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Environmental Sensitivity Index Mapping for Environmental Sustainable Cleanup along NAOC Pipeline, Asemoku, Delta State, Nigeria

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Abstract

During emergency response to oil spills incident accurate information is required in order to reduce the risk associated with oil spill disasters. This study focuses on Environmental Sensitivity mapping for sustainable environmental clean-up and contingency planning along the 3.0 km of AGIP pipeline at Asemoku in Delta State, Nigeria. Geographic information systems (GIS) techniques were used to create an Environmental Sensitivity Index (ESI) map in the study area. A 2018 Google Earth Satellite imagery of the study area was downloaded, and landuse/cover classification scheme comprising of Vegetation, Farmland, Water Body, Wetland, built up area and Bare Surface was adopted. Existing categorization, ranking and classification of the inland habitat were adopted and used to create a Landuse/cover Environmental Sensitivity Index (ESI) map, while the buffer zones of 100 m, 200 m, 300 m and 400 m were adopted. In the ArcGIS 10.8 environment, the landuse/cover map was generated and buffer distances of 100 m, 200 m, 300 m and 400 m were created on the landuse/cover map to ascertain the features that are vulnerable and could be at risk in the event of oil spill. This study established that the Natural Vegetation areas are the most vulnerable and sensitive feature as a result of their size along the created buffer zones. Findings from this study thus provide insight into the most sensitive land-use/land-cover, in the event of a spill or emergency oil spill clean-up response.

Keywords

Sensitivity-Index-Mapping, Environmental-Sustainability, Land-Use/Land-Cover, Asemoku

1. Introduction

Exploration of hydrocarbon which has its advantage as the mainstay of Nigeria's economy [1], has also been identified as one of the major environmental pollutants in the oil producing areas of the country [2] [3] [4] [5] [6]. In the event of oil spills, accurate information and clear communication are required in order to protect the environment and reduce economic losses, while also mitigating the environmental damage(s) [7]. Geospatial assessment has gained popularity in the field of oil spill management due to its efficient storage, retrieval, analysis and visualization interface of spatial data in combining with other tabular data [8] [9]. According to Nwankwoala and Nwaogu [10] Geospatial assessment allows the integration of information from previous oil spill incidents from many different other sources to be presented through one interactive interface. Geographic information system (GIS) is viable and quite suitable for detecting, manipulating, analysing, assessing predicting and managing oil spillage [10] [11]. GIS is helpful in oil spill monitoring, sensitivity mapping, planning and response [8] [12].

The devastation caused as a result of oil spillage is one of the adverse effects of hydrocarbon exploration [13], which can lead to environmental degradation [14], soil depletion [15], water contamination and atmospheric pollution [16], all these affect the inhabitants and the environment where such oil exploration activities are carried out [17]. The effects of oil spill go beyond the loss of fertile land and have led to increase in pollution [18], sedimentation in streams and rivers, which clogs these waterways and causes declines in fish and other aquatic species [19]. Researches [20] [21] [22] have established that a degraded land is also often less able to hold onto water, which can worsen flooding [23]. Oil spillage is affecting the whole ecological system, due to environmental problems such as land degradation which has led to famine, species loss and extinction [24]. The petroleum industry activities including exploration, production, refining, transportation, and distribution are largely responsible for vegetation degradation in oil production and transportation areas [25]. This is mostly possible through oil spillage [26].

Oil spill puts the people and environment in danger [27]. It is better to be prepared for a spill than to be caught unaware by it [28]. Environmental assessment and sensitivity index mapping is one of the established processes used to prepare for oil spills disaster management [29]. It has emerged as a result of worldwide interest in different aspects of hazards control [30]. Udoh and Ekanem [31] defined risk as "the chance of something happening that will have an impact upon objectives measured in terms of consequences and likelihood". Traditionally, results of environmental risk assessment were provided in a non-spatial way [32]. However, this has been changing rapidly over the past decades due to the development of Geographic Information Systems (GIS) [33]. This has greatly improved spatial representation and spatial analysis of all kinds of information and data. As a consequence of this development, environmental risk mapping of pollutants is rapidly developing [34] [35]. Despite global awareness of oil spill incidents happening indiscriminately, little attention is paid to oil spills on land location as compared to offshore [36]. The situation is worse in developing countries, where efforts are made in the news, rather than in physical terms [37]. As a result of this many cases of spills have happened over the years rendering a large land area of Delta State infertile and uninhabitable [38]. To resolve oil spill issues, in the state, in a cheaper and more efficient manner, this study focuses on creation of environmental sensitivity and vulnerability index (ESI) mapping of the land-use/Land-cover with the aim of establishing emergency response zones for quick intervention, in the event of oil spill in the study area (Asemoku, Delta State, Nigeria).

2. Materials and Methods

2.1. Study Area

The study area, Asemoku, is in Ndokwa East Local Government Area (LGA) of Delta State. Ndokwa East is situated in the Eastern part of Delta State, Nigeria. It is bordered to the North by Aniocha south and Oshimili South LGAs respectively. The area is bordered in the East by River Niger and to the South by Isoko south and to the West Isoko North and Ndokwa West as shown in **Figure 1**. The Nigeria Agip Oil Company (NAOC) pipeline under study, traverses various communities. This study area lies between latitudes 5˚55' and 5˚69' North and longitudes 6˚40' and 6˚56' East. The spill point is Long. X_ 6.5616111, Lat.Y_5.6505833.

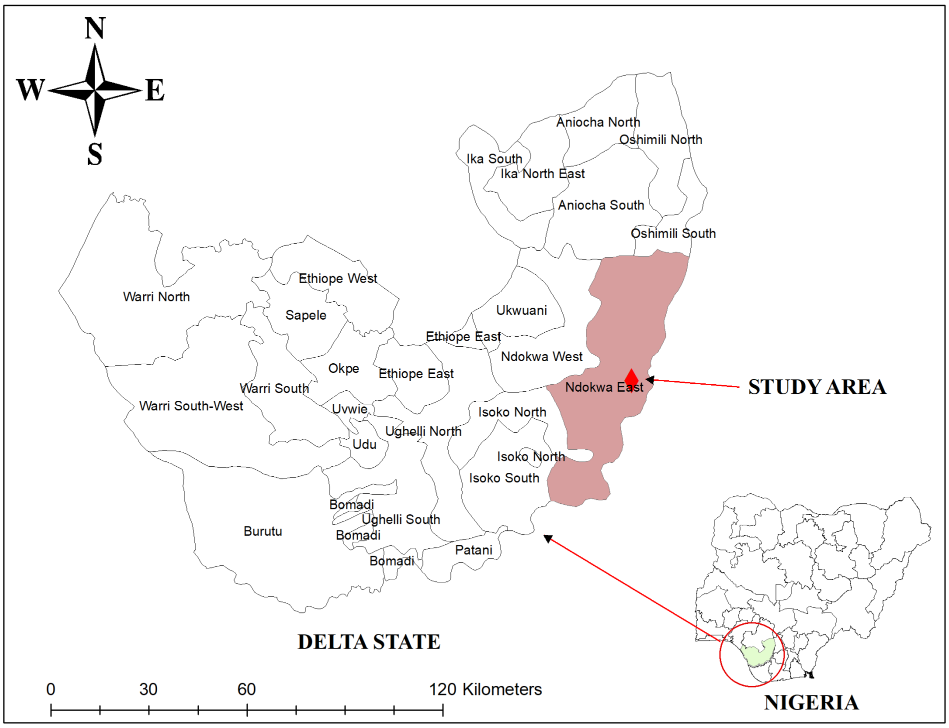

Figure 1. Map of Delta State showing Ndokwa East.

The area lies on the tropical monsoon climate, which is characterised by the rainy and dry seasons. The annual rainfall ranges between 1895 mm and 2105 mm annually. The annual mean temperature ranges between 27˚C and 30˚C respectively. In its original state, the climate supports agriculture and fishing economic activities [39]. The discovery of oil and the haphazard nature of its mining has resulted in serious migration and change of economic activities by the locals, due to poor productivity of land resources—a consequences of years of spills with no corresponding clean-up [40].

2.2. Data Types, Sources and Characteristic

This research used primary and secondary data (**Table 1**). The data was provided through government sources and databases from other organizations. The raw spatial data and satellite images used in the research came from the United States Geological Surveys (USGS), Google Earth Pro, Oil Spill Incident data from the National Oil Spill Detection and Response Agency (NOSDRA). Published oil spill records (https://oilspillmonitor.ng/) NOSDRA is a Nigerian Government Agency tasked with capturing all oil spill incidents both on marineand terrestrial ecosystems across the country [24].

2.3. Inland Habitat Classification

Based on fieldwork data collected coupled with images downloaded from Google Earth with geo-referencing on ArcGIS 10.8, a classification pattern was developed to enhance the classification of the land-use and land-cover inland habitat in the study area [41]. The system of classification is shown in **Table 2**.

Table 1. Showing ESI dataset, source and characteristics.

DATA TYPE	Resolution	DATE	SOURCE	USES
Landsat Image	**30 m**	**2014**	USGS, NIGERSAT.	For LU/LC classification
Google Earth Pro	Eye altitude between 2.6 km to 6.5 km	2018	(c) 2018 Google, (c) 2009	Aid LU/LC classification, identification and location of features
Literatures on resources (biological and human-use)			IPIECA, NOSDRA, NOAA	Help in inland habitat classification
Pipeline locations (Coordinate points)			NOSRA,NNPC Archive	For location features coordinates

Source: Authors compilation (2023).

Table 2. Land uses/cover classification system.

S/N	Landuse/cover Class
1	Built up areas
2	Wetland
3	Natural vegetation
4	Farmland
5	Bare land
6	Water bodies

The supervised classification (SC) was deployed for the classification mechanics of this study [42]. Supervised classification entails the imagery user using developed skill to deploy spectral known categories, i.e rural, industrial, or forest, and thereafter manipulates the software by assigning pixels of the image to landcover which matches the afore classifications. This technique has been termed the most frequently used [43], and has been deployed by [44]. However, the SC was deployed after the demarcated for the study was determined (training-class TC). Three training classes for used for a single category. This was done in agreement with the imagery. To define the TC the area for area land cover class (LCC) was determined [45]. Thereafter, extraction of signatures was done (ES) in the ERDAS imaging V16.6 environment. The SC was applied after the TCs were determined. Two or more TCs were deployed for a single class. The non-parametric (NP) technique was deployed for the classification. The image after these was classified into natural vegetation, farmland, water body, wetland, Build-up areas and bare surfaces (**Table 2**).

2.4. Categorization, Ranking and Classification of the Inland Habitat

The main criteria considered to establish the degree of sensitivity to oil spill and other stress factor of an ecological class include its biological productivity, oil/ecology interaction, ease of clean up, social, economic and human importance [46]. Fasona *et al.* [47] adopted similar criteria in their study (**Table 3**).

It is needful that after classification, accuracy of such classification is validated. This is a quantitatively assesses the efficiency of the sampled pixels and how the match reality. The matching of the classed data and the ground truth (GT) are shown in **Table 4**. Herein, the validation statistics deployed for ESI sensitivity validation was the Kappa statistic using the following equation:

$$\text{Sensitivity} = \frac{ae}{ae + be}$$

$$\text{Specificity} = \frac{de}{be + de}$$

$$\text{error commission} = 1 - \textit{specificity}$$

$$\text{Omission} = 1 - \textit{sensitivity}$$

$$+\ \text{predictive capacity} = \frac{ae}{ae + be}(\textit{user accuracy equivalen})$$

$$-\ \text{predictive capacity} = \frac{ae}{ce + de}$$

where:

ae = agreement between classification and observed values

be = frequency of X not observed to be X

ce = frequency of times X classified was X observed

de = frequency of times X was classified and not observed.

Total points = N = (*ae* + *be*+ *ce* + *de*).

Table 3. Land use/cover Sensitivity Ranking and Classification

Landuse/cover	Environmental Sensitivity Index (ESI) Rank	ESI Class
Built up area	VH	5A
Water bodies	VH	5B
Natural vegetation	VH	5C
Farmland	H	4D
Bare land	L	1F

Table 4. The buffered zones of the land use area.

Buffer Standards →	Buffer 100m		Buffer 200m		Buffer 300m		Buffer 400m	
LULC class ↓	Area (ha)	100%	Area (ha)	100%	Area (ha)	100%	Area (ha)	100%
Natural Vegetation	38.641	71.991	90.704	73.752	135.979	73.963	180.213	73.766
Farmland	2.469	4.600	6.494	5.282	13.770	7.490	23.205	9.499
Water Body	0.491	0.916	1.315	1.069	2.613	1.422	4.210	1.723
Wetland	9.396	17.506	11.969	9.732	13.974	7.601	16.637	6.810
Built Up Areas	0.000	0.00	0.186	0.151	2.163	1.176	3.909	1.600
Bare Surfaces	2.677	4.987	12.317	10.015	15.348	8.348	16.130	6.602
Total	53.674	100	122.985	100	183.847	100	244.304	100

The KAPPA analysis represents a multivariate statistics deployable when the test for accuracy is the need [48]. See equation bellow:

$$K = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}\left(x_i + Xx_{+1}\right)}{N^2 - \sum_{i=1}^{r}\left(x_i + Xx_{+1}\right)}$$

where;

r = total errors that exist is the rows cum columns of the matrix,

N = all observations

X_{ii} = observation in row cum column i

X_{i+} = borderline total of row i, and $X + i$ = marginal total of column i

Generally, where a Kappa output is at 1, this represents total agreement, and the further it is closer to zero, it means disagreement.

2.5. Creation of Buffer Zones

The buffering operation helps in knowing the proximity of resources that are vulnerable or sensitive to oil spill [48]. It is also used to assess the hazard areas along a risk zone (*i.e.* oil pipeline) as it affects the land-use and the land-cover. Buffer distances of 50 m, 100 m, 200 m, 300 m and 400 m (**Table 3**) were adopted; as used by Onosemuode *et al.* [46].

2.6. Emergency Response Zone

Emergency response zone is a location strategically positioned at area considered to be easily accessible, between the area where the inland habitat features are likely to suffer great harm and where responders and equipment can easily be deployed within the shortest of time after oil spill incident has been reported [49]. The emergency response zones along the study area were chosen by considering the following factors a) the most delicate inland habitat feature and b) the proximity and accessibility of required responders and equipment deployment along the pipeline route (see [48]).

3. Results and Discussion

3.1. The Buffered Zones of the Landuse/Land Cover Area

The results of the image processing and ecological classification of the Landuse/cover buffer standards of 100 m, 200 m, 300 m and 400 m respectively, was used for the establishment of the various landuse/cover, that at risk of being affected in the event of oil spill in each buffered zone. The 100 m buffered zone is the off-set of 100 m on each side of the pipe line spill point as shown in colour red in **Figure 2**. The 200 m buffer zone is the 200 m off-set of the pipe line spill point is as shown in colour dark blue in **Figure 2**. The 300 m buffer zone is the 300 m off-set of the pipeline spill point and it is shown in Purple colour and the 400 m buffer zone is 400 m off set of the pipeline spill point is shown in light blue colour. The various buffered zones helped in determining the spread of the spill and how it affects the various classified landuse/cover as shown in **Table 2**.

3.2. Sensitivity Index Ranking and Classification of the Landuse/Cover in the Study Area

The various landuse/cover identified in the study and their ranking and classification are discussed below (see **Table 5**).

3.3. Natural Vegetation Component of the ESI Map within the Buffer Zones

The natural vegetation is the landuse that occupied the most and largest area of land use/cover within the buffer zones. It comprises of grassland, shrubs, rain forest etc. It is also home tofauna species like rodent, Rabbits, squirrel and grass-cutter, snakes etc. [50]. Natural vegetation occupies a total land area of 38.641 hectares (71.99%), 90.704 hectares (73.75%), 135.979 hectares (73.96%), and 180.213 hectares (73.76%) within the 100 m, 200 m, 300 m and 400 m buffer zones respectively (**Table 4** and **Figure 3**).

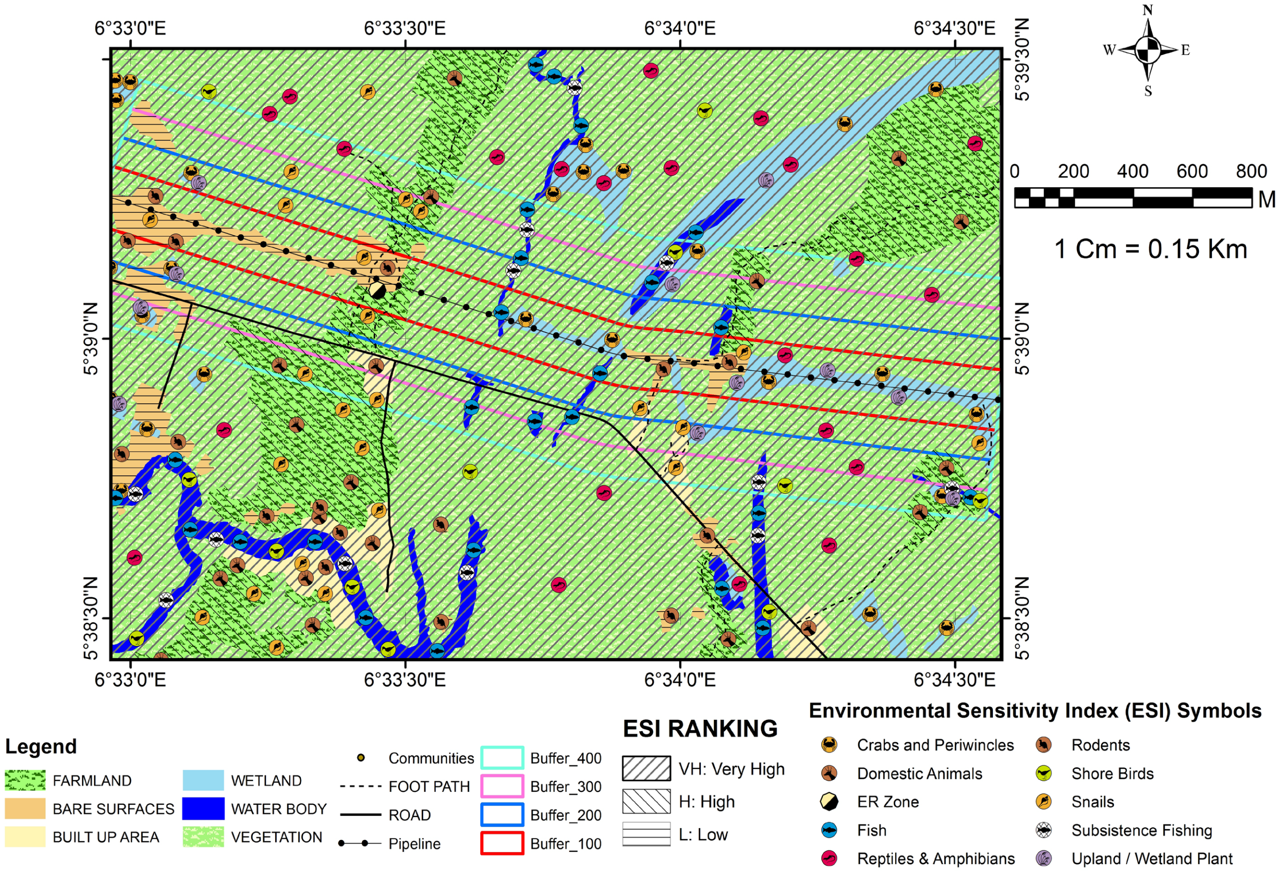

Figure 2. Digitized map of Study Area.

Table 5. Landuse/cover sensitivity ranking and classification.

Landuse/cover Classes	Environmental Sensitivity Index (ESI) Ranks	ESI Class
Built up area	VH	5A
Water bodies	VH	5B
Natural vegetation	VH	5C
Farmland	H	4D
Wetland	H	4E
Bare land	L	1F

3.4. Farmland Component of the ESI Map within the Buffer Zones

Farmlands are areas where agricultural activities are carried out with the aim of producing different crops for personal consumption and also as a source of income [51]. The farmland area occupies a total land area of 2.469 hectares (4.60%), 6.494 hectares (5.28%), 136.979 hectares (73.96%), and 180.213 hectares (73.76%) within the 100m, 200m, 300m and 400m buffer zones respectively (Table 4 and Figure 4).

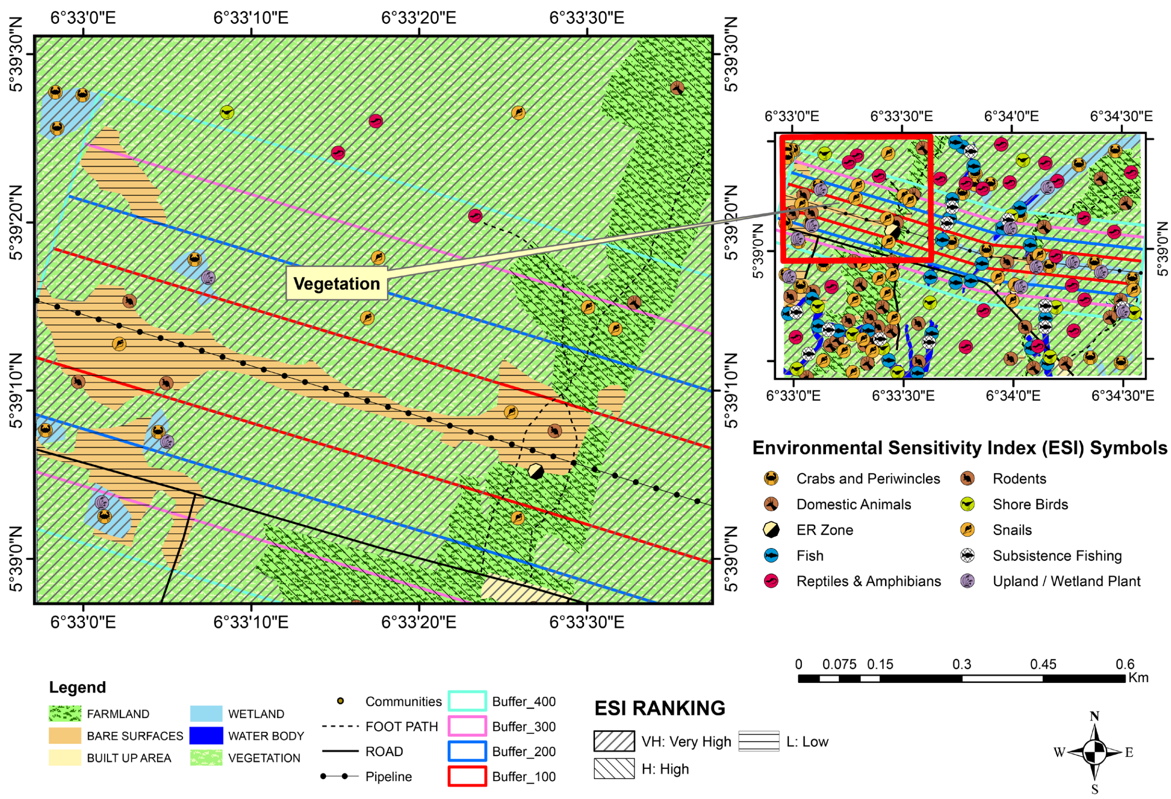

Figure 3. ESI map of Natural Vegetation.

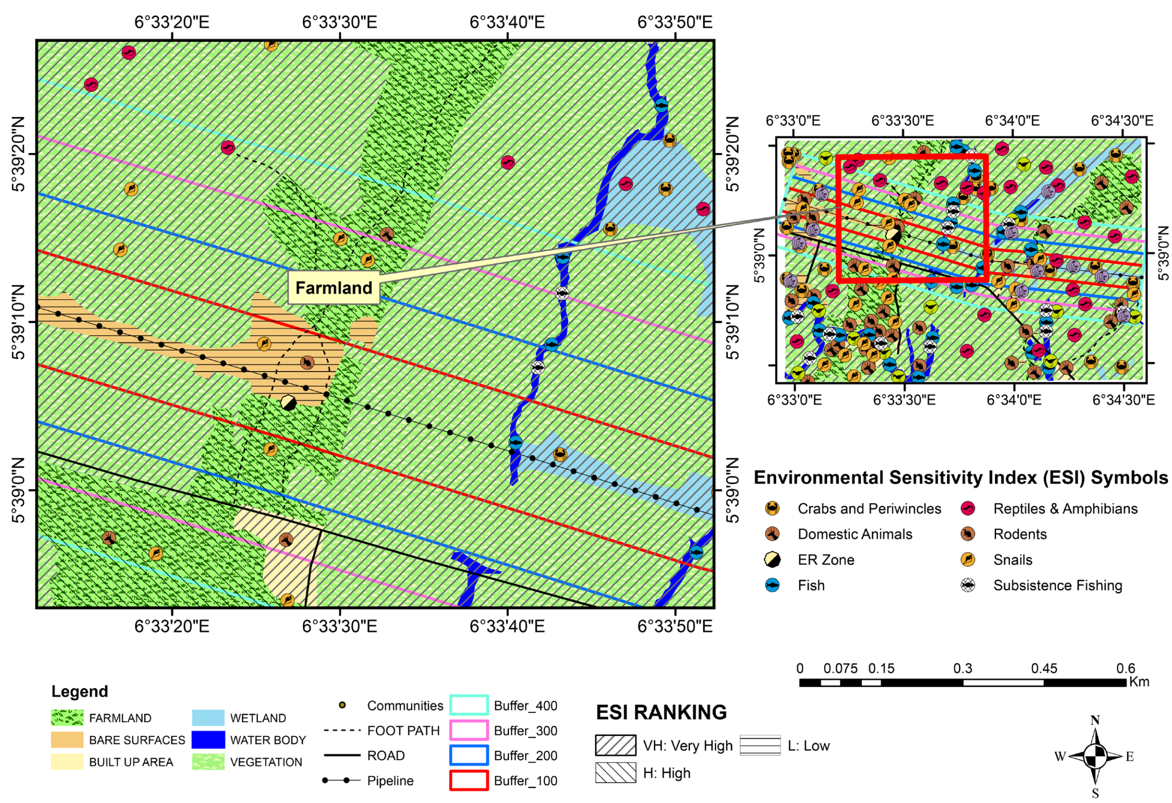

Figure 4. ESI map of Farmland within the Buffer Zones.

3.5. Water Body Component of the ESI Map within the Buffer Zones

The water body within the buffer zones comprise of rivers, streams, ponds and creeks [7]. The water body serves as a source of drinking water, bathing water and for other domestic purposes for some people in the Asemoku community. It also serves as habitat to aquatic plants and animals of various diversities like water lilies, water hyacinths, frog, toads, shrimps, turtles, fishes, and some reptiles [52]. There is water body within the 100m buffer zone. It is also recorded that water bodies occupy a total land area of 0.491 hectares (0.91%), 1.315 hectares (1.07%), and 2.613 hectares (1.42%) and 4.210 hectares (1.72%), within the 100 m, 200 m, 300 m and 400 m buffer zones respectively (Table 4 and Figure 5).

3.6. Wetland Component of the ESI Map within the Buffer Zones

The wetland areas comprise of ponds, marshes, forested freshwater, wet grassland and swamps [53] which is dominant in the study area. Wetland has a very rich unique biodiversity of flora and fauna species. Wetlands support populations of fish, amphibians, reptiles, birds, and animals, with many species reliant upon wetlands for their reproduction and early life stages when they are most sensitive to oil [54]. Migratory water-birds depend heavily on wetlands as is the

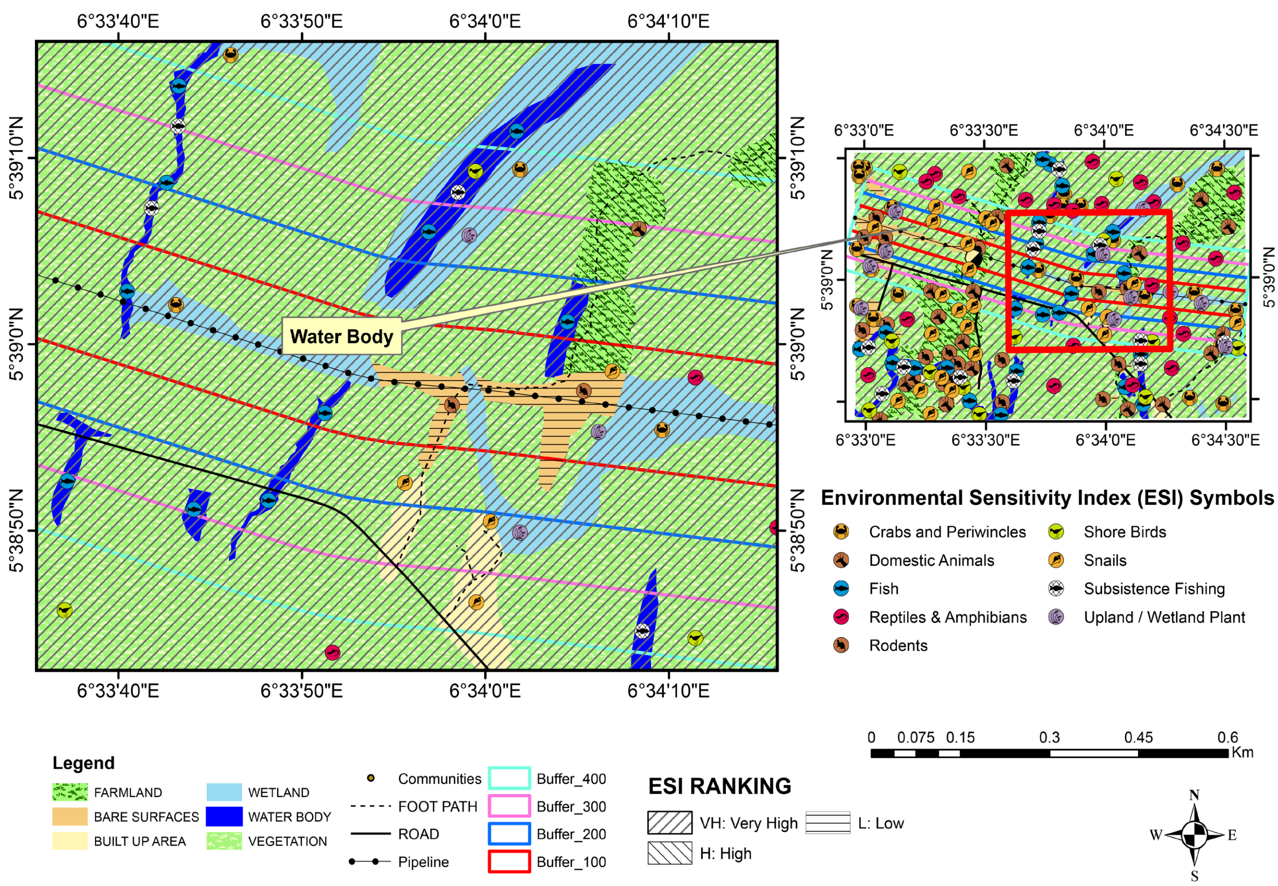

Figure 5. ESI map of Water Body within the Buffer Zones.

case in the study area. The wetland area occupies a total land area of 9.396 hectares (17.51%), 11.969 hectares (9.73%), 13.974hectares (7.601%), and 16.637 hectares (6.81%) within the 100 m, 200 m, 300 m and 400 m buffer zones respectively (Table 4 and Figure 6).

3.7. Built up Area Component of the ESI Map within the Buffer Zones

The built up areas comprises mainly of residential, utility, commercial, religious and educational structures [55]. This area comprises of diverse floras like orange, mango trees, coconut and palm trees, cocoyam, maize water leaf, bitter leaf, scent leaf plants and shrubs [56], which serve as food options for the locals. The faunas consist mainly of domestic animals such as dog, goat, fowls, rat, wall gecko, lizard, frog, cats, insects and microbes that may not visible. The built up area occupies a total land area of 6.494 hectares (5.28%), 13.770hectares (7.49%), and 23.205 hectares (9.49%) within the 200 m, 300 m and 400 m buffer zones respectively (Table 4 and Figure 7).

3.8. Bare Surface Component of the ESI Map within the Buffer Zones

Bare surfaces are exposed surfaces which can be attributed to natural processes and human activities [54]. It hardly supports plants growth because of the limited nutrients in it [57]. The bare surfaces occupy a total land area of 2.677 hectares (4.98%), 12.317 hectares (10.01%), 15.348 hectares (8.34%), and 16.130 hectares (6.60%) within the 100 m, 200 m, 300 m and 400 m buffer zones respectively as (Table 4 and Figure 8).

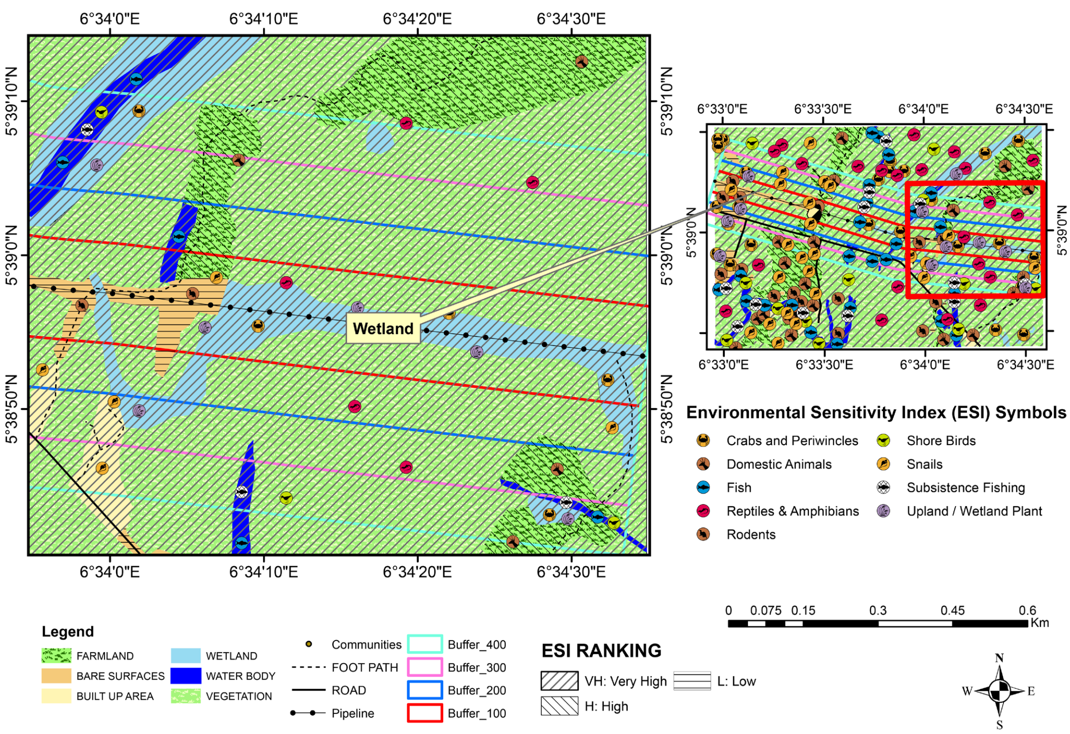

Figure 6. ESI map of Wetland Area within the Buffered Zones.

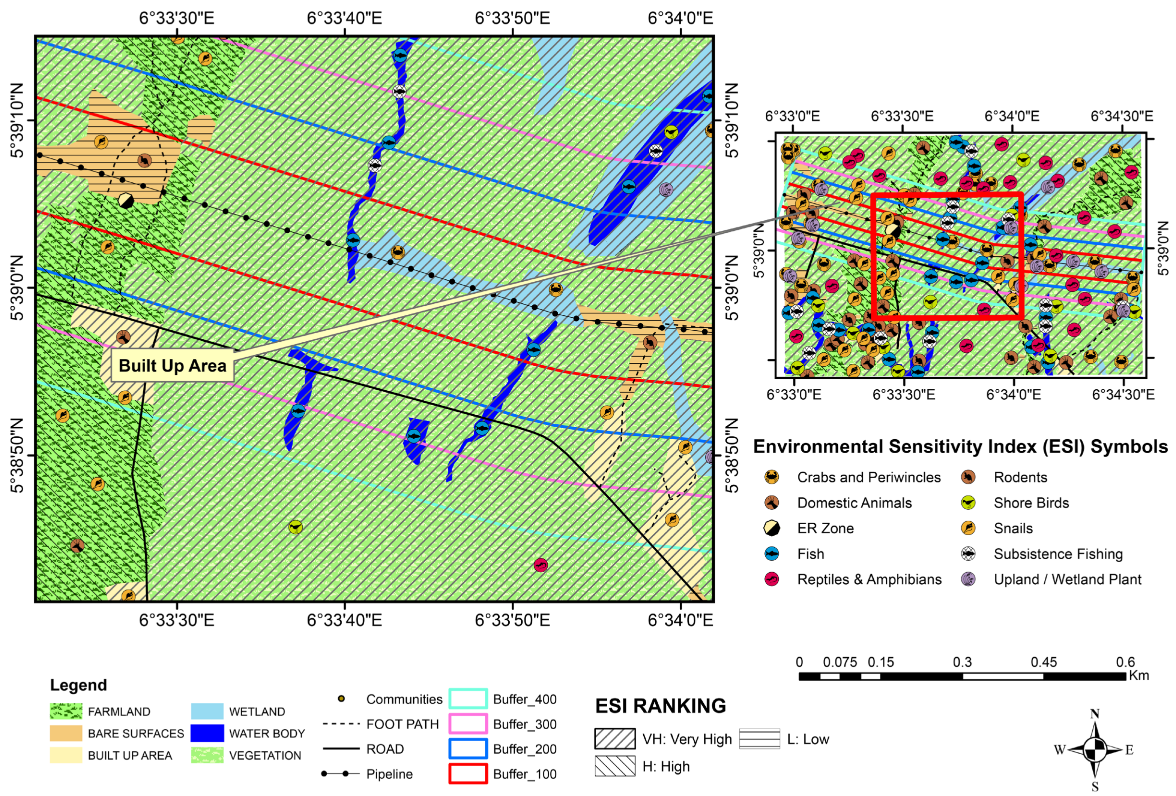

Figure 7. Showing ESI map of Built Up Area within the Buffer Zones.

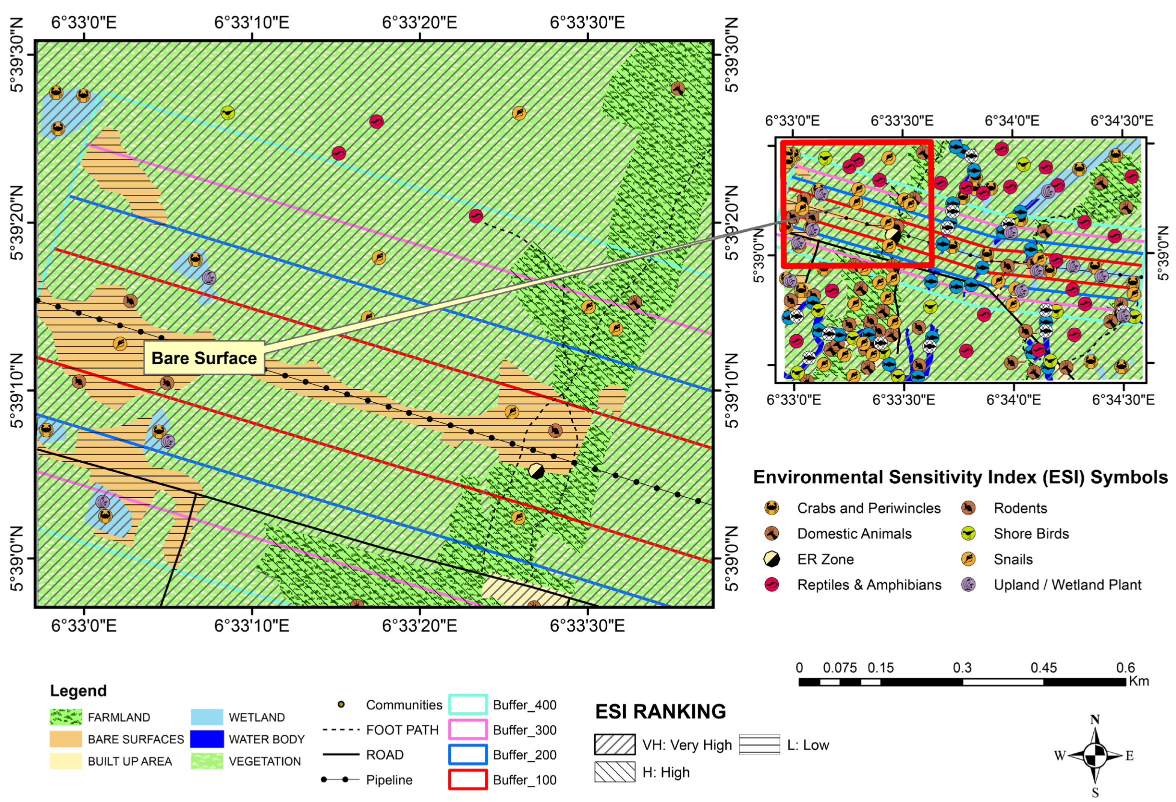

Figure 8. ESI map of Bare Surface Area within the Buffered Zones.

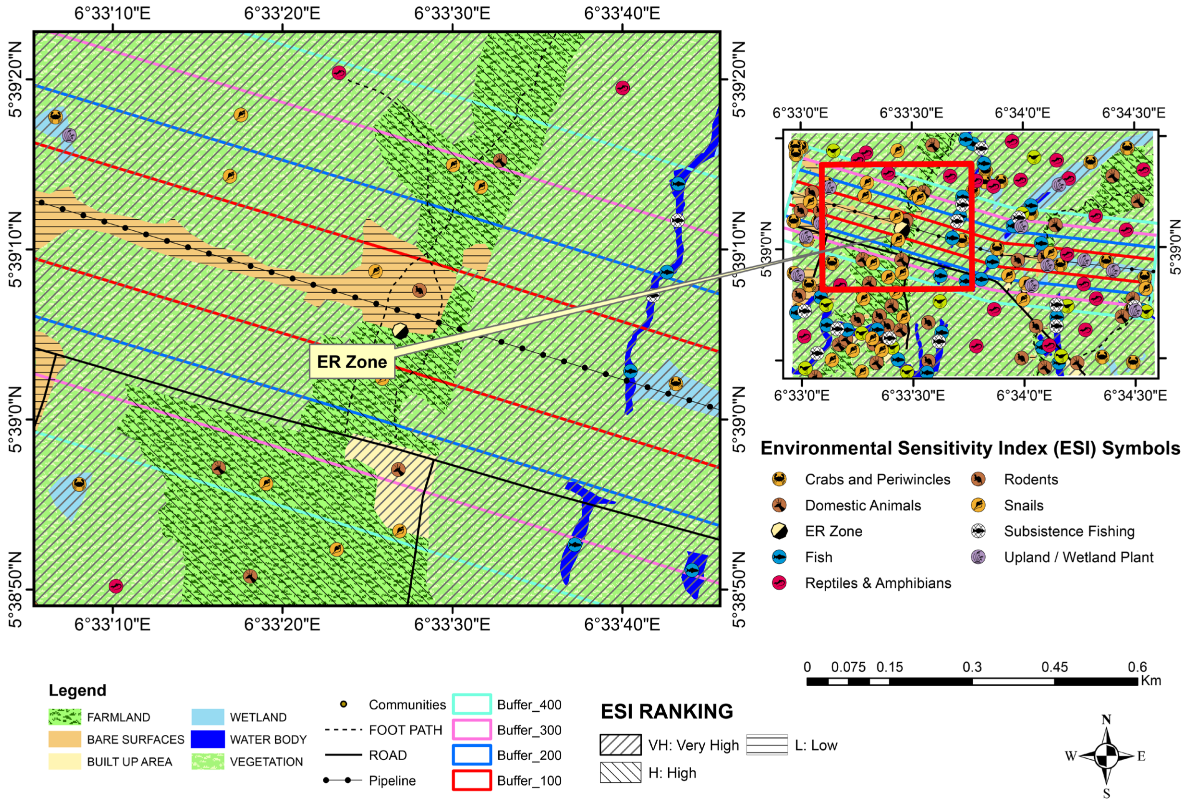

Figure 9. Emergency Response Zone within the Buffered Zones.

3.9. The Proposed Emergency Response Zone (ERZ)

The Emergency Response Zone (ERZ) was proposed to be strategically positioned in the area where the inland habitat and Landuse/cover is likely to suffer great harm in the event of an oil spill and also where responders and equipment such as hard booms, skimmers, storages, fire extinguishers and vehicles can easily be deployed within shortest of time; following Onosemuode *et al.* [46]. The emergency response zone (ERZ) in the study area was proposed to be situated at Asemoku community. The site chosen was within 50 m buffer zone (**Figure 9**). This area was chosen, due to its proximity to the pipeline. Another reason for siting the ERZ in Asemoku community is its accessible road network to the pipeline [48]. This will enable response team deploy response equipment with ease in case of incident of spill along the pipeline [58].

4. Conclusions

The study developed an Environmental Sensitivity Index for environmental sustainable clean up along NAOC pipeline, Asemoku, Delta State, Nigeria. The essence of the study was to stem the devastation caused as a result of oil spillage and the adverse environmental effects of hydrocarbon exploration, such as environmental degradation, soil depletion, water contamination and atmospheric pollution. This research used primary and secondary data. The data was provided through government sources and databases from other organizations. The raw spatial data and satellite images used in the research came from the United States Geological Surveys (USGS), Google Earth Pro, Oil Spill Incident data from the National Oil Spill Detection and Response Agency (NOSDRA). Analysis was performed in the ArcGIS environment.

This study unraveled that the Natural Vegetation is the most vulnerable Landuse/cover in the created buffer zones. By deploying the ESI techniques, the study was able to show clearly, the land uses that were more at risk of crude oil spills. This means that the tool is veritable for use and policy formulation targeted at environmental sustainability. Additionally, the study showed that in the event of an oil spill, the Natural Vegetation will be most impacted and consequently, it will affect the inhabitants which depend on this landuse for survival. This landuse makes hunting, fishing and lumbering activities, possible in the area. Environmental sensitivity Index map of the study area provides early warning and response for potential oil spill disaster. The study was able to identify the location and extent of likely adverse effects in order to inform planning and policy decisions. This research was able to map out the land use/land cover as a quantitative factor giving a better understanding of the habitats and ecosystems and their sensitivity to oil spill. Sensitivity mapping can be used to support the development of a response strategy for oil spill contingency plans. Sensitivity mapping of the study area has shown the types of land cover of the environments and resources potentially exposed to oil spills, thus providing a basis for the definition of priorities for protection and clean-up.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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