ENVIRONMENTAL SENSITIVITY OF RIVERS STATE SHORELINE TO OIL SPILL USING FUZZY LOGIC

[1]Akunna V. O., [2]Lawal O., [3]Ogoro M., [4]Chiweike V N

[1,2,3] Department of Geography and Environmental Management,
Faculty of Social Sciences
University of Port Harcourt

[4] Department of Geography
University of Nigeria

ABSTRACT

Rivers state shoreline is a crucial area because of its economic and environmental parameters, so determining its sensitivity to an oil spill is very important. In this research, physical (landform, slope, soil, land cover) and human (population) resources where utilized. These parameters where chosen as they show the possibility and ease of cleanup and remediation. In order to create a spatially explicit model of environmental sensitivity across Rivers state shoreline, these data (landform, slope, soil, land cover and population) were collated and processed in GIS environment. Fuzzy logic was adopted as it presented an opportunity to access individual parameters based on the criteria and overlay them in other to identify the ones that best meet the criteria. It also presented an opportunity to manage uncertainty due to the vagueness of human thoughts. The result shows that the eastern region of the study area is more sensitivity while the middle and the western region are less sensitive to an oil spill. From these result, it is evident that applied fuzzy logic is an effective method to determine shoreline sensitivity to the oil spill as it allows for rapid dynamic assessment of sensitivity as new information become available. It also allows for a decision to be made based on the availability of data.

Keywords: Environmental, Sensitivity, Fuzzy, Pollution, shoreline

Introduction

A shoreline is the physical boundary between land and water (Dolan, Hayden, May & May, 1980). Within this guide, 'sensitivity' is the resultant consequences of pollution caused by hydrocarbon accident in a marine environment. Sensitivity mapping supports the development of a response strategy for oil spill contingency plans (IPIECA/IMO/OGP, 2012). It equally helps in the detection of potential resources and environment at risk to pollution. Sensitivity mapping provides the opportunity to defined priority areas for protection and remediation. It also provides relevant data to plan the appropriate response strategy (IPIECA/IMO/OGP, 2012).

However, oil pollution has persisted in both developing and developed countries, occurring accidentally and non-accidentally. In Nigeria for instance, most water bodies are being threatened by oil spill. Other developing countries faced with related spill problems include India, China, South Africa to mention but a few. Similarly, developed countries also experience problems associated with oil spill. For example, National Response Center in USA continues to report on the frequency of oil pollution which is threatening the well fair and well being of the people (Jiang, Wang, Lung, Guo & Li, 2012).

An oil spill is a type of pollution that involves the anthropogenic release, into the environment, of petroleum products, most especially marine areas. Oil spill is usually related to the discharge of liquid petroleum hydrocarbons into marine environment, known as marine oil spills, but spillage can also occur on land. The accidental release of oil from oil and gas platforms, tankers, wells, drilling rigs etc. causes oil spill. Spillage may also occur from the discharge of refined petroleum products (such as gasoline, diesel) and their derivatives, heavier fuels used by large ships (such as bunker fuel), or any waste oil (Alves, Kokinou & Zodiatis, 2014).

About 10-15% of discharged oil into the marine environments today occurs inadvertently, the major source of man-made marine pollution being land-based discharges (European Environmental Agency, 2013). Yet oil spill discharges from off-shore platforms create a major environmental and financial problem to marine communities, especially when it involves the release of large quantities of petroleum into the ocean (Sammarco et al., 2013). The effect of accidental oil spill is more severe in confined marine basins because it takes relatively short time for spilled oil to get to the shoreline (Alves, Kokinou & Zodiatis, 2014). This sensitivity of confined basins is further amplified by the population and environmental forces since the major occupation of the marine populace is farming, tourism and in the protection of open maritime routes (Kingston, 2002). In these polluted areas, large oil spills causes a great problem to the best-laid contingency plans, as remediation and recovery actions needs a good number of skilled emergency personnel. A good example of the high sensitivity of confined marine basins to oil spill is the popular MV Exxon Valdez shipwreck of 1989, South Alaska, which had an untold effect on flora and fauna and also on the wellness of the remediation personnel (Petterson et al., 2003).

In Nigeria, several oil spill incidents have occurred at different times and places along the coast; the major spills include 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, Texaco Funiwa-5 blow out in 1980 of about 400,000 barrels, the Abudu pipe line in 1982 of about 18,818 barrels and the Idoho oil spill of 1998 of about 40,000 barrels, the Shell Ogbodo oil spill of 2001 of about 9,500 tonnes, the Shell Bodo oil spill of 2008 of about 1,000 tonnes, the ExonMobil oil spill of 2010 of about 95,500 tonnes, the Bonga Field oil spill of 2011 of about 5,500 tonnes etc (Nwilo & Badejo, 2005).

The hazards related with oil spill can get worse if not properly and promptly attended to and remediated. Setting up standby emergency teams to swing into action at the time of oil spill is, relevant to initiate the necessary counteracting actions during response process and this can be realized when the positions of the most sensitive resources are already identified. The environmental pollution that resulted from the Exxon Valdez accident of 1989 made the International Marine Organization (IMO) to write 'the International Convention of Oil Pollution Preparedness, Response and Co-operation of 1990', also called OPRC 9, with the aim of encouraging countries to co-operate with one another in setting up emergency response priorities to accidental oil spills (Pincinato, Riedel & Milanelli, 2009). They also stipulated that any facilities handling petroleum products must have emergency plans handy. This is because; the clean-up exercise will be more successful if an oil spill is detected and responded to earlier. However, all the activities that leads to the setting up an urgent response program, known as oil spill contingency planning (Assilzadeh & Mansor, 2001), is presently being practiced by several counties around the world. In fact, quite a few studies have dealt on oil spill contingency planning and all acknowledged the fact that oil spill detection and surveillance issue is the most crucial of others as well as assessment and evaluation, spill evolution computer simulation, management and remediation (Keramitsoglou, Cartalis & Kiranoudis, 2006).

The aim of oil spill planning and response (after protecting human life) is to reduce the environmental impact of the spill and remediation exercises (Jensen, Halls & Michel, 1998). This can be possible if the actual positions of sensitive coastal resources are known and documented in advance in the form of Environmental Sensitivity Index (ESI) map. This will assist in setting up protection priorities and cleanup plans.

ESI is a spatial information system which is made up of shoreline ranking system which ranks shoreline types on a scale of 1 to 10; biological resources that are oil sensitive, and human resources of economical, subsistence or recreational value. Considerable attempts have been made in producing sensitivity mapping constituents of oil spill contingency plans around the world. Recently, sensitivity mapping has gone beyond a static product of limited distribution based only on coastal oil spills, to a more resourceful and important tool for a range of natural resource management application (Jensen, Halls & Michel, 1998).

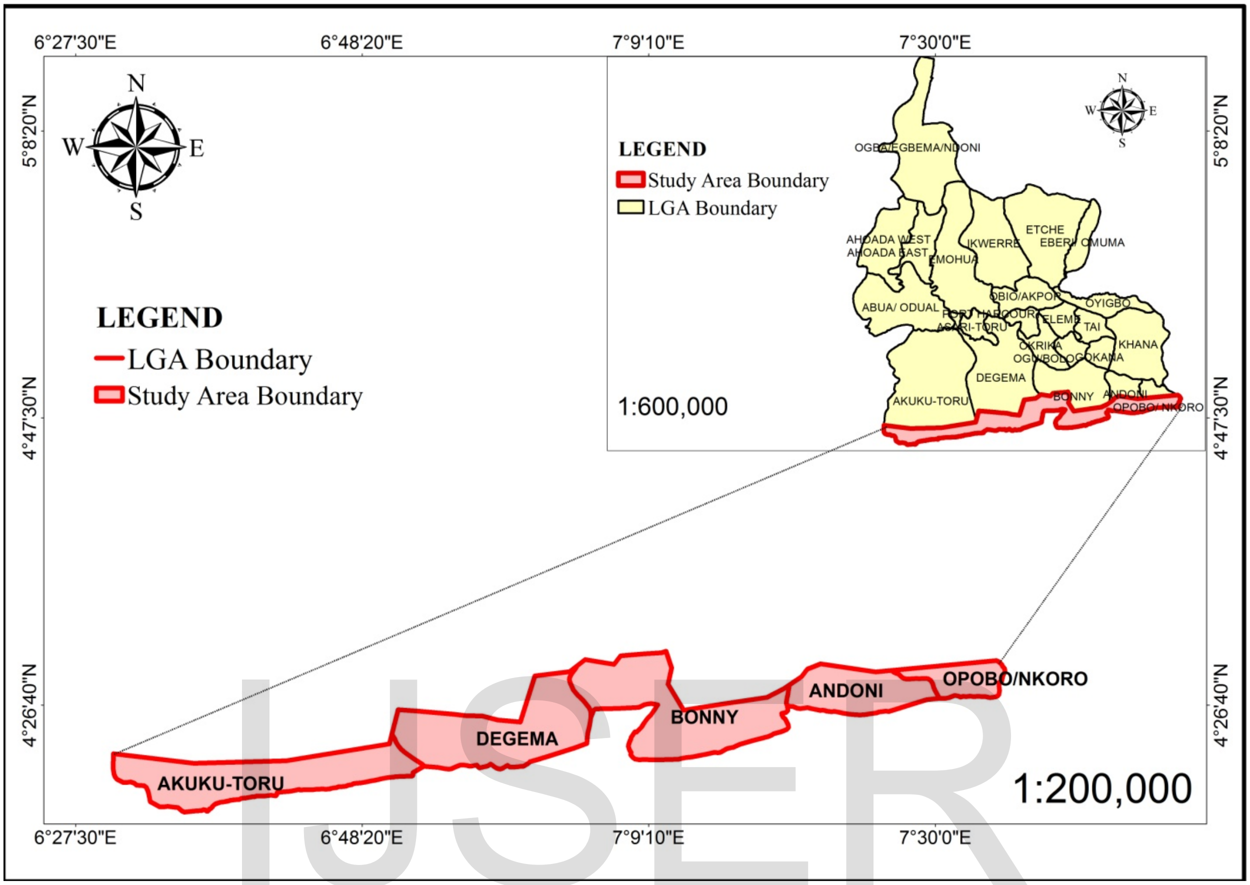
Environmental sensitivity analysis and mapping procedures have been examined in many countries, along thousands of kilometers of shoreline around the world, mostly as a part of national efforts to set up a knowledge-based response scheme to oil pollution that may impact the shoreline.

Fuzzy logic model, introduced by Zadeh (1965) was relevant and to manage uncertainty due to imprecision or vagueness of human thought. It employs the use of different values to showcase the decision maker's uncertainties (Lee, Chen, & Chang, 2008). Similarly, some set of values was selected by the decision maker to reveal the confidence. Also, the standpoint was stated as hopeful, negative or fair, in place of high, low, and middle ranges of values respectively (Jeganathan, 2003). Therefore, the fuzzy model was employed to delineate physical and human resources located along the coastline which are sensitive to oil spillage in other to set priorities and ensure quality decisions during cleanup/remediation operations.

Study Area

ISSN 2229-5518

The area of study is 5km inland off the shoreline of Rivers State cutting across Akuku-Toru, Degema, Bonny, Andoni and Opobo/Nkoro local government of Rivers State (Figure 1).



Source: Rivers State base map

Figure 1: Rivers State showing the study area

Rivers State is within Latitude 4°45'N and Longitude 6°50'E. It is bounded on the North by Imo, Abia and Anambra States, to the South by the Atlantic Ocean, to the East by Akwa Ibom State, and to the West by Bayelsa and Delta States. The State is found within the Niger Delta basin crisscrossed by a system of rivers and creeks. Its shorelines form sections of the West African coastlines. The area witnesses high temperature and high humidity. The shoreline is also characterized by an annual rainfall of between 1,500 and 4,000mm (Kuruk, 2004). The region can be characterized as low-lying and mostly characterized by fresh water and mangrove swamp, tidal flat, fine sand beach, medium to coarse sand beach and mud flat. Nwilo and Badejo (2006) described the area as occupying mainly the south westerly's wind of azimuth 215^0 - 266^0 and with velocities of 2-5m/s. Temperature here is maintained by the cloud cover and by the generally damp air. However, mean monthly temperature varies between 25°C and 28°C throughout the year (Online Nigeria, 2003).

The surface water of the State's coastline is warm with temperature usually greater than 24°C (Nwilo & Badejo, 2006). The surface temperature around the sea is a representation of the cycle of solar radiation, which in the months of October and May, records surface temperatures ranging from 27° - 28°C (Nwilo & Badejo, 2006). Three vegetation types exist in the State; they include the brackish swamp forest, mangrove forest and rain forest. The most significant mangrove plant is Rhizophora acemos, which in the undisturbed state at the outer margins of the mangrove swamps, reaches up to 50 metres in height and attains a girth of 2.7m (Nwilo & Badejo, 2006). The fresh-water zone consists of the lower Delta plains, and flood plains; having fresh-water forest trees which are the edaphic variants of the rainforests. The Abura tree, oil palm, raffia palm, shrubs, lianas, ferns and floating grasses and reeds are the typical vegetation (Salau, 1993). This zone has given many tourist economic opportunities, because of the plants significant economic characteristics. The region is classified into three different geomorphologic zones, although broadly similar, geomorphologic and geotechnical zones, namely; salt water (marine) coastal zone, salt water/fresh water midland transition zone and fresh water upland zones. By way of distribution, the study area falls in the category of salt water /fresh water transitional zone. The area is subjected to seasonal or periodic inundations due to its peculiar topographic characteristics. The soils in the area comprised of three types, namely marine/fluvial sediments, mangrove alluvial soils, and fresh brown loam and sandy loam (online Nigeria, 2003). These three types are found in wet coastal areas and northern areas of coastal sediments, usually brown in colour, with offensive odour, and are usually rich in organic matter, but sometimes are salty during dry season. Those found in fresh water loam are usually found along the delta (online Nigeria, 2003). Their levees are characteristics of the land and are made up of rich loam, from their slopy regions transforming to more acidic and more clayey substances.

Fuzzy Set Theory

To examine the sensitivity of the shoreline to oil pollution, the concept of fuzzy set theory is more suitable, and enables decision makers to express their ideas adequately. According to Zadch (1965), a fuzzy set is mathematically defined as follows: If X = {x} denotes a space of objects, then the fuzzy subset A in X is a set of ordered pairs

$A = \{X, \mu_A(x)\} = \int_u \mu_A(x) / x$ . . . . (Eqn 2.1)

Where A is a fuzzy subset in universe of discourse U and $\mu_A(x) : U \rightarrow M$ is the membership function which takes on values in an ordered set M (membership set). The integral sign is not Riemann's integral but is used to show that the operations apply to the entire items after the sign the slash "/" means "with respect to." The value of $\mu_A(x)$ is the grade of membership of x in A. $x \in X$ means that x is contained in X. Usually $\mu_A(x)$ is a value in the series of 0 to 1, with 1 representing full membership of the set and 0 nonmembership. The level of membership of x in A reveals a kind of ordering that is not dependent on the probability but on admitted possibility. The value of $\mu_A(x)$ of object x in A can object x. In other words, $\mu_A(x)$ of x in A specifies the degree to which x can be referred to as belonging to A. The nearer the number of $\mu_A(x)$ to 1, the more likely x is to belong to A.

To represent geographic data in a fuzzy format, a raster data layer in a GIS can be explained as a fuzzy set since most geographic features lack clearly defined boundaries, and each grid cell (pixel) to be the set element (Sui, 1992). However, each grid cell in the raster file can be merged to a group of membership grades to indicate the extent the cell belongs to certain attributes. Some data layers involved in the GIS modeling process which are stored in GIS as overlays. Mathematically, these overlays can be expressed as a data layer set (Sui, 1992):

$$DL = \{DL_1, DL_2 ....DL_i ,..., DL_n\} \quad \ldots \quad \ldots \quad \ldots \quad \text{(Eqn 2.2)}$$

Where DL_1, i = 1,2, . . . , n, represent all the data layer recognized in the modeling process.

Since the weight of each data layer differs in the modeling process, the weight is represented as another set:

$$W = \{W_1, W_2 ,..., W_i ,..., W_n\} \quad \ldots \quad \ldots \quad \text{(Eqn 2.3)}$$

Where W_1, i = 1,2, . . ., n, represents the weight of each singular data layer.

Lastly, there is a set containing the decision space or valuation scale:

$$V = \{V_1, V_2, ..., V_K, ..., V_m\} \quad ... \quad ... \quad \text{(Eqn 2.4)}$$

Where V_k, k = 1,2, . . ., m, represents each decision space or valuation scale.

For example, V_k, may be the oil spill sensitivity scenario set {Option 1, Option 2, ...} if the sensitivity of the environment to spilled oil is to be represented, or V_k may be the valuation scale (highly sensitive, moderately sensitive, . . .) if the sensitivity of the area is to be examined.

The whole of the grid cells present in the i-th information layer can equally be portrayed as a subset on V, that is:

$$R_{DLi} = \{r_{ijk}\} \quad ... \quad ... \quad ... \quad \text{(Eqn 2.5)}$$

Where R_{DLI} is a fuzzy matrix (Sui, 1992):

$$R_{DLi} = \begin{bmatrix} r_{i11} & r_{i12} & \cdot & \cdot & \cdot & r_{i1m} \\ r_{i21} & r_{i22} & \cdot & \cdot & \cdot & r_{i2m} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & r_{ijk} & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ r_{in1} & r_{in2} & \cdot & \cdot & \cdot & r_{itm} \end{bmatrix} \quad ... \text{(Eqn 2.6)}$$

Where r_{ijk} is the membership grade of j-th grid cell in the i-th data layer to k-th class.

However, in the entire layer, the cells that has similar position considered (similar position but dissimilar attributes) signifies a subset on V, that is: $C_j = \{r_{ijk}\}$

In matrix, it can be presented as:

$$C_j = \begin{bmatrix} r_{1j1} & r_{1j2} & \cdot & \cdot & \cdot & r_{1jm} \\ r_{2j1} & r_{2j2} & \cdot & \cdot & \cdot & r_{2jm} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & r_{ijk} & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ r_{nj1} & r_{nj2} & \cdot & \cdot & \cdot & r_{njm} \end{bmatrix} \quad ... \quad \text{(Eqn 2.7)}$$

Similar to matrix (2), r_{ijk} is equally the membership grade of j-th grid cell in the i-th data layer to k-th class. Matrices (2) & (3) present the vital structure of the fuzzy illustration of raster format data. In a fussy application context, r_{ijk} is equally expressed by accurate membership role. The cartographic modeling procedure (the process of overlaying different data layers in GIS) is a function of set W and Cj, or in algebraic term, a fuzzy mapping from Cj to Bj through W, when merged together with the weight set (Sui, 1992):

$$B_j = W^T \bullet C_i$$

$$= \begin{bmatrix} W_1 \\ W_2 \\ \cdot \\ W_i \\ \cdot \\ W_n \end{bmatrix}^T \odot \begin{bmatrix} r_{1j1} & r_{1j2} & \cdot & \cdot & \cdot & r_{1jm} \\ r_{2j1} & r_{2j2} & \cdot & \cdot & \cdot & r_{2jm} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & r_{ijk} & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ r_{nj1} & r_{nj2} & \cdot & \cdot & \cdot & r_{itm} \end{bmatrix} \quad ... \text{(Eqn 2.8)}$$

where Bj is the j-th grid cell in the result data layer and

Θ represents the operator when carrying out cartographic modeling.

However, there exist different fuzzy operation systems in literature, for this study, the under listed algebraic multiplication operator is used:

$$B = \sum_{i=1}^{n} Wi^{*} r_{ijk} \quad \ldots \quad \ldots \quad \ldots \quad \text{(Eqn 2.9)}$$

The algebraic multiplication operator is assumed to be the fuzzy operator of this study. This is because all the assessment criteria have equally been considered and weighted in such a way that it is empirically accepted with cartographic modeling practice in GIS.

Methods:

Landform: The landform map of the world was downloaded from European Soil Data Center (2008). It was compiled by Iwahashi and Pike (2007). A landform is a natural feature of the earth's solid surface or other planetary body. These natural features together form a given terrain. It is these terrains when arranged on the landscape that make up a given topography. Typical landforms are hills, mountains, plateaus, canyons, valleys. Shoreline features such as bays, peninsulas, and seas, and also submerged features such as mid-ocean ridges, volcanoes, and the great ocean basins are all examples of landforms.

The landform classification according to Iwahashi and Pike (2007) is based on an unsupervised nested-means algorithms and a three part geometric signature. However, the slope gradient, surface texture and local convexity are analyzed and grouped based on natural data set property. It can be described (in terms of thresholds) as a dynamic landform classification method (Batuk & Emem, 2008). The local convexity is determined by using the 3 x 3 Laplacian filter, an image processing operation used for edge development and approximation of the second derivative or elevation (Iwahashi & Pike, 2007). Terrain texture is the measure of roughness or frequency of ridges and valleys. The measure is to highlight its fineness and coarseness, expression of topographic spacing, or grain. Texture is determined by extracting grid cells that outlines the spread of valleys and ridges in the DEM.

According to Iwahashi and Pike (2007), the landforms found within the study area include: medium steep, fine texture high convexity; medium steep, fine texture, low convexity, medium gentle, fine texture, high convexity; medium gentle, fine texture, low convexity; gentle, fine texture, high convexity; and gentle, fine texture, low convexity. Within this guide, landform helps to determine the sensitivity of the study area because it shows the possibility of cleanup and remediation. For instance, fine-textured shoreline soils has the quality of being compacted and stiff and does not allow easy penetration of oil especially during cleanup as workers will not easily trample oil deep into the soil. During oil pollution, cleanup will be much easier as it is highly trafficable and machines can work there easily. Also, compact, fine-textured shoreline substrates prevent oil penetration and reduce the quantity of oiled sediments that will be removed. On sheltered shoreline with fine-textured soil, burial of spilled oil is rarely important because of the effect of low wave energy. On exposed shorelines, deep burial of spilled oil can occur if the spillage occurred immediately after an erosional storm or at the beginning of accretionary period which is seasonal. Cleanup on fine-textured sandy shoreline is simple because of the presence of hard substrate that makes vehicle and foot movement stress-free.

Slope: According to NOAA (2002) Shoreline slope determines the steepness of the intertidal zone between maximum high and low tides. It can be described as steep when it is greater than 30^0; moderate when it is between 30^0 and 5^0, or flat when it is less than 5^0.

The shoreline slope is important in determining the sensitivity of an area to oil spill because of its consequence on wave reflection and breaking in an area not covered by thick vegetation. Steep intertidal areas usually experience sudden wave run-up and breaking, and this enhances natural cleanup of the shoreline. On the other hand, flat intertidal areas, encourage dissipation of wave energy further offshore, making oil to strand for a long period of time. Also, the broad intertidal zones often have wide spread of biological resources. However, slope is of less importance as regards to oil spill impacts in sheltered areas, except that biological resources that are sensitive to oil pollution develop more in flatter areas.

Soil: The African soil map was compiled by Dewitte et al., (2013) and was downloaded from European Soil Data Center (2008). Soil is a combination of mineral, organic matter, gases, liquids, and various organisms that collectively sustain life on earth. Soil is a natural body known as the pedosphere which has four major roles: it is a medium for plant growth; it is a means of water storage, supply and purification; it modifies the Earth's atmosphere; it is a habitat for organisms; all of which, in turn, modify the soil (Ward, 2008). The mineral components of soil include: sand, silt and clay, and their relative proportions determine a soil's texture. Soil texture controls the permeability, shrink-swell rate, porosity, infiltration rate and water-holding capacity of a soil. It also determines the susceptibility of an area to erosion.

This study considered the clay component of the soil because clay is the greatest mineral component and plays an active role in a soil more than the other components. The utmost advantage of sand to soil is the fact that it resists compaction and increases a soil's porosity. Silt has a greater surface area and it is more chemically active than sand. The clay component of soil makes the surface area to be high, makes it to have a greater amount of negative charges and high ability to retain water and nutrients. Silty and sandy soils accept soil erosion more than clay soils as the particles are highly compacted.

Because of the consolidated nature of clayey soils, it has low permeability and low potential depth of penetration, hence, oil penetration is always difficult. Penetration takes place when stranded oil on the surface sinks into permeable sediments. The depth of penetration is controlled by the grain size of the substrate, and also the sorting of the grain sizes in the sediments. Coarse sediments such as gravel with relatively uniform grain size that are well-sorted usually have the deepest penetration.

Clay content of the soil also influences the ability of cleanup crews and machinery to move during a cleanup effort. This means that areas with much clay pose difficulty during cleanup as machinery and people will find it difficult to move because of the slippery nature of clay. It does not encourage natural cleanup by wind and wave energy action as the particles bond tightly to each other.

Land cover: The land cover map was obtained from land cover base map of Rivers State. Land cover is the physical material at the surface of the earth. The land cover observed in the study area includes mangrove forest, secondary vegetation and sand/mud. When an oil slick gets to the shoreline, the oil coats and stick to every rock and grain of sand; if the oil washes into coastal marshes, mangrove forests or other wetlands, fibrous plants and grasses suck up the oil, which damage plants and make the whole area unsuitable as wildlife habitat, hence the importance of this feature in oil spill sensitivity mapping. It also influences the cleanup ability of a polluted area.

Population: In 2014, the population map of Africa that was land cover based was authored by Linard, Gilbert, Snow, Noor, and Tatem (2012). The data set is alpha version 2014 estimates of numbers of people per grid square, with national totals adjusted to match UN population division estimates. Population is the totality of all the organisms of similar group or species living in a particular geographical area, and having the capability of interbreeding. Population in this contest is the estimated persons per grid square (100 m^2) based on the association between land cover and population density. Oil pollution has adverse effect on population. The trace metals and hydrocarbon content of stranded oil contaminates both surface and ground water. Irrespective of the fact that the study area has soils high in clay content which offer some protection to the groundwater aquifer, it is often not enough during oil spill. Spillage also decreases soil fertility, suffocate food crops and economic trees, killing them or decreasing their yield, causing reduction in household food availability.

Preparation, processing of the layers, and fuzzy modeling were performed through ArcGIS 10.1. Also, preparing, arranging and presentation of this work was done in Microsoft word 2010.

Method of Data Collection

The study area delineation was derived from Rivers State base map acquired from the Rivers State GIS (RivGIS) using ArcGIS 10.1. From the base map, 5 km inland from the shoreline was clipped out and delineated and this formed the study area map. The 5km was considered as within maximum impact from coastal activities and other oceanic processes.

1. Landform of the study area was extracted from the landform map of the world compiled by Iwahashi and Pike (2007). The 5km clip of area of study was overlaid on the landform map of the world. This allowed the clipping out of the area of interest (5km inland from the shoreline) and this served as the landform map of the study area which was used for further geospatial analysis.
2. The slope map of the study area was extracted from the Digital Elevation Model (DEM) of Rivers State which was obtained from Shuttle Radar Topographic Mission (SRTM) 30m resolution. The 5km study area shapefile was overlaid on the DEM and the study area DEM was clipped out. The DEM was filled (to remove small imperfections in the data and then the slope calculated. This gave the slope map of the study area.
3. The African soil map downloaded from European Soil Data Center (2008) was compiled by Dewitte et al., (2013). The study area shapefile was overlaid on the African soil map and a 5km soil map from the shoreline was clipped out. This soil map contains the soil textural classes but for the purpose of this study, only the clay content of the soil was considered..
4. Similarly, the land cover map of Rivers State obtained from the base map of Rivers State was delineated to capture 5km from the shoreline and this served as the land cover map used for this study.
5. The population map of the study area utilized in this research was extracted from the 2014 estimated population map of Africa as compiled by Linard, Gilbert, Snow, Noor and Tatem (2012). The study area shapefile was overlaid on it and the population map of the study area was clipped out. The population map in raster format, portray the number of persons per grid square in the study area.

Determination and Preparation of Essential Criteria

The most essential criteria for determining shoreline sensitivity to oil spills, selected through reviewing literature and according to NOAA Environmental Sensitivity Index Guidelines (2002) include:

1) **Landform:** According to Iwahashi and Pike (2007), the landforms found within the study area include: medium steep, fine texture high convexity; medium steep, fine texture, low convexity, medium gentle, fine texture, high convexity; medium gentle, fine texture, low

convexity; gentle, fine texture, high convexity; and gentle, fine texture, low convexity. The landforms was rated as follows:

a) Extremely high sensitivity – 5
b) Very high sensitivity – 4
c) High sensitivity – 3
d) Moderate sensitivity – 2
e) Low sensitivity – 1

From the above rating, the various landforms were assigned sensitivity values, thus:

- Medium steep, fine texture high convexity - 1;
- Medium steep, fine texture, low convexity - 1;
- Medium gentle, fine texture, high convexity - 2;
- Medium gentle, fine texture, low convexity - 3;
- Gentle, fine texture, high convexity - 4; and
- Gentle, fine texture, low convexity - 5

This means that areas that falls within the gentle, fine texture, low convexity has the probability of having extremely high sensitivity while areas within the medium steep, fine texture high convexity has relatively low sensitivity. This is because; the former has a gentle and low convexity which will allow the percolation and sinking of spilled oil and therefore difficulty in cleaning and remediation; while the later will allow runoff and natural cleanup as a result of the steep and high convexity of the area.

2) **Slope:** The slope was obtained from the Digital Elevation Model (DEM) of the study area. It ranged from 0^0 – 37.845^0. From the NOAA Environmental Sensitivity Index Guidelines (2002), slope less than 5^0 are characteriesed as flat, between 5^0 and 30^0 as moderate and greater than 30^0 degrees as steep. That is to say that the study area falls mostly within flat and moderate slope with relatively small areas falling within the steep slope. However, it is a well known fact that the steeper the slope, the more the tendency of an area to undergo natual cleanup hence low sensitivity to oil spill. On the otherhand, flat/gentle slopes accomodate sensitive biological communities more than steep slopes thereby making it higher in sensitivity to oil spill. Moreover, it does not encourage natual cleanup. Intermediate slope, between 5^0 and 15^0 has infauna present but not usually abundant as gentle slope. This makes it more sensitive than steep slope.
3) **Soil:** Basically, the clay content of the soil found in the study area was considered and it ranges between 19 percent and 44 percent of clay. The shoreline type with high clay content (and steep slope) is highly impermeable, and so oil remains on the surface where natural cleanup will take place within a short period of time. However, in the absence of steep slope, cleanup of stranded oil on the surface will be difficult as the area will not be trafficable, posing difficulty for both cleanup crew and machinery.
4) **Land cover:** the land cover found in the study area include mangrove forest, secondary forest and sand/mud. Following the rating, the mangrove forest is rated 5 (extremly high sensitive), sand/mud is rated 4 (very high sensitivity) while secondary vegetation is rated 3 (high sensitivity). In mud dominated areas, substrate is flat and sediments are water-saturated so oil penetration is very low, except where animal burrows the soil because

ISSN 2229-5518

burrows can enable oil to infiltrate an impervious substrate. Also, Sediments are soft, with low trafficability and biological resources are often very high, this makes this feature sensitive to oil spill. Areas that are mangrove and secondary forest dominated are sheltered and therefore not exposed to wave energy (NOAA, 2002), hence natural cleanup is difficult. Any cleanup effort increases the penetration of oil thereby prolonging cleanup/remediation. These areas are normally important habitat for animals both aquatic and terrestrial making them sensitive to oil pollution.

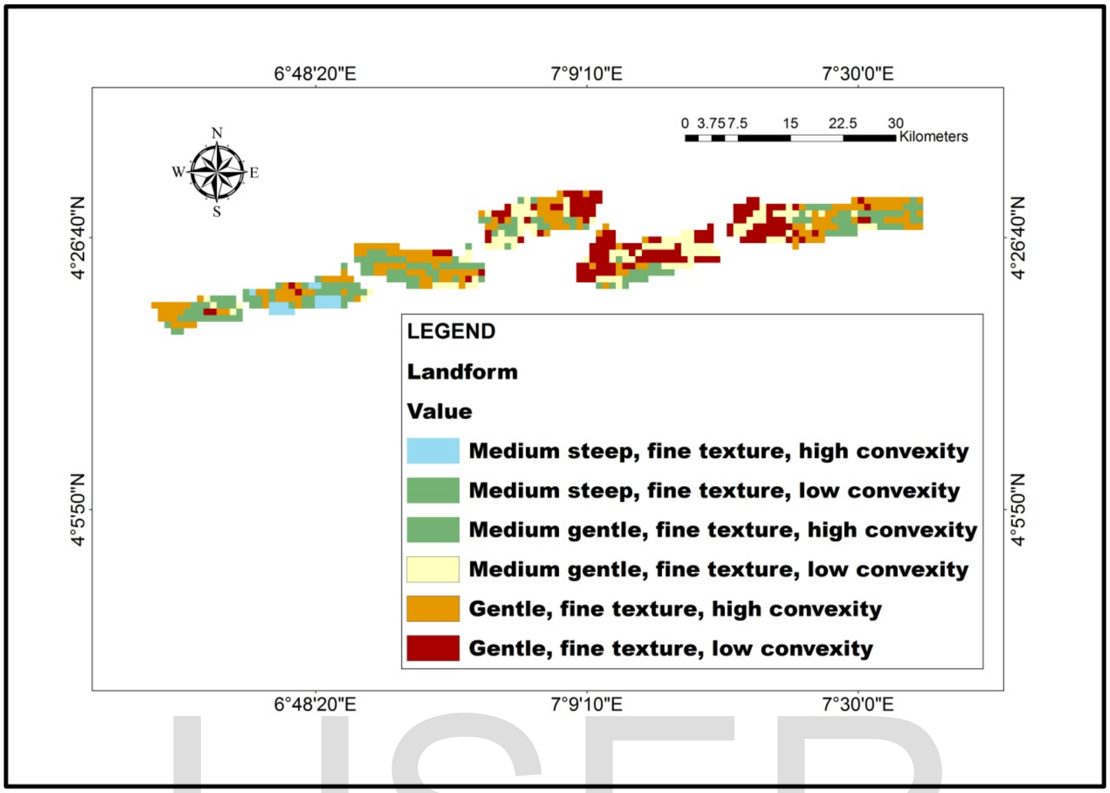
5) **Population:** The study area has the maximum population of four hundred and seventy eight persons per grid square. Human resources are vulnerable to oil spill when a greater proportion of the popuation are concentrated in a relatively small area and the area is exposed to oil spill. Places with high population will have high economic and social resources therefore oil pollution in such area will damage so many resource and will be difficult to cleanup.

For each of these criteria, a thematic map was prepared. These criteria (landform and land cover were classified according to sensitivity ratings while some (slope, soil and population) were classified based on expert judgment. These criteria were rated following the guideline from the standard ESI look-up table set up for Nigerian shorelines by the NOAA. The thematic maps for the criteria were all rasterized in other to run fuzzy membership analysis. The fuzzy membership analysis converts the input raster into a 0 to 1 scale, showing the strength of a membership in a set, based on a specified fuzzification algorithm. The ArcGIS fuzzy overlay was used to combine fuzzy membership raster data together, based on selected overlay type to develop sensitivity map of the study area.

The various shoreline properties

Landform

The western part of the study area is a combination of gentle, fine texture, high convexity; medium gentle, fine texture, high convexity; and medium steep, fine texture, low convexity with a little of medium steep, fine texture, high convexity landform types. In the central region, the landform found include: gentle, fine texture, low convexity; and a little of medium gentle, fine texture, high convexity; medium steep, fine texture, low convexity and medium gentle, fine texture, low convexity. The eastern part of the study area has medium gentle, fine texture, high convexity; and medium steep, fine texture, low convexity landform.

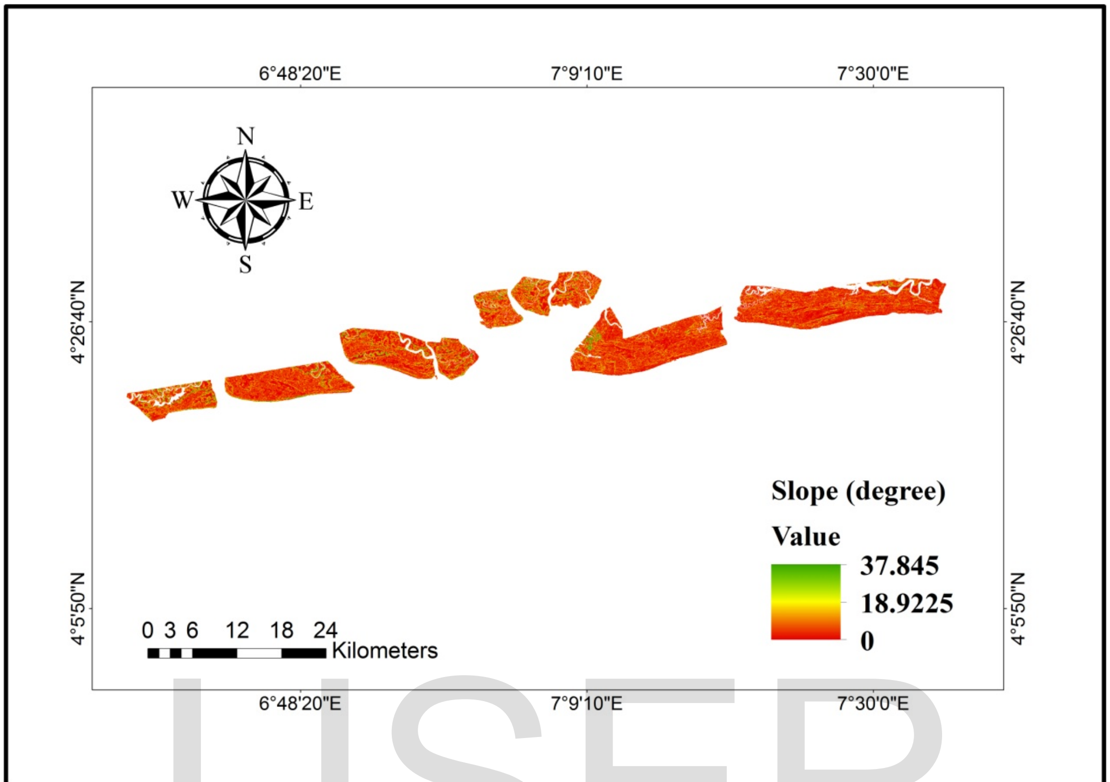


Source: Iwahashi and Pike (2007)

Figure 2 Landform across the Study area.

Slope:

The slope of the study area is generally flat (<5^0) especially at the eastern part of the study area. The central region especially Bonny has a little mixture of steep (>30^0) and moderate (5^0 - 30^0) slope while the western part has a little moderate and flat slope.



Source: Shuttle Radar Topographic Mission

Figure 3: Slope derived from DEM of the study area

Sand:

The map showing the study area soil portrayed the clay content of the soil. The soil of the western part of the study area has higher percentage clay (44%) than the eastern part (19%). The soil of the central part of the study area has mostly 19% clay with a little 44% clay present in the soil.

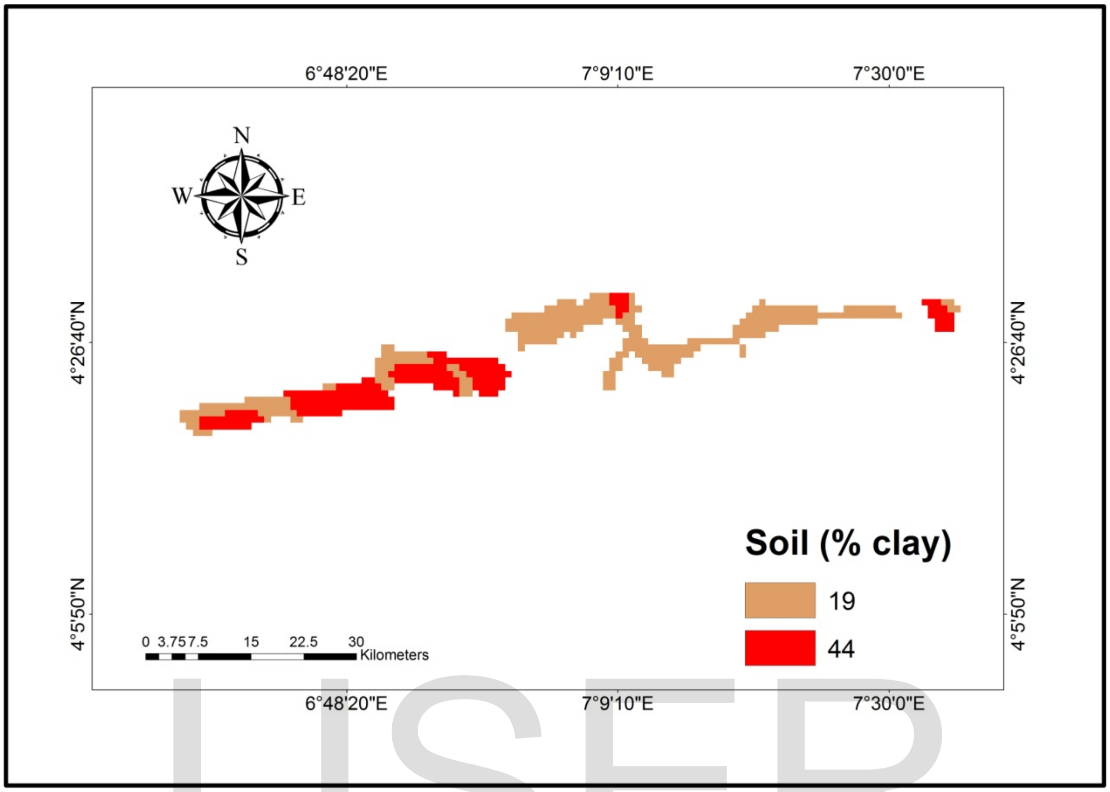


Figure 4 : Soil across the study area.

Land cover

In the study area, mangrove forest is dominant in the central region, while secondary forest is dominant in the eastern region. The western region of the study area has a combination of both mangrove and secondary forest. Sand/mud is sparsely present in the central region (Bonny).

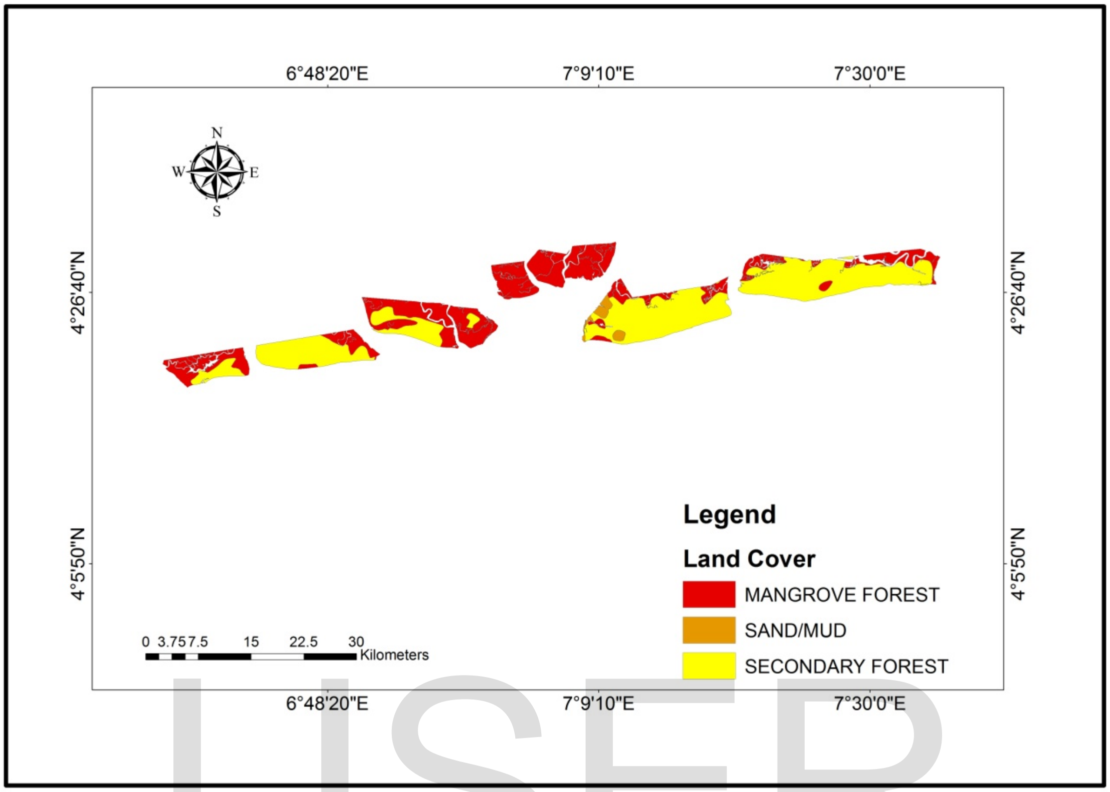
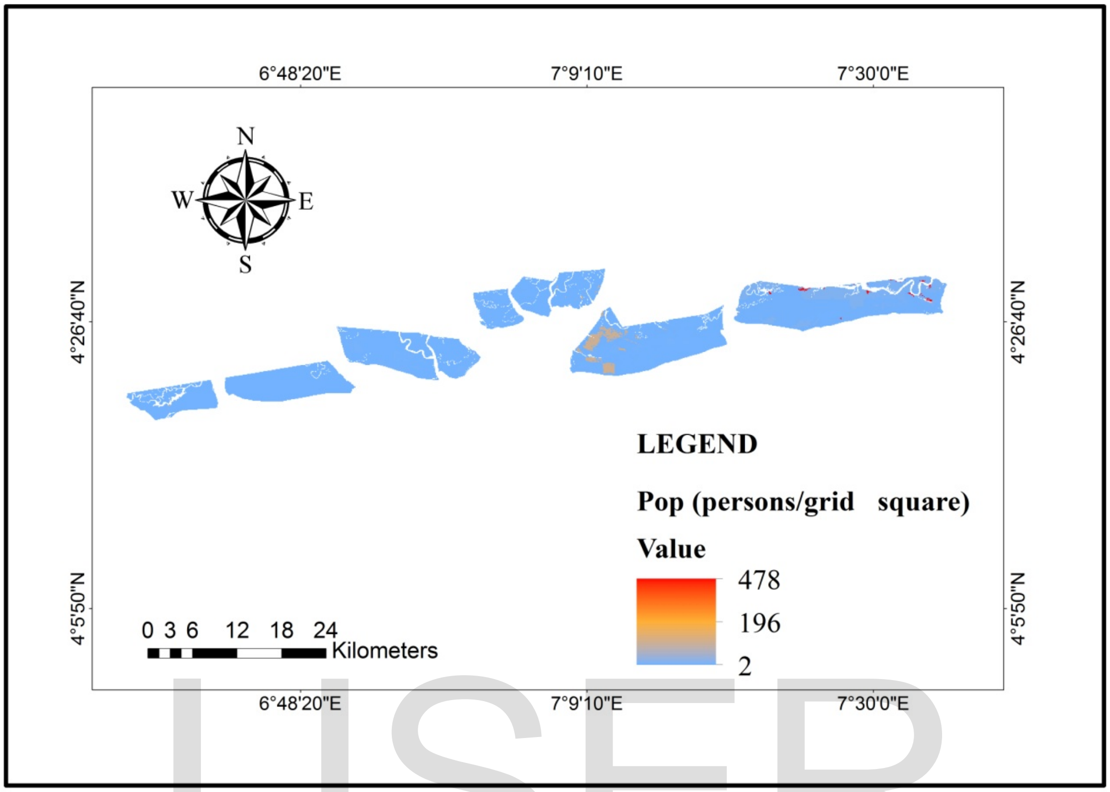


Figure 5 : Land cover characteristics of the study area

Population:

In the population map of Rivers State shoreline, most places show low population (about two persons per grid square). The central region shows about 196 persons per grid square while the eastern region shows sparse population of about 478 persons per grid square.



Source: Linard, Gilbert, Snow, Noor and Tatem (2012)

Figure 6 : Population Density of the study area

Data Analysis

Variations across the Shoreline in Relation to Socio-Physical Factors.

In the study area, variations exist among the resources as can be observed from the maps above. These variations can be accessed across regions.

Towards the western part of the study area the landform is mostly medium steep, fine texture, high convexity; medium steep, fine texture, low convexity; and medium gentle, fine texture, high convexity. In the central part, landforms found are: gentle, fine texture, low convexity; and medium gentle, fine texture, low convexity. Towards the eastern part, landforms found include: gentle, fine texture, high convexity; medium gentle, fine texture, high convexity and a little gentle, fine texture, low convexity landform. However, fine-textured shoreline soils have the quality of being compacted and stiff and do not allow easy penetration of oil especially during cleanup and this quality is found in the landform of the entire study area. Therefore the distinguishing factor is the steepness and convexity of the different regions. The western region with medium steep and high convexity landform will encourage natural cleanup of stranded oil on the surface within the shortest possible time. On the other hand, the eastern and some part of the central regions, dominated by gentle and low convexity landform, will support stagnation of oil on the surface and natural cleanup is impossible, making this region highly sensitive to oil spill.

In slope analysis, the study area has generally flat slope $<5^0$ while 30^0 (steep slope) and above can be seen sparsely especially towards the western and central part of the study area. In the regions where slope is steep (ie some part of the western and central regions), natural cleanup through the actions of wind and wave occurs. This means that stranded oil has the tendency of being removed naturally. On the other hand, flat/gentle slope (found mainly on the eastern region) encourage stranding of oil while natural cleanup is impossible. Also, intermediate slope, between 5^0 and 15^0 found mostly within the western and some parts of the eastern regions have infauna present but not usually abundant as the once found within gentle sloping areas like the eastern region of the study area. In terms of slope analysis however, this implies that, the eastern region has a higher tendency of being more sensitive to oil spill than the other regions of the study area.

In the area of soil, clay content is higher towards the west (44%) and lesser towards the central and eastern part of the study area (19%). This means that the western region with higher clay content will not support oil penetration and so oil will remain on the surface where natural cleanup will take place because of the steep nature of the slope. However, in the absence of steep slope, cleanup of stranded oil on the surface will be difficult as the area will not be easily trafficable, posing difficulty for both cleanup crew and machinery. On the other hand, the central and eastern regions with lesser clay content of the soil will encourage penetration and sinking of oil. Therefore, it can be inferred from above that the soil of most regions of the study area is environmentally sensitive to oil spill.

In land cover analysis, mangrove forest is more towards the central part of the study area while secondary forest is more towards the east. The western part of the study area has a mixture of mangrove and secondary forest. Sand/mud is sparely present in the central part and towards the eastern part of the study area. However, the entire study area which is mangrove and secondary forest dominated are sheltered and therefore the exposure to wave energy is limited thereby making natural cleanup difficult. Also, fibrous plants and grasses suck up oil which damage plants and make the entire area unsuitable as wildlife habitat. In some parts of the central region where sand/mud are found, substrate is flat and sediments are water-saturated so oil penetration is very low, and because of the gentle nature of the slope, there is the presence of sensitive biological communities. These animals burrow the soil and burrows can enable oil to penetrate an imperious substrate. Also, sediments in this mud dominated areas are soft with low traficability. These delineate the entire study area as highly sensitive to oil spill in terms of land cover.

In terms of population, the study area generally has a low population of about two persons per grid square, except for the central part around Bonny where population is about 196 persons per grid square. Towards the eastern part of the study area, population is about 478 persons per grid square making this region highly sensitive to oil spill.

Fuzzy membership Analysis

Fuzzy Membership converts the input data to a 0 to 1 scale based on the possibility of belonging to a particular set. Zero is assigned to those features that does not belong to the set, one is assigned to those features that belong to the set, and the series of possibilities between 0 and 1 are allocated to some level of possible membership (the larger the number, the greater the possibility). In this research, the fuzzy membership analysis converts landform (for instance) to a 0 to 1 scale based on the possibility of being sensitive to oil spill. Zero is allocated to the type of landform which is not sensitive while one is allotted to those ones that are sensitive to oil spill. The series of probabilities between 0 and 1 is determined by the type of fuzzy membership applied. This means that the larger the number, the greater the chances of a feature being sensitive to oil spill. There are various types of fuzzy membership. They include: fuzzy large, small, Gaussian, linear, Mean-Standard-Deviation (MS) Large, Mean-Standard-Deviation (MS) Small and fuzzy near. For the purpose of this research, Fuzzy Large and Small were used.

The Fuzzy Large transformation function is used when there is the likelihood of larger input values becoming a member of the set. It normally has a midpoint of 0.5 which shows the crossover point. This means that, values greater than the midpoint signifies a greater possibility of becoming part of the set, while values less than the midpoint signifies a lesser likelihood of becoming part of a set. In this study; landform, sand, vegetation and population belong to this category.

In analyzing the landform of Rivers State shoreline, values higher than the defined midpoint, assigned a membership of 0.5, has a higher possibility of being analyzed as a member of a set while the landform values below the midpoint has a lower chance of being analyzed as part of the set (Fig 7). Simply put; the higher the rating of the landform, the higher the sensitivity to oil spill. That is to say that places with medium steep, fine texture, high convexity; medium steep, fine texture, low convexity; and medium gentle, fine texture, low convexity (with rating of 1, 1, 2, respectively) is most likely to be less sensitivity to oil spill when compared with places with medium gentle, fine texture, low convexity; gentle, fine texture, high convexity; and gentle, fine texture, low convexity (with rating of 3, 4, 5 respectively). This is because, when oil spill occurs, the areas with gentle and low convexity will allow the stagnation of oil and therefore will be very difficult to cleanup; while the places with medium steep and high convexity will encourage natural cleanup, all things being equal. This means that the landform of the eastern and some part of the central regions of the study area is sensitive to oil spill while the western region is not.

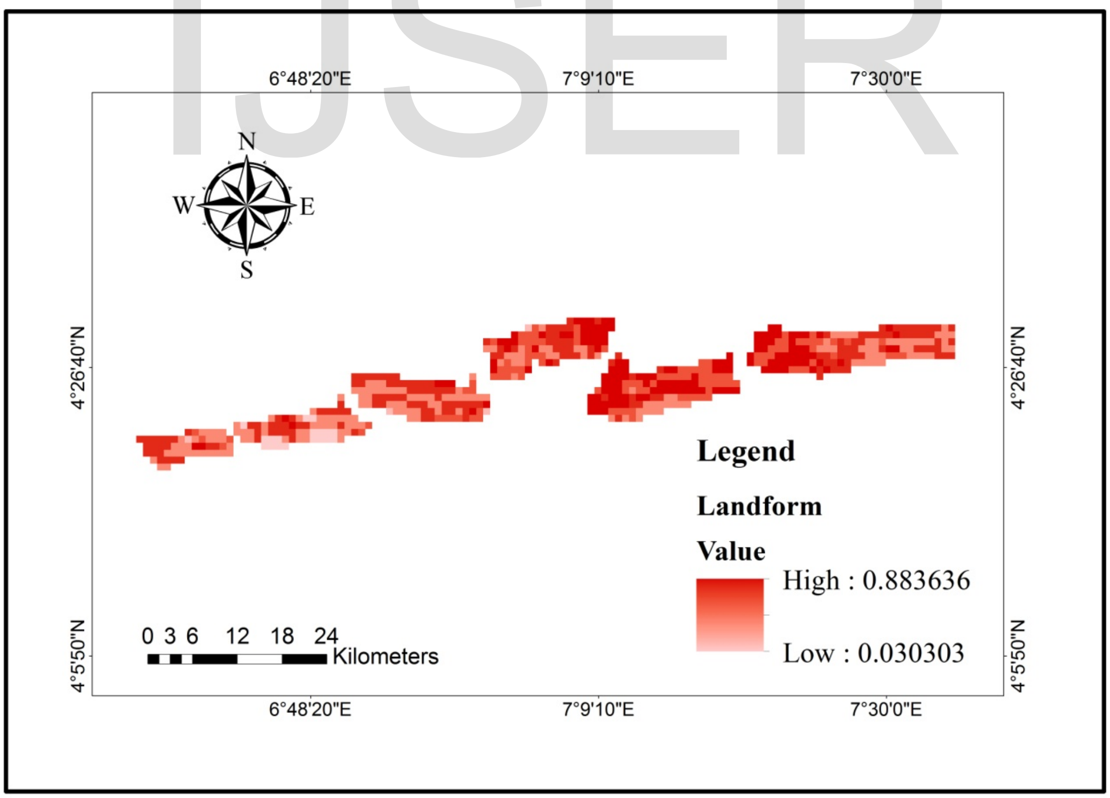


Figure 7 : Fuzzy membership of Landform for the study area.

In analyzing the soil of the study area, the regions with clay soil value greater than the midpoint of 0.5 has high possibility of being a member of a particular set while those below the midpoint having a decreasing possibility of belonging to the set. It can be deduced from the map that the soil of the study area is sensitive to oil spill since the entire region has clay soil value greater than 0.5 which means they all belong to the same set (Fig 8). This notwithstanding, the soil of the western part is more sensitive than the rest of the regions. In fuzzy large transformation function, this simply means that the higher the clay content of the soil, the more sensitive the area is to oil pollution.

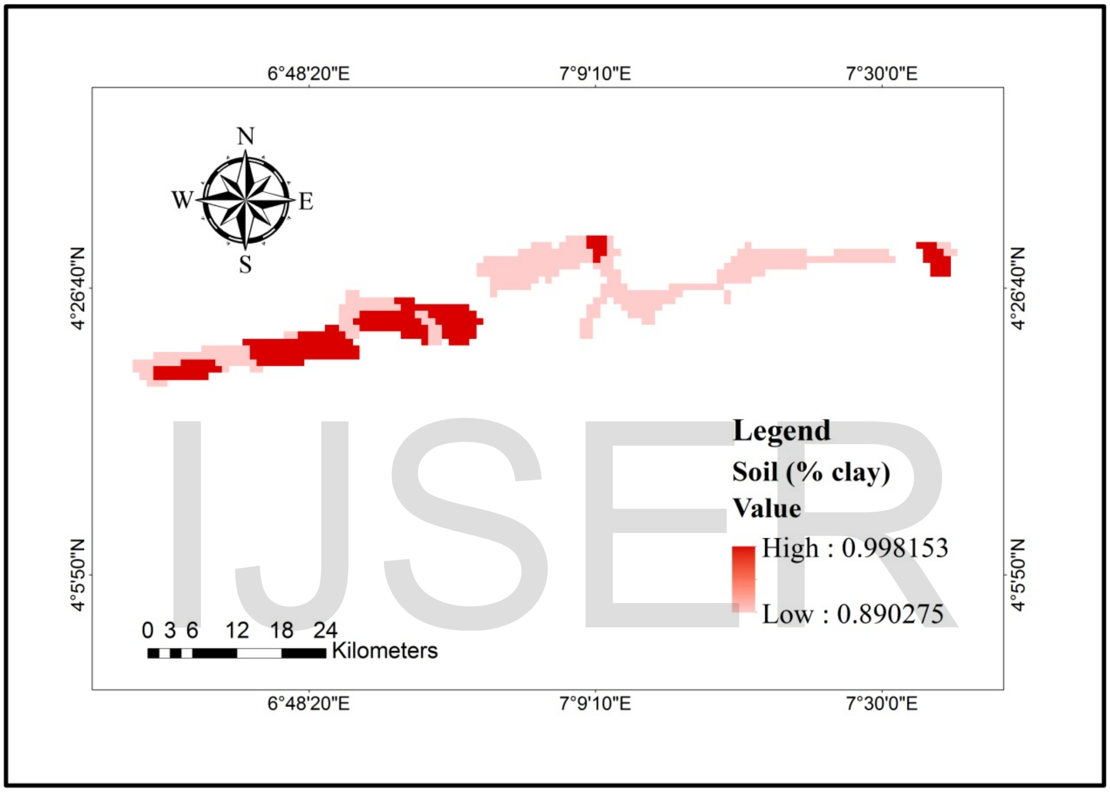


Figure 8 **: Fuzzy membership of clay content for the study area.**

Similarly, land cover with the sensitivity rate of 3, 4, 5 (that is, high, very high and extremely high sensitivity respectively) for secondary forest, sand/mud and mangrove forest respectively is also a member of this functional class. This means that, the land cover of most part of the western and eastern regions of the study area have high sensitivity while the central region has low sensitivity to oil spill. That is; the higher the value, the more sensitive the area is likely to be to accidental oil spill.

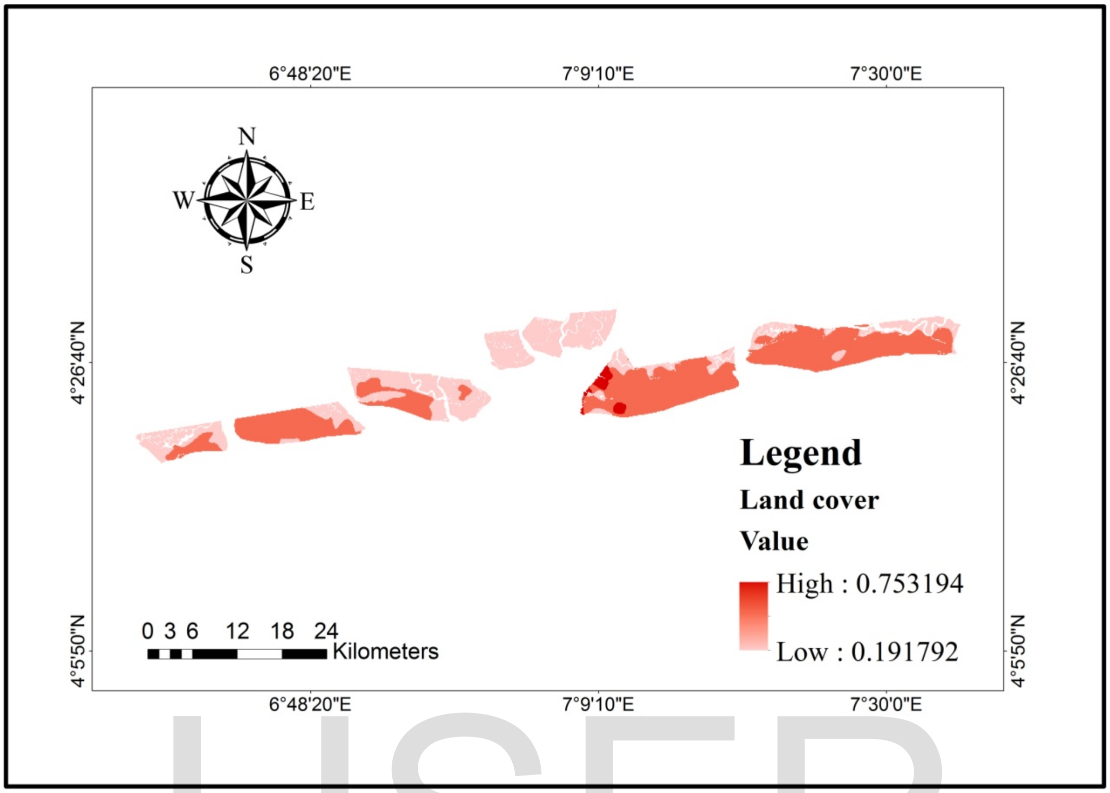


Figure 9: Fuzzy membership of land cover for the study area.

However, fuzzy large transformation function is also applied in analyzing the population sensitivity of the study area to oil spill. From the fuzzy membership of population map, it can be seen that the eastern region of the study area has values greater than 0.5 which means that it belongs to a particular set while the central and the western regions have values less than 0.5 indicating less likelihood of belonging to that particular set. That is to say that area within the eastern region with high population per square grid is more sensitive to oil spill than areas found within the western region with lesser population per grid square (Fig 10).

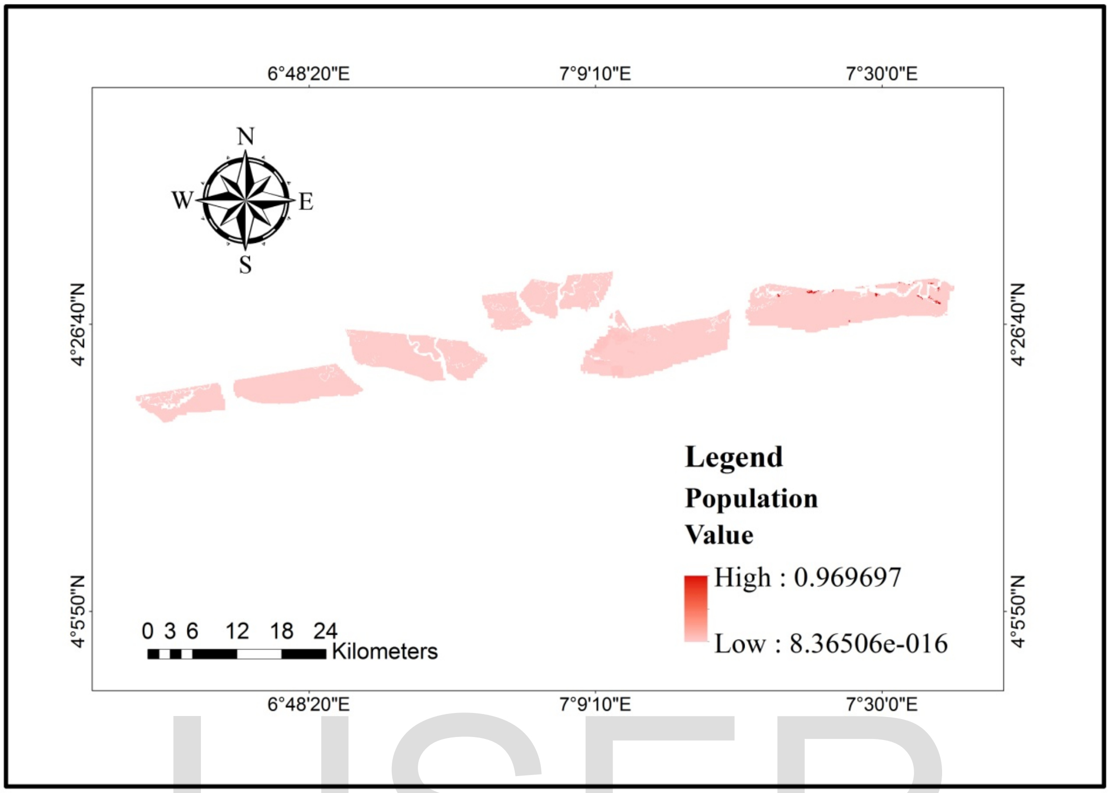


Figure 10: Fuzzy membership of Population density for the study area

On the other hand, fuzzy Small transformation function works when there is a likelihood of smaller input values to belong to the set. Here the midpoint is 0.5 and it shows the crossover point and values greater than the midpoint indicates a lower probability of becoming part of the set and vise versa. Fuzzy small transformation function is applied in analyzing the slope of Rivers State shoreline. The steeper the slope, the less sensitive an area is to spilled oil (Fig 11).

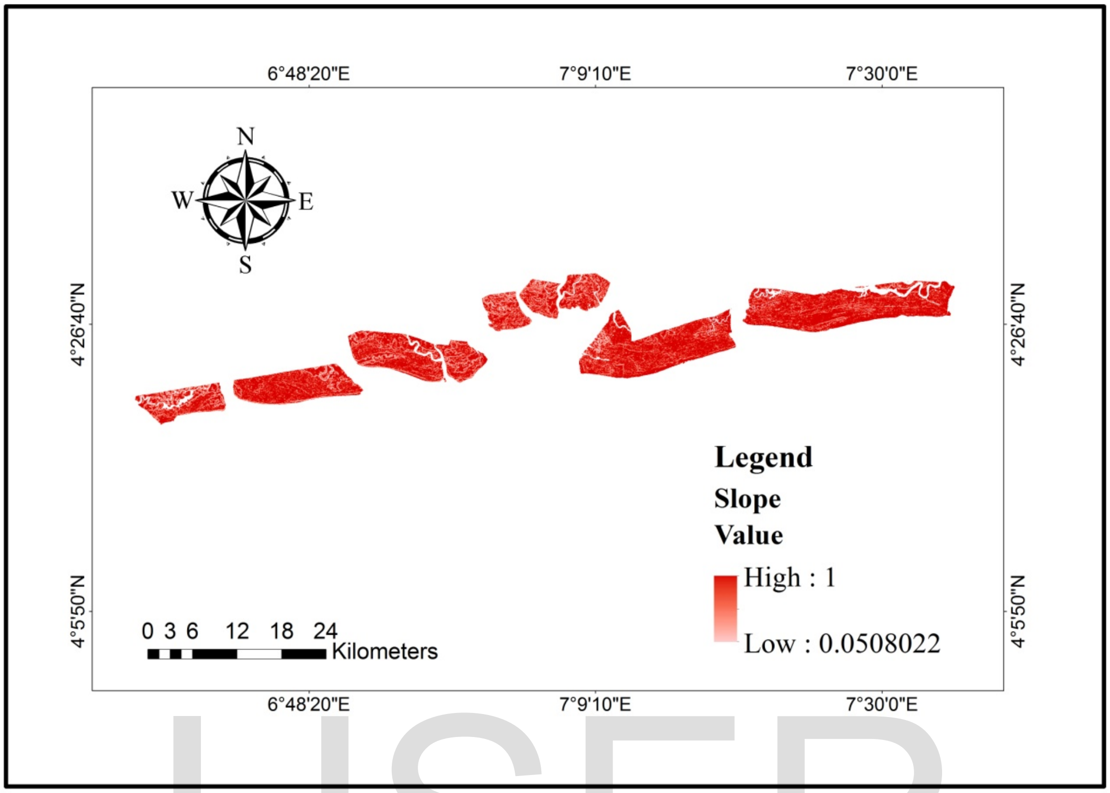


Figure 11: Fuzzy membership of slope for the study area

Fuzzy Overlay

Fuzzy overlay combines fuzzy membership raster data in a continuous field of polygon together, based on selected overlay type. The Fuzzy Overlay tool gives room for the analysis of the probability of a feature belonging to multiple sets in a multi-criteria overlay analysis. Aside establishing the particular sets a feature is possibly belonging to, it also determines the relationships between the memberships of the multiple sets. There are various Overlay types that exist in literature, they include: fuzzy and, fuzzy or, fuzzy Product, fuzzy Sum, and fuzzy Gamma. These methods allow the examination of the membership of each cell belonging to various input criteria. For the purpose of this study, Fuzzy Gamma overlay was utilized.

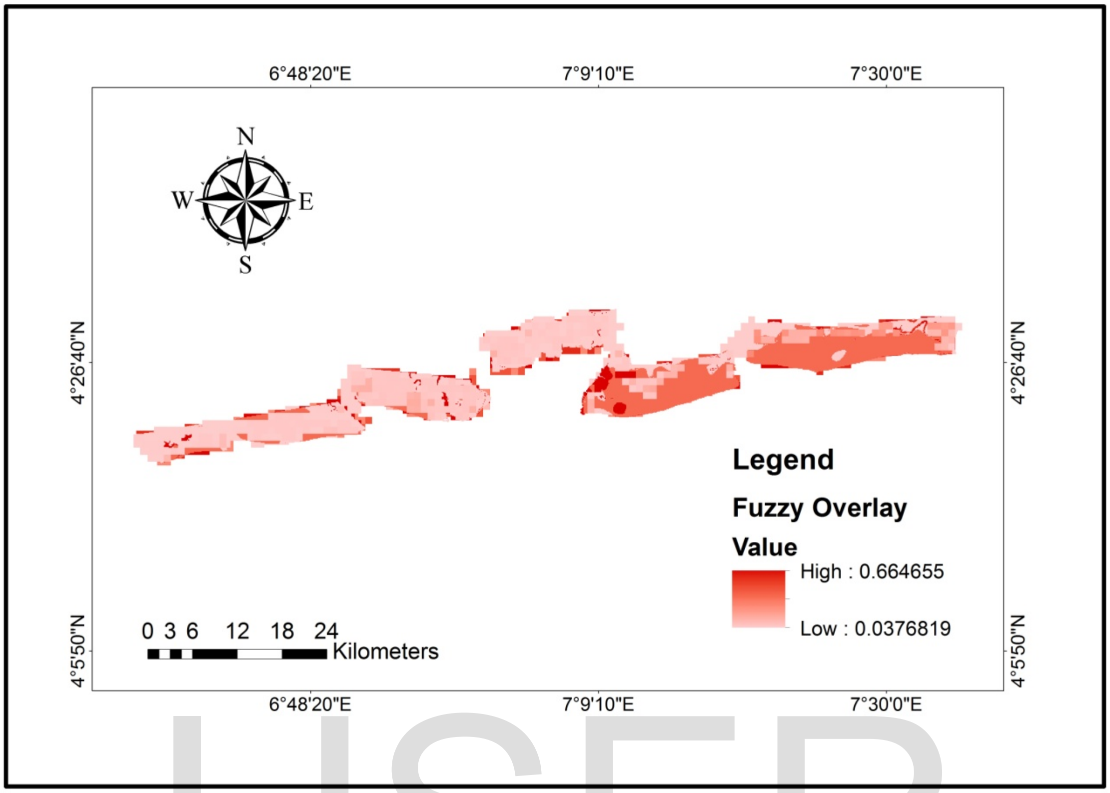


Figure 12 : Sensitivity map of Rivers State shoreline.

Fuzzy Gamma ascertains the relationships that exist between the various input criteria and it does not reverse the value of a single membership set. It is an algebraic result of fuzzy Product (which for a particular cell, multiply each one of the input values for the entire input criteria) and fuzzy Sum (which is the addition of all the values of each set the cell location is a member), and are both raised to the power of gamma (Esri, 2016). It was used to overlay all the fuzzy membership criteria and a spatially explicit model of environmental sensitivity of Rivers State shoreline to oil spill was created (Fig 12). This sensitivity map shows that resources found within the eastern region of the study area comprising of Andoni, Opobo/Nkoro and the eastern part of Bonny local government areas are more sensitive to oil spill than the once found within the central and western regions (comprising of Akuku-Toru, Degema and the western part of Bonny).

Conclusions

In this study to determine the sensitivity of Rivers State shoreline to oil pollution, fuzzy logic was effectively utilized. Using this model seems to be more convenient and enables experts express their ideas freely and adequately. It is also flexible and dynamic and allows the use of available data to determine the sensitivity of a data deficient area. The result of the research implies that the predicted sensitive region of the shoreline is at the best likely location which means that the fuzzy model is a proficient and reliable method to assess the sensitivity of an area to oil pollution. It showcased the eastern part of the study area (cutting across Andoni, Opobo/Nkoro and the Eastern part of Bonny local government area) as having the most sensitive resources.

ESI maps can be provided as a tool that can be used by oil spill response personnel to identify resources potentially at risk during oil pollution, in other to set priorities for protection and cleanup within the shortest possible time. ESI maps are essential tool for contingency plan. They can identify sensitive areas and also suggest suitable clean-up methods to curtail the negative impacts of spilled oil on the environment.

Recommendation

In order to reduce the response time and remedy resources at risk to oil spill, the application of GIS as an operational tool is hereby recommended. Information on the position and possible size of the oil spill can be made available via maps. This will enable the combat team set priorities for protection and remediation.

Also, it is essential to create regional spill response centers along shorelines as this will help in managing oil pollution. The staff of these centers should be trained personnel who can be able to create and interpret sensitivity maps and will use these maps to swing into action during oil spill.

Government should encourage more studies on the coastline by providing information and data base in other to ease research.

For further studies, it is recommended that the abilities of other types of fuzzy membership such as fuzzy Gaussian, fuzzy Near, fuzzy MS large and Small can be assessed for the determination of shoreline sensitivity to oil spill.

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