Inland Habitat Environmental Sensitivity Index Mapping And Modeling Using Geographic Information Systems And Remote Sensing Technology

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Abstract

This study applies the Inland ESI mapping model developed by ERML and ESRI for the Niger Delta to the southeastern coastal region of Nigeria. Traditionally ESI mapping had been applied to shoreline areas and the maps typically contain three types of information: shoreline classification in terms of sensitivity to oiling, human-use resources, and biological resources. The ESI shoreline classification scheme is a numeric characterization of the sensitivity of coastal environments and wildlife to spilled oil. ESI was developed to reduce the environmental consequences of a spill and help prioritize the placement and allocation of resources during cleanup efforts. An improvement to the traditional ESI atlas has further been added through the development of ESI for inland/interior areas. This is particularly significant in the Nigeria context where many oil and gas facilities are located in the inland/interior habitats. This study shows that the model developed for the Niger delta is equally applicable to southeast coastal environment. The modeling is done using satellite imagery followed by rigorous field data collection and modeling within Arcview GIS environment. The GIS approach is quite ideal for ESI modeling because of its capability to sequentially overlay different data layers for various kinds of spatial statistical analysis and spatial modeling. The most critical element is the construction of the database: the relational database structure adopted greatly facilitates data search and analytical operations.

Keywords: Environmental Sensitivity Index, geographic information systems, remote sensing

Introduction

The Environmental Sensitivity Index (ESI) mapping concept was developed in 1976 and has since become an integral component of oil-spill contingency planning and response as well as coastal resource management in the USA and other countries worldwide [1]. The first ESI maps were prepared days prior to the arrival of the oil slicks from the IXTOC 1 well blowout in the Gulf of Mexico [2]. Since then ESI atlases and databases have been prepared for most of the U.S. shoreline, including Alaska and the Great Lakes. ESI Atlases are used in oil spill evaluation, prevention, and clean up processes. It must be noted that prior to 1989, ESI atlases were often prepared manually using traditional cartographic methods. However, since then, ESI Atlases have been generated using Geographic Information Systems (GIS) techniques. The use of GIS and remote sensing techniques in the development of ESI Atlases is made possible because of the rapid development in computing and other allied information technology fields [3][4].

Traditionally ESI mapping has been applied to shoreline areas and the maps typically contain three types of information: shoreline classification in terms of sensitivity to oiling, human-use resources, and biological resources [5], [6]. Managers can look at an ESI map of an area threatened by a spill to quickly identify the most sensitive locations. Generally ESI maps have become a vital decision support tool used by government and industry to improve oil spill response and enhance the protection of the most sensitive habitats and localities.

ESI mapping can be described as the cartographic presentation of selected environmental attributes of a given area. The attributes are classified and ranked in terms of sensitivity to a stress factor (e.g., oil) and colour coded to distinguish environment type/class. In reality, it is a measure of the sensitivity of coastal zone natural resources to a stress factor (in this case oil /chemical spill), which is then depicted in form of maps and atlases [7].

The ESI shoreline classification scheme is a numeric characterization of the sensitivity of coastal environments and wildlife to spilled oil. Shorelines are colour-coded differently to indicate their sensitivity to oiling. To code them differently, a form of objective assessment and ranking of the shoreline attributes in terms of their perceived value in the ecosystem plays a significant role. The shoreline ranking concepts described by [8], and others, provide a scale of one to ten (ten is most sensitive) to indicate shoreline sensitivity and the use of symbols and patterns to indicate point or polygon (area) locations that are ecologically and/or socio-economically important. Within each numeric division, there are several alphabetic sub-classifications that further clarify the type of coastal environment and its sensitivity to spilled oil.

On ESI maps, warm colours like red and orange denote the shorelines that are most sensitive to oiling, such as tidal flats, swamps, and marshes. Cool colours like blue and purple indicate the least sensitive shorelines, such as rocky headlands and sand and gravel beaches. Shades of green denote shorelines of moderate sensitivity [9]. Large habitat areas, such as tidal flats used by shellfish and wetlands used by shorebirds or waterfowl, are shown as colored polygons. Wildlife of all types is mapped based upon known habitats, locations, and seasonality. This information is cross-referenced for each map in the atlas and is scientifically based and documented thoroughly. Each atlas comes with a detailed documentation, legends, and metadata to provide scientific support for oil spill responders. Other information of great importance on ESI maps include sensitive biological resources such as seabird colonies and marine mammal hauling grounds which are depicted by special symbols on the maps. In addition, important human-use resources such as water intakes, marinas, and swimming beaches are depicted with appropriate symbols on the maps [10].

Reference [11], noted that ESI was developed to reduce the environmental consequences of a spill and help prioritize the placement and allocation of resources during cleanup efforts. The successful use of analog and digital geographic information system versions of the ESI concept during the past ten years has led to improvements and refinements, including (1) the development of tidal inlet protection strategy maps produced before a spill that specify the type of response (e.g., boom, skimmer) and where and how to place it, (2) new large format seasonal summary maps, (3) geographic expansion of the ESI concept inland to classify the sensitivity of rivers using a river Reach Sensitivity Index (RSI), (4) regional watershed analysis to identify hazards and potential spill consequences, and (5) the identification of unusually sensitive areas to environmental damage if there is a hazardous liquid pipeline accident. Despite all these, the basics of ESI mapping have remained constant throughout almost all projects, which serve to support the validity of its original conceptual design and format [12]. An improvement to the traditional ESI atlas has further been added through the development of ESI for inland/interior areas. This is particularly significant in the Nigeria context where a lot of oil and gas facilities are located in the inland/interior habitats. Environmental Resources Managers Limited (ERML, Nigeria) in association with Environmental Systems Research Institute (ESRI, California) developed an ESI habitat modeling approach for the inland areas of the Niger Delta oil producing region. This paper is concerned with the application of this model in an oil producing region in Nigeria's southeastern coastal area.

Objectives

The aim of this study is to demonstrate the utility of the inland ESI habitat modeling approach developed by ERML, Nigeria and ESRI, California for the Oil Producers Trade Section (OPTS) of the Nigeria Chamber of Commerce and Industries in the evaluation of the sensitivity of an area in Akwa Ibom State, Southeastern Nigeria that has a large number of oil and gas facilities. In order to achieve this, the following objectives and stages provided the required direction to the study:

i. To collect all relevant primary and secondary data and information relating to oil and gas activities as well as the locations of communities and other biological resources in the delineated study area
ii. Using appropriate software, to develop the initial habitat classes using unsupervised classification algorithm (Level 1 ESI map)
iii. Based on (ii) above, design appropriate sampling plan for the field data collection and verification of the initial habitat classes (Level 1 ESI map)
iv. To collect georeferenced habitat based data on soil, vegetation, wildlife, socio-economics, and beach geomorphology
v. To determine the sensitivity of the terrestrial and socio-economic resources within and around the area of study to oil/chemical spill damage so as to enhance development of a more effective and coherent strategy for pollution response and prevention
vi. On the basis of the above, to model the sensitivity of each inland and outer coastline habitat within the delineated area.
vii. to identify and inventory environmental resources within the delineated area.
viii. to characterize, classify and rank identified resources based on sensitivity to oil; and
ix. to develop and produce cartographic representations of the environmental attributes of the areas for the purpose of oil spill response

Area of Study

Administratively, the study area is located in the Mbo Local Government Area (LGA) of Akwa Ibom State, Nigeria. Geographically it is located within Latitudes 8^0 12’ and 8^0 18’N and Longitudes 4^0 32’ and 4^0 36’E. The area is located adjacent to the Cross river estuary which is one of the most important river estuaries in Nigeria. The study area is about 35km from the Calabar Town Export Free Zone and about 18km. east of Qua Iboe terminal and 244km. east of the Brass River LNG development project. This study area comprises of a number of oil and gas facilities both onshore and offshore. The onshore area consists of dry, flat, fresh water rainforest and mangrove swamps and beaches, while the offshore component is largely made up of ocean water.

Methodology

The methodology used in this study is contained in the ‘ESI Mapping Standard and Protocols’ [13], developed for the OPTS. For the purpose of ESI classification, a distinction is made between the inland/interior and the coastal/shoreline habitats [14]. Coastal habitats are defined as those areas affected by marine, brackish, or riverine processes. Inland habitats do not experience marine processes being typically at least 1.5m above sea level in elevation.

The vegetation is essentially rain fed, although heavy rains may cause flooding in some parts. The inland /interior habitats in the oil and gas producing areas do not have the same history of sensitivity analysis as the shoreline and coastal environments, primarily because spills that occur on land are commonly locally controlled, cleaned up, and replanted so that the effects are relatively short-lived [15].

Figure 1 shows the cartographic model that was employed in the study. The data used in the ESI modeling for the inland habitat and the outer coastline sensitivity were derived from both primary and secondary sources. The secondary data were derived from relevant bibliographic and spatial data from the oil and gas companies operating in the area of study.

These materials were reviewed in terms of their suitability for integration into the ESI database that was ultimately used in modeling the interior inland habitats. The primary data collection involved the direct collection of the required data from the study area on vegetation, soil and geomorphologic characteristics. In collecting the primary data, Landsat satellite imagery covering the study area provided a significant direction on how the field sampling was carried out.

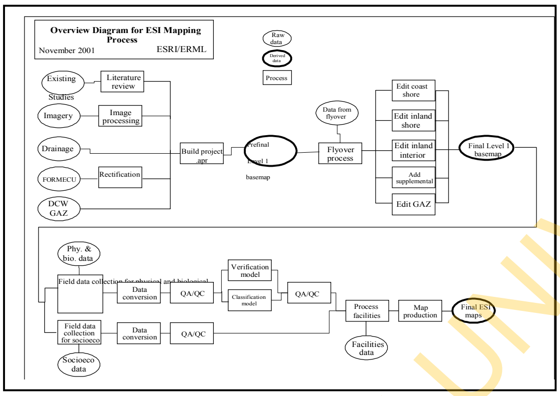

Figure 1: Cartographic Model for the ESI Mapping

Image Processing

The second most important activity involved the development of the Pre-Final Level 1 ESI map used in the field data collection. A Landsat ETM imagery which was acquired in January 2006 was used in the development of the ESI Map. The image was georeferenced and enhanced in order to visually differentiate possible inland habitats in the study area [16]. The satellite imagery was classified using an unsupervised classification algorithm technique to derive initial habitat classes. The unsupervised classification algorithm yielded four different habitats: two inland and two shoreline types. The four habitat types identified on the image provided the basis for planning the field investigation especially the selection of sampling sites. However, prior to the field sampling, a contingency plan was made to sample additional habitats that may not have been captured on the image but which are visible on ground. This is one problem that a helicopter over flight would have solved easily, but because of logistic problems, the fly over could not be done. The implication of skipping the flyover component was that more effort was expended in the field sampling.

Field Sampling Design

A random site selection process was used to identify inland and coastal sampling sites to facilitate the extrapolation of the data collected at those sites to other places in the study area. This methodology uses the word "site" to describe a location where samples are collected. But for the inland/interior habitats a site is made up of six "stations" from which specific measurements and observations were made. Data on the six stations were subsequently combined to represent a set of single site indexes that enabled comparisons among sites and polygon types [17]. Site coordinates generated by the GIS were located in the field using a global positioning system (GPS) receiver. The application of the random site selection algorithm involved the placement of 400m x 400m tessellations on the pre-final level 1 ESI Map. The grids were created using ArcView 3.3 Avenue script. Another Avenue script was used to randomly select fifteen (15) cells (sites) from the grids covering each habitat. The selected sites must however be completely within the habitat and not located at the boundary of the habitat and other habitats.

In all, thirty (30) sampling sites were thus randomly selected for the five identified habitats. The centroid location for each grid then became the sampling origin for data collection during the field survey. The coordinates of the centroid points were extracted using ArcView GIS Software. Once all 30 alternate sites had been selected, transect bearings were established for each site. The design was such that transect station 5 would always begin at the direct center of the square (See Figure 2)

In terms of the shoreline sampling design, at least three sampling sites were established on each type of shoreline encountered during the field survey. A series of station points were located at 400-meter intervals along the shoreline and each station point was numbered sequentially. A random selection procedure was equally employed to identify the shoreline segments from which samples would be subsequently collected during the field sample. For each instance of shoreline type, three station points were randomly selected from the total number of the 400m segments. The selected coastal /shoreline segments were sampled adequately for ESI related data collection

Establishing the Transect

Once all the sites were identified, the next activity involved the determination of the transect direction in each of the sites. The first step in determining transect bearing was to identify the latitude and longitude point of the exact center of the square. From that point the transect radiated outward for 100 meters. A random process was used to determine what bearing from north the transect would follow. At least one backup bearing was generated for each site [18]. The second 100-meter transect always fell 90^{o} clockwise from the original transect. To establish a bearing, the magnetic north was determined using a hand-held compass. Next, the bearing was determined by randomly selecting a direction using a pie chart.

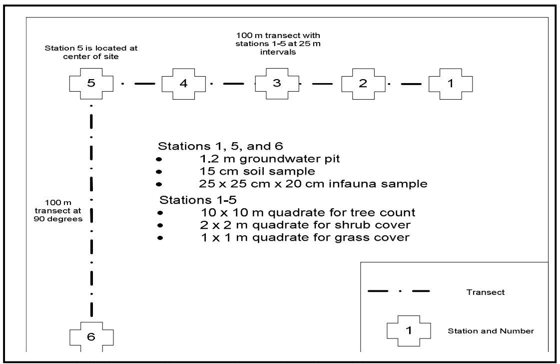

Figure 2: Field Sampling Design:Inland Habitat Type (OPTS 2001)

Field Data Collection Activities: Inland Habitat Data Collection

Four parameters related to spill persistence and cleanup difficulties which were measured in the field include (a) type of substrate (b) presence of near surface groundwater (c) presence of inhibiting penetrating layer and (d) presence of surface debris [19]. Figure 2 shows the field sampling design for the inland/interior ESI habitats mapping for the study area. For each of the five (5) sites, six stations each were established in line with the above diagram. Furthermore, field templates contained in the ESI Mapping Standards and Protocols [20], were used in recording the collected data in-situ. A brief description of the types of data collected with the templates is provided below. Further detailed description of this methodology is contained in the ESI Mapping Standards and Protocols.

The following data were collected for the inland/interior habitat locations during the field data collection exercise:

1. Environmental data on each station including the geomorphology, sediment type, flora and fauna, health of vegetation, locations of small water bodies and groundwater were collected. All the sites were visually inspected for the amount of surface debris covering the site including leaf litter, dead trees, and broken branches. A visual aid contained in the ESI Mapping Standards and Protocols was used to estimate the percentage of debris cover at each of the site visited. The surface debris values were recorded in the appropriate field template form.
2. Three soil samples for grain size and total organic carbon analysis were taken of the top 15 cm of sediment. The sediments were taken at a distance of 0m, 100m and another 100m at a right angle to the origin of the transect [21]. These locations correspond with stations 1, 5, and 6 in Figure 2.
3. Vegetation samples were taken at a distance of 0m, 25m, 50m, 75m and 100m from the transect origin. The number of each vegetation species at each site, their condition and status were recorded into the appropriate field template forms.
4. In areas where no surface water is visible, 1.2 m pits were dug at three locations corresponding to stations 1, 5, and 6 in figure 2 to determine the presence of near surface water which can easily be polluted in the event of an oil spill. Inhibiting layer (Top 50 cm) is a layer of clay that can inhibit the downward movement of spilled oil. Such layers are particularly important especially in areas of heavy clay. The extent of inhibiting layers present in any site was calculated from the percent of silt + clay found in the soil sample after the laboratory analysis. A 45% or greater silt + clay content defined an inhibiting layer.
5. Animal species associated with each site were observed and recorded in the appropriate field template forms. Additional information about the animal species in the locality was also obtained from local hunters in the nearest community to the sample location. The information provided by the hunters was regularly cross-checked against a field guide and sometime a picture of the animal that hunters claimed to have been sighted was shown to them to ensure consistency. Information with regards to animals was also sourced from existing literature on the area of study. Important protected and endangered species were noted. This information was assembled in order to have a comprehensive understanding of the animal species present in the area of study. Bird and reptile species associated with each station were also observed. Previous records of bird and reptile species from the locality were also obtained from reliable literature sources and from local knowledge. Again, important protected, and endangered species present in the area were noted.
6. The population density of trees was determined using the quadrat method. The size of the quadrat used was 10 m x 10 m. Trees were defined as having trunk diameters of 10 cm or greater at breast height. Tree density was measured by counting the number of individuals of the study species rooted within the quadrat and recorded on the appropriate form. The procedure was carried out five times along the 100 m transect (Figure 2). The height of the trees was determined using a clinometer.
7. Coverage by shrubs and grasses in the understorey: Percent cover of grasses and of shrubs in the understorey were estimated using the line intercept method. A 100m tape measuring rule was stretched along transect. The transect direction was selected from the center of the site along a randomly pre-determined compass direction (see Figure 2). Percent coverage by shrubs and by grasses at five stations (25 m intervals) were recorded on the appropriate ESI field form. For shrubs, the diameter within which coverage was measured was 2m. For grasses and low-lying plants, a 1 m^2 -point quadrat was used at each of the 25m interval. The point quadrat frame has 10 holes. Each point quadrat was lowered vertically through the vegetation. The measure recorded was the percentage cover. The pins were lowered one at a time, and the species touched by each pin was recorded. The final number of "hits" from a number of sample "frames" was then expressed as a percentage of the total number of pins. The summary of all hits on a species provided a measure of the "total cover" of a species, a measure which reflects the size of plants or a species as well as its abundance in the vegetation. Any species in notable abundance (>5% cover) that could not be identified in the field were collected for later

identification. Important, medicinal, protected, and endangered plants were also noted.

During the field data collection, each plant species was also visually inspected to detect notable levels of fungal or bacterial infestation and defoliation due to disease. Where infestations were noted, these were recorded as percent "stressed" or "normal" in the appropriate ESI field template form. The total percentages of “stressed” and "normal" were calculated from the individual data for all measured species.

8. Sediments for Infauna were taken with a hand held garden spade at stations 1, 5, and 6 adjacent to the other sediment sample locations. Sample size taken was a 30cm x 30 cm x 5cm deep sediment. The samples were stored in polythene bags and preserved with 70% alcohol solution. Infauna population at the shoreline was equally examined. Samples collected especially at the sand beaches were washed and preserved for further identification of the contents.

Coastal/Shoreline Habitat Data Collection

1. The descriptions focused on the primary biological and physical characteristics of the shoreline site. In addition, the following conditions were documented with respect to each shoreline segment: sediment type, exposure to waves, flora, and fauna. Exposure to waves was described as high (open ocean), moderate (embayment or large rivers), or low (sheltered or riverine areas). The field sketch of the shoreline from oblique perspective was drawn on the field template. The drawing highlights the beach width and slope, sediment type, wave height and direction, vegetation, the backshore area, and any other distinguishing characteristics. It also indicates the location of samples taken for infauna and grain size.

2. A single soil sediment sample was taken from the upper 15 cm of the middle beach face using shovel. The collected samples were analyzed for grain size (using the USA Standard Sieve Mesh) and total organic carbon (TOC) (using Walkeley-Black method). The average slope in degrees of the active middle beach face was determined. An average of three measurements was taken in order to determine shore slope. Visual estimation of slope was employed especially when physical access was not possible due to inaccessibility (overabundant vegetation, unstable footing, or deep mud). Wave height in meters was also estimated during the field survey. Current direction was estimated based on a 360-degree compass bearing. This was done by tossing a buoyant object into the surf and observing its direction of movement [22].

3. Sediments for infauna analysis were taken with a hand held garden spade at three locations at the mid-beach face, adjacent to the site used for grain size analysis during the field data collection exercise. Samples of 30cm x 30cm x 5cm deep of sediment were collected at each of three locations. The samples were mixed into a single polythene bag and preserved with 70% alcohol solution. The number of crab burrows along the upper swash zone within five of 1-meter squares randomly placed along the upper swash zone was also counted and recorded.

4. A vegetation survey to determine relative coverage of species was undertaken along a 100 meter transect within the area of study (See Figure 3). The transect was located at the center of the site corresponding to the beach profile sketch. Transect was laid out perpendicular to the shoreline beginning at the high water mark and proceeding inland. Observations were made on the percentage coverages of individual species along the transect. The values obtained were recorded in the appropriate field template form.

Database Creation

Following the successful completion of the field data collection activities, all the collected data were compiled into a database within a GIS environment.

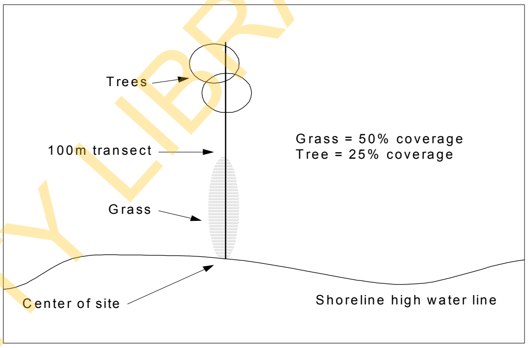

Figure 3: Shoreline Vegetation Observation (OPTS, 2001)

This was done in order to be able to model the field data in line with the requirement of the Protocols. In order to ensure consistency and accuracy of data, a rigorous data inspection and quality control exercise was carried out prior to the modeling phase.

Results and Discussion

The results of the field survey and laboratory analysis show that there are five distinct shoreline/coastal habitats and two inland habitats in the area of study. Table I shows these different inland and shoreline habitats. Data were collected for each of the habitats and managed in a relational database using Microsoft Access. The data were first entered into their corresponding thematic tables using a unique identification code (ID). Site coordinates were chosen as the unique identification code for each survey site. As an example, data such as depth to ground water, percent clay, and wave height were entered into the geo-characteristics table, while data on vegetation diversity index, percent grass, and tree and shrub coverage were managed under the vegetation table. The animals table contains all data and information on fauna and infauna species.

Table I: ESI Classes in the Study Area

	Coastal/Shoreline ESI Habitats	**Inland / Interior ESI Habitats**
1	Fine Sand Beach	Bush Fallow
2	Mangrove/Nypa palm shoreline	Farmland
3	Exposed Manmade structure	

4	Freshwater swamp forest	
5	Huts over shoreline	

In analyzing data the six-station data would first be aggregated into site data and then the five sites data were aggregated into habitat data. The data collected for shorelines were validated using the procedure contained in the ESI Mapping Standard and Protocols. The verification involved averaging the grain sizes for each shoreline type into an average grain size range for that class. The average grain size range for each shore line type was compared to the existing standard grain size range for that shoreline type. Wherever the grain size determined from the field data collected was outside the existing standard range, then the habitat delineation would be changed to reflect another habitat type (see Table II).

The variables used in the validation were dominant grain size, slope, and wave exposure. The dominant grain size is determined by averaging the percent grain sizes for the three sample locations on a given shoreline to give an indicator of that shoreline's grain size. The grain size with the highest percent average is the dominant grain size. The average slope in degrees and the average exposure of the beach to wave energy were compared with the standards for each shoreline type (see Table III)

Based on the results contained in Table III, the five distinct shoreline types observed in the area of study have the three dominant indicators used in assessing them within the established range for those shoreline types. The 'man-made structure' and the 'huts over shoreline' type of coastal habitats did not have any readings for grain size because they are mainly concrete structures. The huts over shoreline are actually huts directly placed over the coastline with water running under them.

In terms of sensitivity to spill, the most sensitive is the huts over shoreline area. Indeed these areas are very critical in view of the fact that if there is any spill, it is likely to affect humans directly. This is followed by the freshwater swamp forest, which according to [23] has the highest biological diversity of all the habitats in the region. The least sensitive is the sand beach because although it can provide a good recreational facility, it has limited biological diversity. The chance of ecological damage occurring on the sandy beach is therefore comparatively minimal.

Table III: Shoreline Sensitivity Assessment.

Shoreline/Habitat Type	**Dominant Grain size (mm)**	**Standard Grain Size (mm)**	**Slope Angle (Degrees)**	**Standard Slope Angle (Degrees)**	**Wave Exposure**	**Standard Wave Exposure**	**Average TOC Content (%)**	**ESI Class**
Sandy Beach	0.14 (FS)	0.0625—0.25	2.47	$< 5^0$	High	Low-High	0.18	3A
Manmade Structure	ND	>64mm but depends	29.32	Moderate - High	High	Moderate – High	ND	1B
Mangrove/ Nypa Palm	0.056 (SC)	Mud < 0.0625	0.01	$< 3^0$	Low	Low	1.56	10A
Fresh water Swamp	0.056 (SC)	Mud < 0.0625	0.01	$< 3^0$	Low	Low	1.49	10B
Huts on Shoreline	ND	ND	ND	$< 3^0$	Low	Low	ND	9C

Notes: MS = Medium Sand, FS = Fine Sand, SC = Silt and Clay, ND = Not Determined, NA = Not Applicable, TOC = Total Organic Content

Modeling the sensitivity index for the inland habitat was more rigorous as it involved not only the averaging, but also the computation, of some new indices. Three levels of modeling are involved. First, 'parameter models' was used to model field measurements into parameter values for each habitat type, while 'valuation models' was used to model site parameters into biota and geomorphologic indexes. The ESI model models biota and geomorphologic indexes into ESI classes.

First all the measurements from all the five stations were averaged to site index. This average is stored in the site index table. The five site indexes were subsequently averaged to characterize the habitat types. The habitat type average was then compared to a parameter valuation table and entered into the corresponding parameter value in the habitat type table. For the detail of the weighting used see [24], [25]. While ESI valuation for the shoreline only required a look up table to compare ESI indices, the inland habitats were modeled to determine their relative ESI valuation and rank. Table V gives the final ESI valuation and the final ESI model result for the two inland habitats observed in the area of study.

In terms of sensitivity, the result shows that farmlands are relatively the more sensitive habitat compared to the bush fallow. This result is not surprising in view of the socio-economic importance of farms (Table IV).

Table IV Final ESI Valuation for the Interior/Inland Habitats

	Valuation Indices				
Habitat	**ESI – geomorphic Characteristics**	**ESI - Vegetation Characteristics**	**ESI - Mammals**	**ESI – Total**	**ESI Rank**
Bush Fallow	14.2	56	22	102.20	**3**
Farm	12.3	46	18	76.30	**2**

Farmlands are typically cleared forestlands that are put under cultivation. Commonly cultivated crops include yam, cassava, corn fluted pumpkin and other vegetables. Oil palm trees and other useful economic trees are protected within the farmlands. Biological production is low compared to some of the other inland habitats while organic content can be as high as 1.3%. The predominant surface grain size is within the medium range. In terms of its predicted oil impact, the geomorphic and biota characteristics of farmlands indicate a low sensitivity to oiling. They are not exposed to marine and tidal influences. If oiled, vegetation mortality may occur; this will have more of a socio economic impact. They become more vulnerable if located near pipeline routes. If oiled, surface oiling will be generally confined to a small area. However, depending on surface debris and presence of confining layers, oil may percolate into the subsurface. Oil that reaches the groundwater may be difficult to clean up and can potentially cause a health hazard due to the presence of shallow wells in these areas [26].

Bush fallow is an abandoned farmland or cleared area that is left to regenerate. The fallow period ranges between three and five years. Fallow lands are generally more densely vegetated habitats than farmlands. Weeds and relic crops that were left in the farm e.g. cassava, typically dominate this habitat. If the fallow period is long enough the area turns into a secondary forest. Medium grain sized sediments predominate on these sites and their organic content is as high as 1.02% [26]. With respect to the predicted oil impact, many more biological resources may be impacted by spilled oil than on the farmlands but, impacts are generally restricted and localized because fallow lands are land-based rather than water-based ecosystems. Oil persistence may be worsened if oil percolates into the subsurface. Oil that reaches the groundwater may be difficult to clean up and can potentially cause a health hazard due to the presence of shallow wells in these areas. Recovery is dependent on the degree of oiling and penetration into the substrate, but with proper cleanup, restoration can be relatively rapid.

Conclusion

This study set out to demonstrate the applicability of the ESI mapping model for inland or hinterland areas developed by ERML and ESRI for the Niger Delta environment in a comparable portion of the southeastern Nigeria coastal region. The procedures adopted closely followed those prescribed in the model and the model standards for environmental indexes were relatively easy to apply to the study area. The findings of this study demonstrate that ESI modeling is more or less equally applicable to the shoreline and the hinterland of oil producing coastal regions. The ESI modeling also shows the integration of biodiversity variables into sensitivity index mapping. The terrain in the hinterland areas is less intricate and fragmented than in the shoreline zone. Therefore, it is relatively easier to classify and delineate the existing habitats both on imagery and in the field. The hinterland terrain is also more conducive for the field data collection phase of the exercise because of the better going conditions. In this study the benefits of aerial survey were not fully utilized because of the skipping of the helicopter flyover. Hence, the field operations stage was more demanding and time-consuming than it would have been ordinarily. The GIS approach is quite ideal for ESI modeling because of its capability to sequentially overlay different data layers for various kinds of spatial statistical analysis and spatial modeling. The most critical element in the construction of the database: the relational database structure adopted greatly facilitates data search and analytical operations. ESI has potential for application for other types of environmental perturbations apart from oil spill.

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