very high hazard are found around the tank farm in Qua Iboe Terminal and the flow station in Iko.

Table 2: Final Hazard surface zones

Hazard surface zone	Area km^2	Percentage
HZ 1: very High	84.40	3.02
HZ 2: high	1694.55	60.73
HZ 3: moderate	781.35	28.00
HZ 4: marginal	230.19	8.25
Total	2790.49	100.00

The local governments they cover include ibeno, ikot abasi, eastern obolo and Mkpat Enin. Hazard was modeled in the study area by sources of petroleum oil spill moderated by surface characteristics. The analysis of hazard sources identified four spill sources as the main determinants of hazard oil wells; Pipelines; tank farm and flow station. The significant hazard layers are all associated with petroleum oil related facilities involving extraction, transportation and storage of crude oil. The tank farm is located in The Exxon Mobile operating base in mkpank, ibeno.

Oil spill is a common occurrence around this facility. As the final separation of oil from water is carried out here; oily waste water is spilled through channels into the Atlantic Ocean where the separation is not efficient. A flow station exists in Utapate near Iko, Eastern Obolo LGA. The facility belongs to shell where oil gathered from various oil fields are dewatered and pumped into storage tanks. Oily waste water is an important waste product from here. Before shell discontinued the use of the facility, it was also a hydrocarbon gas flare point.

Oil wells are oil drilling sites that constitute the most widely distributed oil facility in the study as they are found in all the 13 LGAs used for the study. Drilling mud, waste pits into which such waste are discharged equipment malfunction, leakages are some of the causes of pollution around drilling sites. In December 2007, crude oil leaked in Ikot Ata Udo drilling site hence polluting the neighboring environment. The oil pipelines are another oil facility in the area.

Two can be identified. One is in the western portion of the study area, being part of shell facilities. It links the oil wells through the flow station to the other shell facilities in the Niger delta. Oil pipeline is found towards the right of Qua Iboe tank farm, an Exxon Mobile facility. The implications of petroleum oil facilities/infrastructure as hazard determinants can best be appreciated when viewed against the background that the tempo of petroleum exploitation, refining and marketing activities are increasing in recent years in the study area. The Akwa Ibom State government has identified mineral development as an important element in the social and economic transformation of the state hence promoting the Akwa Ibom Petroleum and Energy Limited (APEL) as a holding industry in oil and gas production. Also private investment efforts like Amakpe Refinery Limited, Frontier Oil and Universal Oil means that the landscape would soon be crisscrossed by a network of petroleum pipe lines that link oil related facilities. This increases the likelihood of hazard causing events. Globally, although the exact location of the next oil spill cannot be predicted, the likelihood increases where oil related facilities are present. Equally, where the facilities are not properly maintained or are tampered with, chances of oil spill multiplies. For an example, a ruptured pipeline in Northern Russia in 1994 caused the third largest oil spill in history.

TED Case Studies (1997) reports that most of the gas and oil pipelines in this area are poorly maintained as some of them are >20 years of age. Along the pipelines, hundreds of leaks and breakage are experienced each year hence saturating the ground with oil; some of which have seeped into the water table. In most parts of the Niger Delta, ruptured pipelines either through old age or sabotage are rampant. Investigations by Ifeadi and Nwankwo (1987) show that oil spill incidents due to corrosion involved 18.4% of the total spills incidents studied with pipelines experiencing the highest occurrences followed by plant farms/flow stations and then well heads. The study also showed that sabotage cases accounted for 20.3% of all spill incidents amounting to about 3.2% of the total quantity spilled.

In recent years, there has been increasing incidents of pipeline explosions due to sabotage of facilities by vandals. This trend calls for serious actions as the end results are always the spilling of petroleum oil into the environment. The implication of all these is for an integrated framework that will take into consideration the potentials of petroleum oil facilities as sources of hazard. All these point to the fact that as oil related activities increases so is the need for equipment monitoring so as to reduce the chances of oil spill.

CONCLUSION

The study, a GIS based oil spill hazard modeling has proved the need for a sustainable and integrated approach to the management of a fragile and dynamic system like the Niger Delta of Nigeria. For a sustainable protection of such an environment, spatial data is a prerequisite. This includes past information about the environment, knowledge of the present status and what would be the future of that environment given certain circumstances. Geographical Information System (GIS) can be used to provide an objective strategy to environmental problems arising from the negative effects of petroleum exploration. It provides an informed decision support alternative, approaches and possibilities to environmental planners. The study will help eliminate some of the current oil spill and general environmental management practices that are not only manual but also subjective and conflict generating.

The study will provide environmental decision makers, an orderly, clearly stated and consistent way of evaluating the existence of oil spill hazards and the magnitude of their existence and the risk they pose to the environment. It should be seen as a first step in the process of a comprehensive risk management as it forms the foundation on which the coastal areas of Akwa Ibom State can build their strategies to mitigate oil spill based risk.

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