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Full Length Research Paper

GIS based risk assessment of oil spill in the coastal areas of Akwa Ibom State, Nigeria

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Assessing the total loss and damages that may result from oil spill constitutes risk assessment. The study area is the coastal Local Government Areas (LGAs) of Akwa Ibom State, located in the Niger Delta of Nigeria. The delta generates the greatest proportion of foreign exchange and internal revenue earnings of the country as the crude oil sector accounts for 90 to 95% of export revenues. Since most of information used for oil spill risk assessment have some form of spatial content, extensive use of Geographic Information System (GIS) capabilities are used in the study. A combination of hazard and vulnerability data layers constitutes the GIS based risk assessment. Hazard was modeled in the study by sources of petroleum oil spill moderated by surface characteristics, while data on crop suitability, socio-economy, environmental sensitivity, accessibility, and settlement development, were used to model vulnerability. The resulting risk layer was classed into four Risk zones of very high, high moderate and marginal risk. Iko and the environs were found to be in the very high risk zone. Based on the fact that increasing investments are being made in the petroleum oil sector in Akwa Ibom State, the study analysis the implications of the findings and stresses the need for a comprehensive GIS based oil spill contingency plan for the area.

Key words: Risk assessment, vulnerability assessment, impedance surfaces, cost distance modeling.

INTRODUCTION

Akwa Ibom State is located in the Niger Delta, the petroleum oil rich region of Nigeria. With about 25 billion barrels of crude oil and gas reserves of about 130 trillion cubic feet, the Niger Delta Region generates the greatest proportion of foreign exchange and internal revenue earnings of the Federal Government. The crude oil sector alone accounts for 90 to 95% of export revenues. Gas, hitherto flared is beginning to make meaningful contributions to Nigeria's income - earning a total of US$9197.5 million in export in 2001. In addition to these, potentials in fishery, agriculture, and forestry products emphasize this unique region's riches. The region however encounters myriad environmental problems ranging from health hazards, poverty to flooding, coastal erosion, and oil spill.

Oil spill issues in Nigeria have been very contentious with local communities pitched against giant multinational companies and, government and regulators being accused of double standards and collusion. However, it is generally agreed that oil spill is dangerous to the operating environment which by nature is very difficult to clean up if contaminated by oil. It is obvious that as long as petroleum resource is being explored and exploited, spills will still take place. Ways of minimizing them and their effects need to be explored particularly as the people most affected by the spill are those in the host communities where the exploration and exploitation of crude is being carried out.

Pollution is a man-made hazard hence as with natural hazards, improved understanding is needed for the sources, extent and responses to contamination in affected areas to be controlled. Risk assessment has emerged as a result of worldwide interest in different aspects of hazards. Mitchell (1989) asserts that it involves the identification of hazards, estimating the threats they pose to humanity and the environment and the evaluation of such risk in a comparative perspective. Granger et al. (1999) emphasized that risk modeling must be seen as an "understating of the probability of

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occurrence of events of particular severity and the levels of uncertainty that exist in the data employed and the models themselves.” Hence, given these uncertainties, the study stressed the need for caution about presenting most of the findings as nothing more than the future. Standards Australia (1995) define risk as the chance of something happening that will have an impact upon objectives measured in terms of consequences and likelihood, and can be expressed simply using the following pseudo – mathematical form: Risk (Total) = Hazard x Elements at Risk x Vulnerability. This approach asserts Granger et al. (1999), is not only elegant but also practical as it lends itself to quantitative, qualitative and composite analytical approaches, and also enables one see the various elements at risk as being interdependent.

The procedure and rationale for risk assessment according to Van Westen (2008) can be summarized as follows: Hazard disaster depends on two factors: hazard and vulnerability. While hazard refers to the probability of occurrence of potentially damaging phenomenon, vulnerability is the degree of loss resulting from the occurrence of the phenomenon. In order to create a risk map, you first generate a qualitative hazard map by combining several factor maps. Then, a vulnerability map is made. The combination of hazard and the vulnerability map results in a risk map. The synthesis of data and the essential mapping of the spatial relationships between the hazard phenomena and the elements at risk require the use of tools like Geographic Information System (GIS). In most risk management tasks, at least 90% of the information used has some form of spatial content. Hence, to accommodate this spatial emphasis, extensive use is made of GIS in this study which allows one generate, store, analyse and display environmental data easily.

The capability of applying GIS in various aspects of risk assessment has been demonstrated by many researchers. Van Westen (2008) used simple data sets from Colombia (South America) to demonstrate on a national scale the meaning of hazard, vulnerability and risk. To create the hazard map, attribute tables are created for the following input maps: Seismic hazards, landslide hazards, volcanic hazards, tsunami hazards, beach, erosion /accumulation hazards. To all classes in these maps, different weight values are assigned in their attribute table. Finally, all factor maps were summed with a MAPCALC statement in ILWIS software to obtain a hazard map which was then classified into five classes: Very low, low, moderate, high, and very high hazard. Population density, data on industrial regions, concentration of economic activities, and main infrastructure were used to create and classify the vulnerability map into four classes (Very low, low, moderate, and high vulnerability). For the risk map, a two dimensional table was created in which for each combination of hazard classes and vulnerable classes, an output risk class was assigned. A three class risk map (High, moderate, and low risk) was obtained by applying the two- dimensional table on the classified hazard map and the classified vulnerability map.

Similar procedure were used by Damen and Van Westen (2008) to model cyclone hazard zonation in the South of Chittagong, Bangledish, Van Westen and Tertien (2008) to demonstrate the potentials of GIS in hazard zonation of landslides triggered by earthquakes in Manizales, Colombia, and Van Westen (2008) to demonstrate the use of quantitatively defined weight values in the making of hazard maps. Granger et al. (1999) equally utilized GIS to synthesize and model the spatial relationship between vulnerability and hazard in order to study the risk faced by Cairns in Australia to multi – hazard phenomenon. The study identified, operationalized and mapped the main factors affecting the community vulnerability with the following datasets, buildings, mobility power, water supply, logistics support, health, wealth/economic resources protection, languages and ethnicity, religion, education, and community services. Thumerer et al. (2000) developed a GIS based risk assessment model by combining oceanographic and climatic data with data on sea defenses, elevation values and patterns of land use to assess the implication of sea level rise along the English east coast using the Arc-Info GIS package.

Specifically, Miller and Onwuteaka (1999) evaluated the vulnerability of the landscape to oil spills in the East Central area of coastal Nigeria. ARC/INFO GRID was used to model the potential risk of oil spills from existing oil facilities and refined hydrocarbon shipping lanes. Land cover classifications from digital Landsat TM imagery and digitized maps were used to model the sensitivity of the regional environment to oil spills. The resulting model was then integrated into ArcView GIS as a decision support system. Also, Krishnan (1995) demonstrated the effectiveness of the GIS in determining the critical areas that need to be protected in the event of an oil spill.

Risk assessment procedure now integrates multi criteria technique with GIS in dealing with environmental problems as GIS has an added advantage, the ability to integrate a wide spectrum of data sets in order to satisfy many stakeholders. Hence, various researchers have effectively applied this combination. These include Jorin et al. (2001) for land suitability assessment, and Pramojanee et al. (1997) for flood vulnerability mapping.

The overall aim of this work was to examine the ways GIS can be used to effectively appraise the degree of threat posed by oil spill in the study area. With the resultant hazard, vulnerability and risk map layers, the study aimed at creating an objective criteria for decision making in managing an oil spill prune environment like the Coastal Areas of Akwa Ibom State, Nigeria.

METHODOLOGY

In this study risk assessment was operationaliesd using three sets

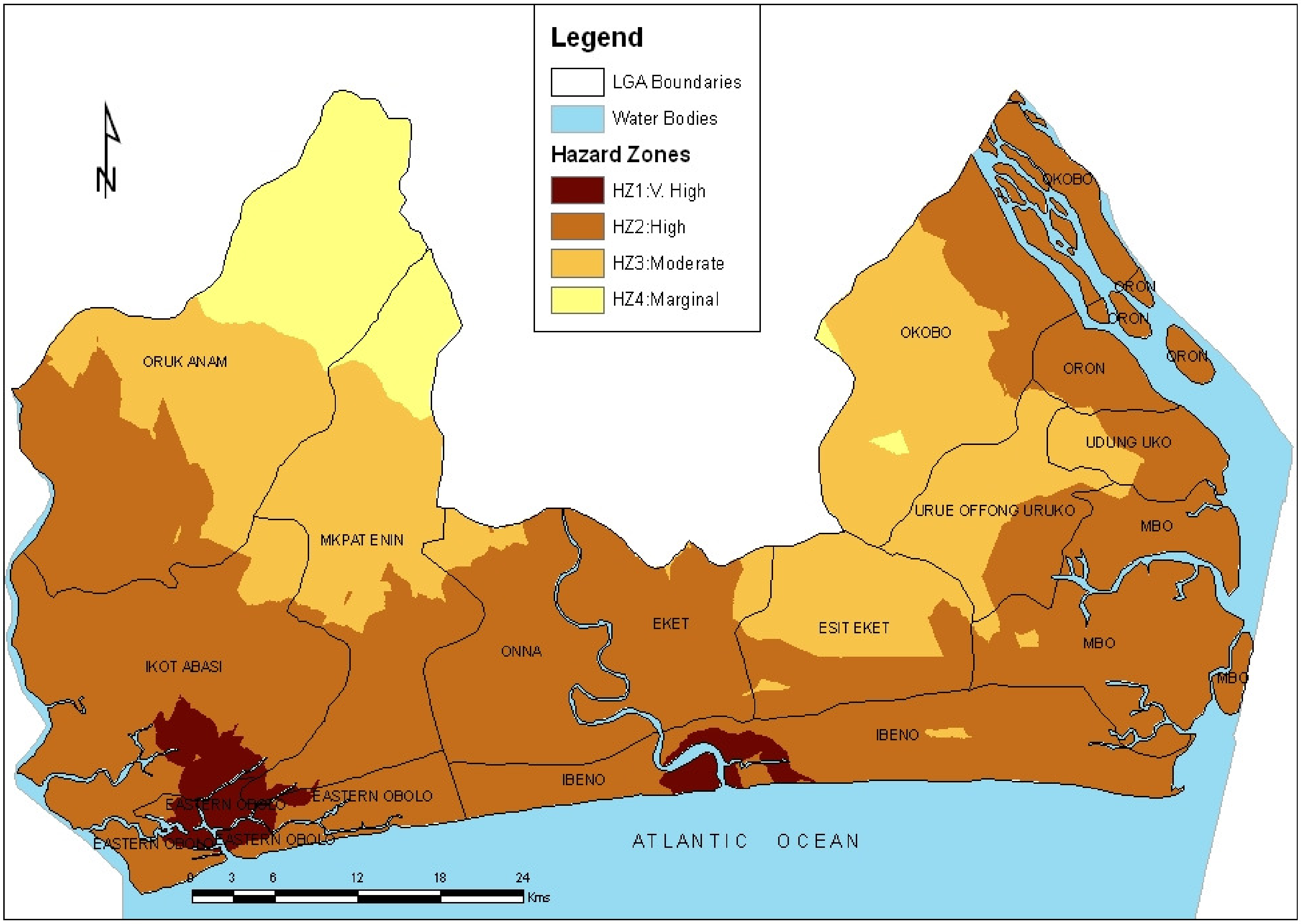

Figure 1. Final hazard map.

of variables that are embedded in the following questions: What are the sources of oil spill based hazards in the study area? Who and what are at risk? What is the vulnerability of the elements at risk? Answering these questions helped generate the various datasets used for the GIS based assessment. Based on the reviewed literature, the study was carried out under the following procedure.

Hazard sources and modeling

Two components used to model hazard surfaces in this study includes: Hazard sources and impedance surface. These were used as input to produce the hazard surface in the cost distance operation in Arc map 9.1 software's spatial analyst extension. Hazard in this study was identified and operationalised from the sources of petroleum oil risk in the study area which includes: Well heads, flow station, tank farm, petroleum pipelines and water bodies (ocean and major rivers). The hazard sources were grouped and prioritized depending on their oil spill causing capabilities as follows: Flow station and tank farm = 1 (highest), oil well = 2, pipeline = 3, pipeline = 4, water bodies-ocean = 5 (lowest). Lower numbers indicate higher oil spill causing ratings and vice versa.

Since the rate of movement of oil spill over 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 (Miller and Onwuteaka, 1999). In this study, impedance surfaces were identified and modeled by the following layers: Soil association, physiographic and geomorphologic units, hydrologic units and slope surface. Impedance surfaces create cost distances from hazard sources. Arcmap 9.1 software has a cost distance spatial analyst module that allows one to model the movements from a source across impedance/cost surfaces. Hence, using each Hazard source Hazard surfaces were modeled to reflect the impact as oil moves over each impedance surface. A final hazard surface (Figure 1) was created by prioritizing and weighting the hazards for the various components, combining the components and finally zoning the resultant surface into hazard classes. In modeling the hazard, the various components were ranked and weighted based on their perceived contributions to the final hazard surface as recommendations from literature and also as deducted from their known characteristics. Hence, soil association is ranked and weighted highest as an impedance surface (30%) than slope (20%).

The tool used for the combination of hazard layers was the single output map algebra module of Arcmap 9.1 software which is based on a simple syntax similar to algebra, resulting in an output raster dataset from some manipulation of the input (ESRI, 2005). For this study, the combination of the component raster layers to create the output hazard surface was performed in two stages: The product of the cost distance analysis from the 5 hazard sources

Table 1. Final hazard surface zones.

Hazard zones (HZ)	Area (Km^2)	%
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

Source: Analysis by author.

were fist combined to produce 5 hazard layers which were further combined to form a single final hazard layer that was the used to represent and explain the hazard surface of the study area. The hazard surface was then zoned into 4 hazard classes as follows: Zone 1: very high hazard zone, Zone 2: very high zone, Zone 3: moderate hazard, and Zone 4: marginal zone.

In determining the final hazard surface, the 5 hazard surfaces were ranked and weighted in order of their perceived ability to cause oil spill - Pipeline (30%), Oil well (20%) tank farm and flow station (35%) ocean (10%), rivers (5%). An analysis presented in Table 1 shows 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 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. When displayed in Figure 1, it shows at a glance the spatial spread of oil spill based hazard. In terms of the area coverage, the analysis has revealed that the areas prone to very high hazard oil spill based hazard are found around the tank farm in Qua Iboe terminal and the flow station in Iko. The LGAs they cover includes Ibeno, Ikot Abasi, Eastern Obolo and Mkpat Enin.

Vulnerability modeling

Vulnerability is the measure of how the elements at risk in a landscape would be damaged if they experience same level of hazard (Coburn et al., 1994). It is the degree to which an area, people, physical features or economic assets are exposed to the loss, injury or damages caused by the impact of the hazard. Like hazard, vulnerability is multidimensional, and each element will be affected differently by hazards of different severity. For this study vulnerability is operationalised and modeled by ranking and assigning weights to the following identified elements at risk in the study area - crop suitability, socio-economic, environmental sensitivity, accessibility and settlement development vulnerabilities.

Crop suitability vulnerability

10 crop suitability raster layers: Root crops (cassava and yam), maize, cow pea, groundnut, sugar cane, swamp rice, forestry wildlife, dry season repeatable, and oil palm were combined into a single layer using the single output algebra of Arc map 9.2 to create the overall crop suitability layer for the study area. Crops provide food that sustain the people. They also provide the means of livelihood for the predominantly rural populace 90% of who are engaged in agriculture.

Socio-economic vulnerability

Population density and poverty raster layers were produced from population density and poverty data of the study area. Each was classified into 4 zones (very high, high, moderate and marginal) and used to produce the socio-economic vulnerability. While low poverty values attracted high socio-economic vulnerability values (and vice versa), low population density attracted low socio-economic values (and vice versa).

Environmental sensitivity vulnerability

Land use, normalized difference vegetation index (NDVI) and ground water table values were used to model the environmental sensitivity of the landscape to oil spill. The sensitivity index of each of the three sub classes were ranked and combined into a single layer with single output algebra of Arc map 9.1 software. The land use land cover classes generated from the image analysis were ranked 1 to 5 thus: Settlement ESI 1, Bush Fallow ESI 2, Secondary Forest ESI 3, Fresh Water Swamp ESI 4, and Mangrove ESI 5. NDVI is a measure of the area of stressed and non stressed vegetation. It is an image analysis functionality of ILWIS 3.1 software. NDVI has been found to be sensitive indication of the presence and condition of green vegetation (ILWIS user). Sensitivity index of ground water table was operationalize to be inversely proportional to the depth of the water table. Hence, the deeper the table, the lower the sensitivity. Water tables closer to the surface are likely to be more affected by oil spill hence attract high sensitivity.

Accessibility vulnerability

As a rural coastal marine ecosystem, nearness to roads becomes an asset to any location. For an example, oil spill locations nearer to roads could easily be accessed and remedial actions taken immediately than those that are not easily accessible. Accessibility surface was created using Euclidian Distance tool of the Arcmap 9.1 software's spatial analyst function with the road networks as source data. Isolated and rural locations, assert Blaikie et al. (1994), are more vulnerable to hazards than accessible sites. Hence, places closer to the roads are operationalised to have lower ranking than farther locations.

Settlement development vulnerability

Favourable environment is needed for the development and grow of settlements in any area. Hence since the study area is a low land area liable to flood as stated by Akwa Ibom State (AKS) (1989) and AKS (2002), land with higher elevation would be very valuable for settlement purposes. Settlement development was modeled from elevation data extracted from digital elevation model (DEM) of the study area.

Vulnerability prioritizing and zoning

The 5 selected vulnerability layers were each reclassed, weighted and combined into a single vulnerability layer using the single output algebra of Arcmap. The output was then reclassed and zoned into 4 vulnerability categories (very high, high, moderate, marginal) as shown in Figure 2. The analysis in Table 2 shows that while high vulnerability zone occupies the largest area of 56.62%, the marginal zone occupies the smallest with 7.27%.

Risk surface modeling and zonation

To create the final risk surface, the hazard and vulnerability layers were combined equally (50% each) using the single output map

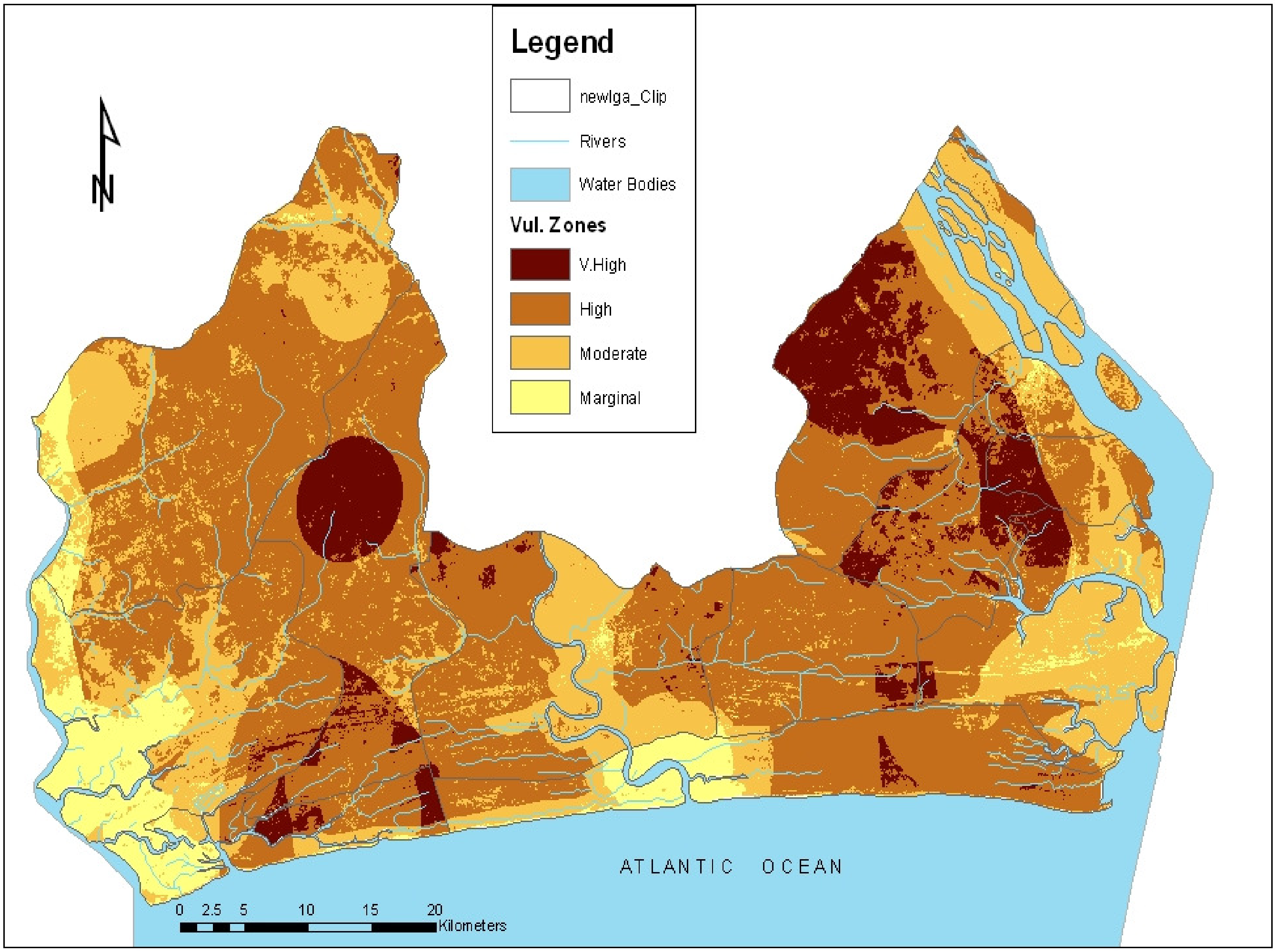

Figure 2. Final vulnerability map.

Table 2. The spatial spread of the vulnerability zones.

Vulnerability zone (VZ)	Area (Km^2)	%
VZ 1: V. High	276.59	9.89
VZ 1: High	1583.02	56.62
VZ 1: Moderate	732.28	26.19
VZ 1: Marginal	203.19	7.27
Total	2795.08	100

Source: Analysis by author.

algebra of Arcmap. The resultant map was reclassed and zoned into four risk zones very high risk, high risk, moderate risk, and, marginal risk as shown in Figure 3 and Table 3.

FINDINGS AND DISCUSSIONS

The study has demonstrated the capabilities of GIS in assessing oil spill risk in the Coastal areas of Akwa Ibom State, Nigeria. The study identified and modeled oil spill hazard using hazard sources and impedance surfaces. Like hazard, vulnerability used for the risk model is multidimensional, and each element will be affected differently by hazards of different severity. Vulnerability is operationalised and modeled by ranking and assigning weights to the various elements at risk in the study area. The combination of the hazard and vulnerability layers created the risk surface. The resultant layer was classed into 4 risk zones of very high, high, moderate and

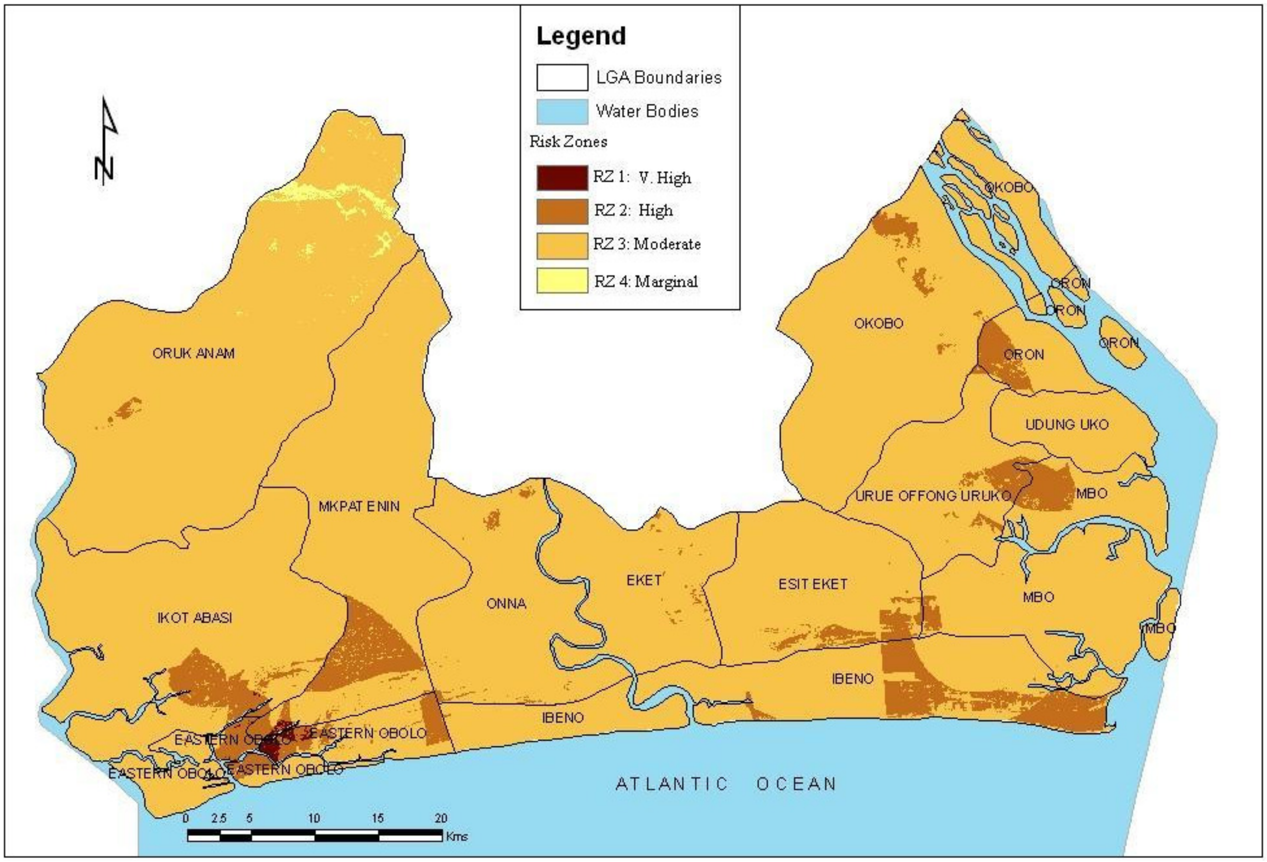

Figure 3. Risk surface of the study area.

Table 3. The spatial spread of the risk zones.

Risk zone (RZ)	Area (Km^2)	%
RZ 1: Very high	4.41	0.16
RZ 2: High	199.36	7.14
RZ 3: Moderate	2574.46	92.26
RZ 4: Marginal	12.16	0.44
Total	2790.38	100

marginal risk. The analysis reveals that 4.41 km^2 (0.16%) of the area falls under the very high risk zone, 199.36 km^2 (7.14%), 92.26 km^2 (92.26%) under moderate zone, while 12.16 km^2 (0.44%) is under marginal risk zone. GIS based risk assessment modeling sees risk faced in a location as a combination of vulnerability and hazard. No risk is encountered if these are hazards but zero vulnerability, or if there is a vulnerability population but no event. Risk is a function of varying degrees of hazard and the varying degree of vulnerability. Disaster occurs when a significant portion of some elements in the environment experiences a hazard and suffers damages or disruption of their livelihood. A GIS based risk assessment has helped in the understanding of how disaster occurs, when hazard affects vulnerability people. This conforms with Blaihie et al. (1994) that formulated the pressure and release model based on the idea that disaster is the interaction of two opposing forces: Hazard and vulnerability. The study has enabled us identify areas at risk where disasters are likely to occur. Indeed, areas of high hazard are likely to be areas of disasters. The analysis identified areas around Iko in Eastern Obolo including the surrounding LGAs of Ikot Abasi, Mkpat Enin and Ibeno as areas with very high risk. Here the interaction between hazard and vulnerability produces the highest effect.

Risk assessment of oil spill as demonstrated in the study is indispensible tool in contingency planning especially in developing nations. Environmental Protection Agency (1999) describes contingency planning as a "game plan" or set of instructions that outlines the steps that should be taken before, during and after an emergency. It looks at all the possibilities of what could go wrong and the contacts, resource list and strategies to assist in the response to the spill when such an event actually happens. It provides the details about the various steps required to prepare for and respond to spills. Different spill scenarios and addresses many cause different situations that may arise before or after a spill. Hence risk assessment enable one identify and prepare fore hazardous events in places that are likely to be more impacted by such an event.

Oil spill does not occur in a vacuum but in specific locations in space. Vulnerability measures the amount of damages to elements in the environment if they are exposed to hazard of varying severity. Based on the spatial spread of the vulnerability zones, the various elements used for the modeling in the study area have lots of implications for the management of the area. For an example, the study area has a mean population density of 436 persons per km^2 and mean poverty of 57.01%. This high population density and above average poverty index is likely to produce a populace that is highly susceptible to the harmful influences of oil spill and indeed any other hazard. Generally, economically marginalized people have insecure and less rewarding access to livelihood and resources and therefore generate high levels of risk. Also, the people are likely to be a low priority for government interventions intended to deal with hazard mitigation (Blaike et al., 1994). Of significant importance also is crop suitability as a component of the vulnerability model. Yams, cassava and maize are important food crops in the area. Oil palm is an important economic tree that is not only a cash crop but also used for domestic consumption. Although cowpea and groundnut are not cultivated in commercial quantity, yet the fact that the area is suitable for their cultivation is a sign of the great agricultural potentials of the coastal Akwa Ibom State.

Generally, the study has demonstrated the use of GIS coupled with remote sensing techniques in risk assessment. Remote sensing provided the basis for land use/land cover monitoring, and the investigation of surface characteristics. The 2003 Landsat images used for the study provided the digital data needed for an up to date land use of the study area. The Landsat data was also used to generate a normalized digital vegetation index (NDVI) a measure of the vegetal health. As a coastal environment with increasing oil exploration going on, monitoring of vegetal health is very necessary. NDVI was as an input for vulnerability analysis. Slope angle and elevation data were derived from digital elevation model (DEM) which are important surface characteristics needed for the analysis in the study. GIS was the operating environment for storing and analysis and presentation of the data. A wide variety of data of different scales and format were used for this study. Integrating these was made possible in a GIS environment.

Conclusion

To minimize the harmful effect of oil spill, there is need for a comprehensive contingency GIS based plan for oil spill management in the study area. The study has provided useful input in tackling the four major elements of a contingency plan, hazard identification, vulnerability analysis, risk assessment, and response actions.

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