Environmental Sensitivity Indexing of Lagos Shorelines

[1]Adeofun C. O.[1] and [2*]Oyedepo J. A.

[1]Department of Environmental Management and Toxicology, College of Environmental Resource Management, University of Agriculture, Abeokuta, Nigeria
[2]Environmental Resources and Conservation Research Program, Institute of Food Security, Environmental Resources and Agricultural Research, University of Agriculture, Abeokuta, Nigeria;

[*]Corresponding Author; E-mail: jonhnoyedepo@yahoo.com

Abstract

Environmental Sensitivity Indexing (ESI) mapping of Atlas Cove, Lagos, Nigeria was carried out with the objective of producing an Environmental Analysis Index map of the shorelines. The study integrated methodologies developed by National Oceanic and Atmospheric Administration (NOAA) and Nigerian Oil Producing Trade Sector (OPTS). The result of the assessment was validated by comparison with the ESI standards in Nigeria. Nine ESI types were found in the area namely; ESI 1b, 2a, 2b 3a, 4a, 6b, 9b, 9c, and 10a. Animal biodiversities such as shorebirds (*Tringaly poleucos* and *Charadrinning marginatus*), sea turtles (*Dermocellys spp*) and white crabs (*Occipoda africana*) were more prominent on the western shores. Spearman's Correlation coefficient (r) value of -0.6 was obtained for the association between number of socioeconomic features and biological species along the shores. The result shows that a cause and effect exists between biological productivity and anthropogenic activities along the shorelines. The study ranked Mangrove swamps, creeks and fresh water swamp highest with ESI values of 10a. Margalef's index also shows that the same areas are the most sensitive with respect to species richness. The database developed from the study provides baseline information on the biophysical and socio-cultural condition of the environment and can serve as good decision support system for coastal managers.

Key words: ESI, Oil spill, GIS, Atlas-cove

Introduction

Atlas cove coastal environment in Lagos is undergoing progressive degradation from pipeline spills since the construction of the 64 million litre Nigerian National Petroleum Corporation (NNPC) oil depot in 1981. Oil pollution resulting from faulty petroleum facilities in the area is so unremitting that repeated loss of lives and ecological devastation has been recorded. In addition, this environment and the adjoining sea, fall within Oil Prospecting License blocks (OPL306, OPL311 and OPL 454). The implication is that the Atlas cove coastal environment is vulnerable to both inland and off shore oil spill disasters.

Environmental/ecological degradation from oil spill results in gradual erosion of biodiversity pools and species; which incidentally forms the basis for the survival of the human species. Prevention of such disasters through rapid and precise response action is not negotiable (Fabiyi, 2002a). Comprehensive information on the sensitivity levels of each category of a susceptible environment is an important requirement for effective oil spill disaster management. Regrettably, the ESI documents that could support the development of good and robust oil spill contingency plans for the study area are not available.

In Nigeria, ESI mapping began (Gundlach et al., 1981) as attempts by oil and gas operators to characterize the environment in their respective areas of operation by providing detailed and consistent source of information as a critical tool in oil spill response. Although nuances exist between versions of sensitivity maps from zone to zone, the basic principles of the mapping have remained constant.

This paper is a Nigerian example of ESI calculation. The paper adopted a modified Oil Producing Trade Sector protocol (OPTS, 2001) and National Oceanic Atmospheric Administration (NOAA, 1996) methodology respectively for ESI mapping of the study area. The methodology derived from the integration of the two techniques was designed to correspond to the available data at the time of the project. A new technique for validating shoreline sensitivity was added in Margalef's Species richness computation.

Study Area

The study area is geographically described by latitudes 6^0 22' 33" and 6^0 26' 39" and by longitudes 3^0 32' 00 and 3^0 45' 00. The area lie south west of Lagos city; overlooks the Bight of Benin (Atlantic Ocean) and is enmeshed with a net work of tortuous creeks and other water bodies (Figure 1). It has a variety of shore types ranging from marine to fine grained sand beaches. The area is part of the Oil Prospecting License (OPL) blocks, and the presence of the 64 million litre Nigerian National Petroleum Company (NNPC) depot with series of oil pipelines/flow stations makes it highly vulnerable to risk of oil spill.

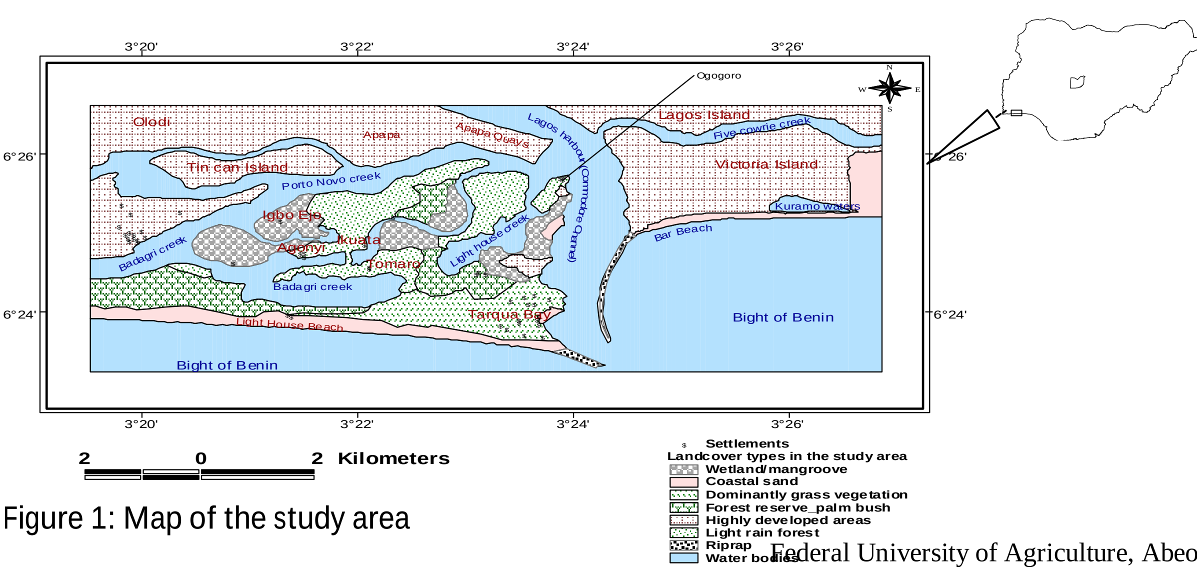

Figure 1: Map of the study area

Materials and Methods

The Topographical and NNPC facility map were digitized at scale of 1:20000. An overlay of the two digitized map was performed to produce the Digital Base Map (DBM) of the area. The DBM was updated with an Ikonos image acquired for December 2005. Field site logistic plan was then developed to determine requirement and date for field work, types of primary data to be collected, location of data collection and data size. Stations were created at interval of 400m along the shoreline and in each of the stations; data were collected in-situ as indicated in Figure 1

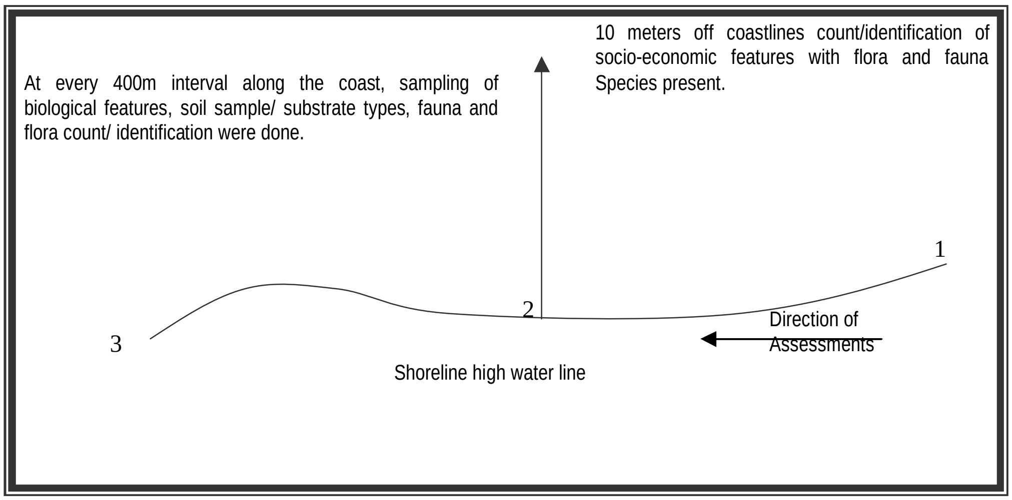

Figure 2: Rapid shoreline assessment plan

The data gathered in-situ was used to build up a relational database for the shorelines on the Updated Digital Base Map (UDBM) to derive the Level 1 GIS map (L1GM). Results of the rapid assessment from (field notes and observations) along the shorelines were compared with the standard ESI look-up table prepared for Nigerian shorelines by the OPTS for validation. The shore types were classified into sensitivity ranks on a scale of 1 to 10 based on the original index of Gundlach and Hayes (1978) for Nigeria. The shorelines were later colour coded using ArcView 3.2 colour palette customizations.

Rules for Sensitivity Determination

The results of the rapid assessment along the shorelines were compared with the standard ESI validation table (Table 1).

Table 1: Standard ESI validation table for shorelines

ESI	Shore Type	Dominant Sediment type and slope	*Slope*	Exposure
1a	Exposed rocky shores or banks	Rocky = boulders (>256 mm) Banks = marked by scarping, clays and mud (<0.625 mm) are common	*Moderate-High*	*Moderate-High*
1b	Exposed sea walls and solid man-made structures	Vary from Boulders and cobbles (> 64 mm) to sand bags, solid concrete, sheet pile or wood	*Moderate-High*	*Moderate-High*
2a	Un-vegetated/Eroding bank	Silt and clay (<0.0625 mm)	*Very low slope*	*Moderate*
2b	Exposed wave-cut platform	Bedrock or boulders (> 256 mm)	*Low slope backed by bluff or cliff*	*Moderate-High*
2c	Rocky shoals, bedrock ledges	Bedrock or boulders (> 256 mm)	*Low slope*	*Moderate-High*
3a	Fine sand beach	Fine sand (0.0625 – 2.0 mm)	*Low slope,(< 5^o)*	*Low-High*
3b	Scarps or steep slope in sand	Sand = 0.0625 – 2.0 mm	*Marked by scarp or steep slope*	*Moderate-High*
4a	Medium to coarse sand beach	Grain size = 0.25 – 2.0 mm	*Low to moderate*	*Moderate-High*
5	Mixed sand and gravel beach, bar or bank	Grain size = 1 – 64 mm	*Low to moderate slope (8-15^o)*	*Moderate-High*
6a	Gravel beach or bar	Grain size < 2mm, Moderate	*Steep slope (10 – 20^o)*	*Moderate-High*
6b	Riprap	Boulders (>256 mm)	*Moderate to steep slope (>20^o)*	*Moderate-High*
7	Exposed tidal flat	Coarse sand – mud (< 2mm)	*Low slope (3^o)*	*Low – moderate*
8a	Vegetated steeply sloping bluff	Soils (sand - mud)(<1mm), boulders (>256mm)	*Moderate to steep slope (>15^o)*	*Low*
8b	Sheltered Riprap	Boulders (>256 mm)	*Moderate to steep slope (>20^o)*	*Low*
8c	Sheltered rocky shore or scarp	Bed rock or boulders (>256mm)	*Moderate to steep slope (>15^o)*	*Low*
9a	Sheltered tidal flat or sand mud	Medium sand-mud (<0.5mm)	*Low slope (3^o)*	*Low*
9b	Vegetated low bank	Soils [sand to mud(1mm)]	*Low to moderate slope (20^o)*	*Low*
10a	Mangrove Nympa palm	Mud (0.625mm) Vegetation will indicate shore type	*Low slope (3^o)*	*Low*
10b	Fresh water swamp		*Low slope (3^o)*	*Low*
10c	Marsh		*Low slope (3^o)*	*Low*

Source: OPTS (2001)

Results

The observations along the shores of Atlas cove which guides in understanding the potential behavior of oil slick at the shores and the ESI types to which each shoreline belongs are shown in Table 3. From Lagos harbour to Tarqua bay and light house beaches, the grain sizes are finer (0.0625 – 0.25mm) than those of the Bar beach and Kuramo beach in Victoria Island (medium sized grain 0.25-2.0mm) (Table 3). The creeks and the mangroves substrates however have the finest grain size (0.0625mm). Along the west and east moles heavy quarried rocks were placed as shoreline fortification, the largest in terms of substrate size (>256mm) (Table 3).

With respect to shore slope and exposure to wave energy, the ranking is similar to sediment grain size. The deepest slope (0.75%) and the highest exposure to sea wave energy were observed along the west and east moles where the substrate size are also largest. The flattest slope (10%) also corresponds to the Light house and Tarqua Bay shores with the finest substrate size. The observed trend is typical of the geomorphology of Nigerian coastlines (Gundlach et al 2001, Noshkarhe et al 2001)

Table 3: Physiographic characteristics of the shorelines

hore location	Dominant substrate type (mm)	Shore description	Slope	Exposure to wave energy
Victoria island (Kuramo)	Grain size = 0.25 – 2.0	Medium to coarse sandy beach	0.15	High
Victoria island (bar beach)	Grain size = 0.25 – 2.0	Medium to coarse sandy beach	0.15	Very High
Light house beach	Fine sand = (0.0625 – 0.25)	Fine sandy beach	0.10	High
Tarqua bay beach	Fine sand = (0.0625 – 0.25)	Fine sandy beach	0.10	Moderate
East mole v/I side	Boulders (> 256)	Rip rap	0.75	Very high
East mole (Lagos harbour)	Boulders (> 256)	Rip rap	0.75	Very high
West mole (Lag harbour)	Boulders (> 256)	Rip rap	0.75	Very high
West mole (light house)	Boulders (> 256)	Rip rap	0.75	Very high

Lagos harbour(V/I side)	Solid concretes	Sea walls/solid man-made structures	--	Moderate
Lagos harbour (Atlascove)	Fine sand = (0.0625 – 0.25)	Fine sandy beach	0.20	Moderate
Badagri creek (water)	Sand-mud (< 0.0625)	Brackish/fresh water swamp	--	--
Light house creek	Sand-mud (< 0.0625)	Brackish/fresh water swamp	--	--
Five cowry creek	Sand-mud (< 0.0625)	Brackish/fresh water swamp	--	--
Porto-Novo creek	Sand-mud (< 0.0625)	Brackish/fresh water swamp	--	--
Badagri creek fringes	Sandy loam Soil (0.0625–0.25)	Sheltered Veg low banks	0.20	Low
Five cowry creek fringes	Sandy loam Soil (0.0625–0.25)	Sheltered Veg low banks	0.20	Low
Porto-Novo creek	Sandy loam Soil (0.0625–0.25)	Sheltered Veg low banks	0.20	Low
Light house fringe	Sandy loam Soil (0.0625–0.25)	Sheltered Veg low banks	0.20	Low
Ogogoro, Kuata, Tomaro, Tarqua bay	Sandy loam Soil (0.0625–0.25)	Huts along shorelines	0.20	Low
Mangrove (via Ogogoro)	Grain size = 0.25 – 2.0	Mangrove	0.15	Low
Mangrove (Via NNPC)	Grain size = 0.25 – 2.0	Mangrove	0.15	Low
Mangrove (Tarqua bay)	Grain size = 0.25 – 2.0	Mangrove	0.15	Low
Mangrove (L.H. cork)	Grain size = 0.25 – 2.0	Mangrove	0.15	Low
Mangrove (Badagri crk)	Grain size = 0.25 – 2.0	Mangrove	0.15	Low
Mangrove(Badagri crk)	Grain size = 0.25 – 2.0	Mangrove	0.15	Low
Mangrove	Grain size = 0.25 – 2.0	Mangrove	0.15	Low
Igbo Ejo swamp	Sand-mud (< 0.0625)	Brackish water swamp	--	--

Source: Adapted from Gundlach *et al* 2001

The information in Table 3 revealed 9 ESI types in the study area. The information is made more explicit in Table 4. ESI type 1b (Sea walls/solid man-made structures), 2a (Un-vegetated or Eroding bank), 2b (Exposed wave cut platform), 3a (Fine sand beaches), 4a (Medium to coarse sand beach), 6b (Riprap), 9b (Sheltered vegetated low banks), 9c (Huts along shorelines) and 10a are Mangrove/swamps. The relative proportions of each shoreline categories reveals that sheltered vegetated low banks are the most prominent with almost 40% presence. The observed is perhaps an indication of the overall sensitivity of the entire area.

Table 4: Shoreline by categories

ESI	**Shore types**	**Location**	**Total (km)**	**length**	**Percentage of entire shoreline**
1b	Sea walls/solid man-made structures)	Eastern side of Lagos harbour, Apapa quays, part of five cowrie creek, Tin can island port and NNPC Depot	19.53	23.5	
2a	Un-vegetated or Eroding bank	Bar-beach end of Victoria island.	2.46	3.0	
2b	Exposed wave cut	Badagri creek near Kuata village.	0.056	0.1	
3a	Fine sand beaches	Tarqua bay light house and western side of Lagos harbour	12.28	14.8	
6b		West and Eastern Lagos harbour	8.74	10.5	
9b	Sheltered Vegetated low banks	Found along all creeks occurring along upper reaches of creeks embayment.	31.03	37.3	
9c	Huts or settlements along shorelines	Ogogoro, Kuata and Tomaro villages.	1.44	1.7	
10a	Mangroves/swamps	Around NNPC Depot	5.77	6.9	

In Table 5 the distribution of socio-economic and biological features along the shorelines are presented. Table 5 reveals the richness of each shoreline with respect to biodiversity. The Table also gives insight to geographical targeting of protective or containment actions. From the results in Table 5 it appears there is a relationship between the distribution of socio-economic features and biological productivity of the shorelines.

Table 5: Biological and socioeconomic features per shore locations

Location	ESI type	Socio economic features	Biota.
Victoria island beach (Kuramo)	4a	1	6
Victoria island (bar beach)	2a	1	-
Light house beach	3a	-	23
Tarqua-bay beach	3a	1	6
East mole V/Island	6b	1	25
East mole (Lagos harbour)	6b	-	22
West mole (Lagos harbour)	6b	-	25
West mole (light house beach)	6b	-	17
Lagos harbour (V/Island)	1b	9	5
Lagos harbour (Atlas cove side)	3a	3	26
Badagri creek (water)	10c	-	10
Light house creek	10c	-	10
Five-cowrie creek	10c	-	10
Porto-Novo creek	10c	-	10
Badagri creek fringes	9b	2	17
Five-cowrie creek fringes	9b		15
Porto-Novo creek	9b	5	21
Light house fringe	9b	-	27
Mangrove (via Ogogoro village)	10a	-	23
Mangrove (Via NNPC depot)	10a	-	22
Mangrove (Tarqua bay)	10a	-	27
Mangrove (Light house crk)	10a	-	26
Mangrove (Badagri crk upper)	10a	-	22
Mangrove(Badagri crk)	10a	-	27
Igbo Ejo swamp	10c	-	25

ESI map

Figure 3 is the composite of the information in Tables 1 and 3. The information was utilized to depict the relative shore sensitivity on the Initial ESI map. The color codes used presents the entire coastline environment according to relative sensitivity. Warm tones depict high sensitivities and cooler tones, lower sensitivities. The map presents most of the shoreline in warm colours relative to the proportions of the map in cooler colours. The cooler tones are seen to be generally contiguous with the ocean front. The location of more sensitive shores is identifiable. Human settlements located along shorelines at Tarqua Bay, Ogogoro and Tomaro were coded orange. The named shores exhibits extensive vegetation that requires saturated soils for growth and reproduction and are assigned ESI 9c. The mangrove and wetlands (assigned ESI 10a) were coded red.

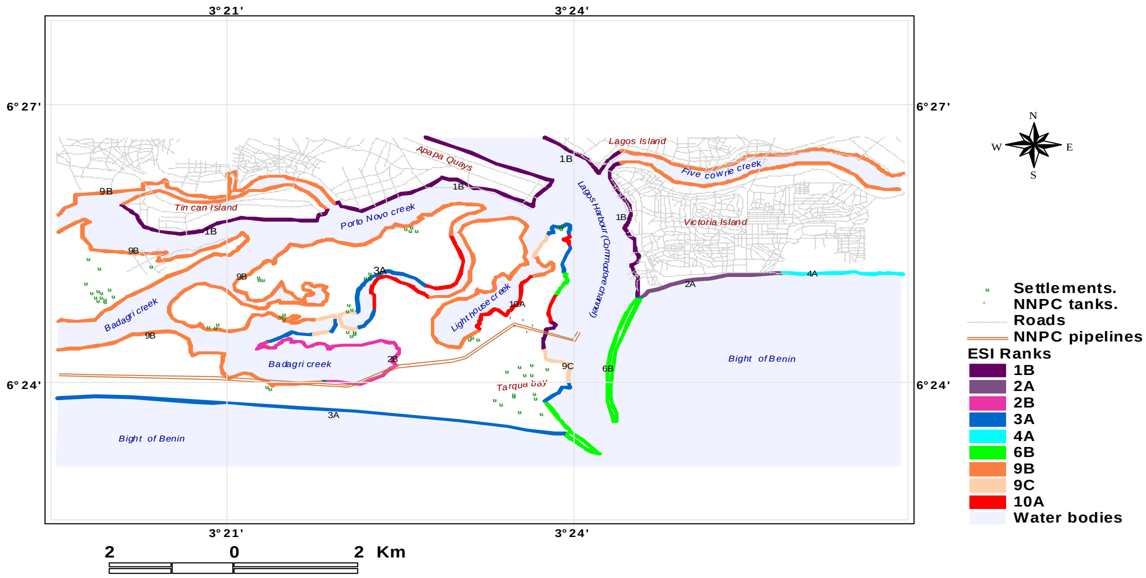

Figure 3: Atlas cove Shoreline sensitivity

Figure 4 is the overall ESI map which contains the positions and symbols of important features in the environment. The map reveals the location of socio-economic features and sensitive biological resources that may be affected by oil spill

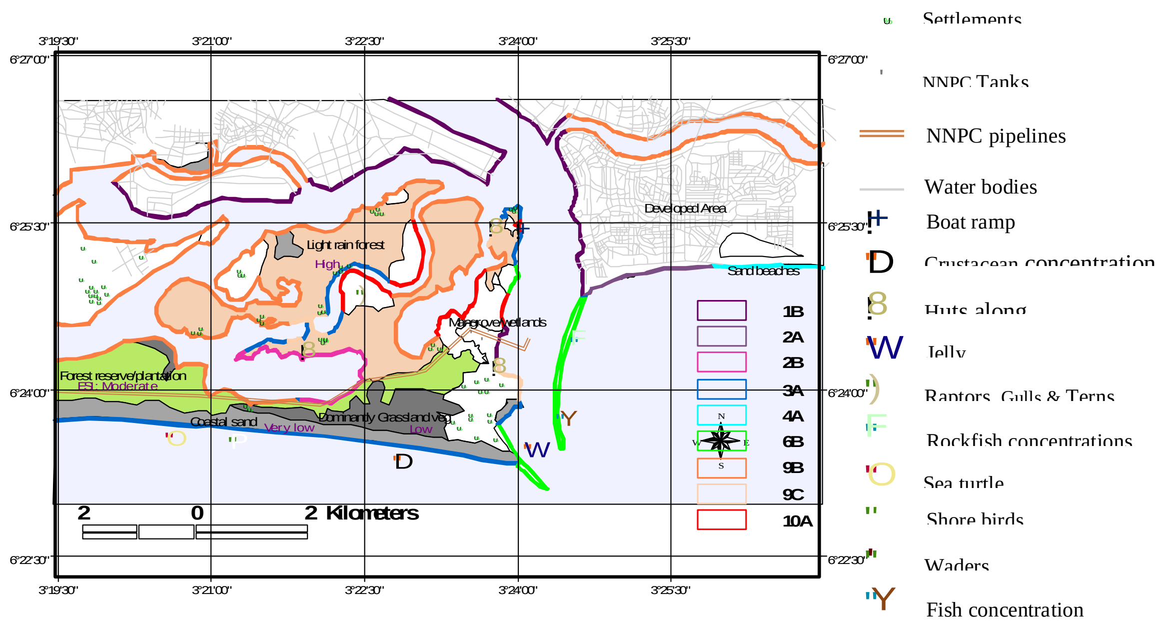

Figure.4: ESI Map of Atlas cove

Discussion

To distil the complexities of shorelines into biodiversity distribution pattern and proportion of shore types alone will lead to gross simplification and the underlying assessment becomes unavoidably subjective. Looking at the importance attached to individual issues in ESI mapping, it was essential to dwell on the physical attributes of each shorelines. Dwelling on the physical attributes lent some accuracy to prediction of the behaviour of oil and possibly guided in recommending the best clean up method. A complementary profile on the physical attributes of the shorelines and relative biological productivity contains shore information that borders on coastal dynamics and sensitivity.

Impact of oil may not be so severe along the solid man-made structures since it is made of hard impregnable sea walls and pilings exposed to direct wave action. Any oil deposited on these sea walls or solid man-made structures will be rapidly removed from exposed faces. Although oil persistence on any specific shoreline is related to the incoming wave energy, which for most of these shore type is relatively weak compared to the ocean wave. The most resistant oil on solid man-made structures would only remain as patchy bands, which can easily be recovered at or above the high water line. However to prevent leaching of the oil from the structures, high pressure spraying with dispersant may be required to remove oil from the solid man-made structures. Clean up crews should make sure they recover all released oil.

At the bar beach in Victoria Island, any oil slick from the sea will easily get to the shore with high wave action but it is also most likely to be washed away in a short time. The situation at the Light house and Tarqua bay resort beaches will be different. Here the oil may be buried by sand within the first few weeks since they are accreting beaches. It is important to note that during small spills, oil will most likely concentrate in bands along swash line of sandy beaches. Maximum penetration of oil into fine grain sand will be less than 15cm. While penetration into coarse grain sand can reach 25cm, burial of oiled layers by clean sand within the first few weeks after the spill will be limited usually to less than 30cm whereas burial up to 60cm on coarse grain is possible. If the oil is stranded on shore at the beginning of an accretion period, such as after a storm, the deepest burial will occur but much of the oil will be removed during the next storm. Heavy accumulations of residual oil can form tar mats. However biological impacts are likely to be low except when the beaches are being used for nesting and foraging.

However, because of the heavy recreational use of the beaches in the area, an extensive clean up efforts to remove as much of the oil as possible may be required. Victoria Island beach has a very high exposure to wave energy, which could explain its eroding nature. Sand removal should therefore be kept to a minimum to avoid further erosion problems. The use of heavy equipments for oiled sediments do lead to removal of excessive amount of sand therefore manual clean up may be preferable. Mixing oil into deeper sediments and contamination of adjacent clean areas should be prevented. If possible cleanup crews should wait for all the oil to come offshore prior to the removal of oiled sediments.

Rip raps are generally exposed to very high wave energy. Deep penetration of oil between boulders is likely where the riprap is placed at the water line especially on the East mole on Victoria Island side of the commodore channel. Oil may readily adhere to the rough rock surfaces and if not quickly removed, it may cause chronic leaching until the oil hardens into an asphalt deposit. When the oil is fresh and liquid, high pressure spraying and or water flooding may be effective making sure to recover all released oil. Heavy and weathered oil will be more difficult to remove. As such it may require scraping and or hot-water spraying. If the oiling is beyond was can be put under control, it may be necessary to replace heavily oiled riprap. If oil should adhere to the rough surfaces of the heavy boulders, it may result in chronic leaching until it hardens to an asphalt deposit on impermeable surfaces. Fresh oil could be removed by pressure spraying. Weathered oil may be more difficult to remove by ordinary pressure spraying or water flooding. Removal of weathered oil may require water spraying, scraping or even complete removal of the rip rap in case it is heavily oiled.

Sheltered vegetated low banks (ESI 9b) were found almost along the banks of all creeks colonized by terrestrial plants that grow in aerated soils. The vegetated low banks occur prominently along the upper reach of creeks and their embankments. In the event of spillage, oil will adhere to any vegetation along the water line. Very heavy accumulations will be trapped along shoreline irregularities and pool in any surface depressions. Response staff should therefore note that all free oil must be removed by vacuum or low pressure flushing. If it is necessary to remove the contaminated vegetation it should be done only when confirmed necessary and under close supervision.

The mangroves, creeks and brackish water swamp ranked highest with scores of 10a, 10c and 10c respectively. Similar studies (Gundlach *et al* 2001) in the Niger Delta region of Nigeria support the fact that mangroves and wetlands are about the most sensitive in terms of impact of oil spill on biodiversity in shore line. Oiling would impact heavily on the area since it would be difficult to clean easily and several life forms would be affected. The mangroves and wetlands have low exposure to wave energy but since the slope is a gentle one, slight tidal increase will get oil on to it. Moreover, the NNPC pipeline right of way passes directly through part of the mangroves. The NNPC pipes for many points along its length have been mutilated by vandals and it is beyond mere conjecture to say it will be a big threat to the ecosystem of the entire area in the very near future. Oil would adhere to vegetation and if not quickly removed may smother and kill the animals. Heavy oil accumulations will be trapped in irregularities and depressions hence, the use of vacuum, low pressure flushing should be considered.

Where Huts, houses are located along shoreline (ESI 9C), boom should be put in place before the oil slick arrives because of the high value placed on human habitats. In cases of contamination, detergent or dispersant options should be considered.

From the ESI map for the shorelines, two ready source of oil spill pollution are depicted. One is the NNPC depot that appears centrally located in the area. The other is the Ocean, which could be a ready source of pollution coming from tankers accidents or drift from the off shore wells of Ondo, Ogun and Lagos States, if and when they begin to mine the recently discovered oil deposit.

Conclusion

The established Environmental Sensitivity Index Mapping of Atlas cove Lagos shorelines is expected to improve the information and preparedness of coastline managers in their effort at protecting Nigerian shorelines from major oil or chemical disasters. The safest means of protecting the Atlas cove shorelines from marine spill therefore is to place a boom at the entrance of the Lagos channel while curtailing the oil from getting to very sensitive areas like Kuramo end of Victoria Island beach and the light house beach respectively. Response agencies like National Oil Spill Detection and Response Agency (NOSDRA) and National Emergency Management Agency (NEMA), and Nigerian Environmental Study Team (NEST) among others should take note of important and sensitive areas like the light house beach. The beach provide habitat for shore birds and rare species sea turtles. The Atlas cove environment is vulnerable but highly sensitive to oil spill.

The data gathered in this study is expected to be managed by a robust information management system, which would guarantee update in real time and help in decision support with respect to rapid response in future. From this study, GIS-supported Environmental Sensitivity Index mapping has proved very useful in this regard. GIS will remain one of the most important tools in contingency planning and rapid response to oil spill. The ESI maps will also sometimes find wider usage in areas such as coastal resource inventory/assessments, Environmental Risk Assessment, coastal and recreational planning, Environmental Impact Assessments and Baseline Environmental Studies.

The ecosystem's sensitivity level while still imperfectly understood has perhaps being the most critical aspect of the pollution debate. Ecological aspect of the environment need be given serious consideration in studies of this nature. The emphasis given to the issues of species extinction and environmental resources protection appear to a large extent yet unfruitful probably because previous studies in Nigeria placed emphasis on human use/socio-economic features rather than the ecosystem as a whole. To put priority on human use, resources may be important but it should be noted that genes species and organisms are the product of over 3 billion years of evolution and they are the basis for the survival of the human species. Therefore, earth's resources ought not to be put in jeopardy at the instance of human socio-economic features. There is therefore the need to incorporate biodiversity into Environmental Sensitivity Indexing as shown in the present study.

References

Fabiyi O.O. (2002a): Real Time Space Remote Sensing data and GIS for Oil Spill Disaster management in Nigerian Niger Delta: a call for paradigm change. Report of UN/ECA workshop on Disaster management in Africa, http/www/uneca.org Edited by David Stephens

Gundlach, E.R. and M. Hayes, (1978): Classification of coastal environments in terms of potential vulnerability to oil spill damage. Marine Technology Society Journal, vol. 12(4), p. 18-27. (http://www.oil-spill.com/Pubs ESI/Vulnerability 1978 MTS.pdf)

Gundlach, E.R. and Murday, M. (1987): Oil Spill Sensitivity Atlas for Mauritius. Prepared for United Nations, International Maritime Organization, U.N. Development Program, and Mauritius Ministry of Housing, Lands and the Environment, 146 pp

National Oceanic and Atmospheric Administration, (NOAA, 1996): ESI Guidelines, Technical Memorandum NOS ORCA 115, 175 pp. (http://response.restoration.noaa.gov/index.html)

Nosakhare, E., Fairbairn D., and Taiwo, L. (2004): Mobile Handling of Environmental Sensitivity Index (ESI) Dataset. http://www/gisig.it/coastgis/papers/erharuy.pdf