International Journal of Multidisciplinary Research and Publications
ISSN (Online): 2581-6187

Environmental Sensitivity Index Mapping for Oil Spill using GIS Approach, Case Study from Bashayer Oil Terminal, Sudan

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Abstract— *The Environmental Sensitivity Index (ESI) has become a benchmark for coastal managers, planners, and scientists in determining the effects of oil spill on coastal habitats. The Sudanese Red Sea Coast is highly important for the country exports and imports. It is characterized by rich environment of mangrove, fishes and coral reefs. This study aimed to produce ESI of Red Sea Coast to oil spill during the period from December 2007 to January 2008 using geospatial techniques with considering of Bashayer II Crude Oil Export Terminal. The data used include digital elevation model, LandSat scene and coraf reef distribution in the coast, slope of the area and the distance from marine terminal (MT).Various image processing techniques were conducted including true color composite (bands 2/3/4), clipping the study area, on-screen digitization and shapefile conversion of land use/land cover classes and buffering tool to categorize the distance from MT. Wind direction data was used to identify the imminent effects of wind on the coral reef. Then a model was formed to rank the different coral segments to oil spill. The result showed that six segments ranged from the most sensitive to the least sensitive; three segments were far from MT, two were close and one was very far. Moreover, the study ranks reef segments sensitivity following the wind direction. Closed reef segment to MT and moderately sheltered (ESI-6) were the most highly sensitive category, followed by next five ESI ranks; whereas very far reef segment from MT (ESI-1) with moderately sheltered characteristic was ranked as the least sensitive. The study has demonstrated the effectiveness of GIS in monitoring and modeling oil spill in the area. The study recommended preparation of ESI maps by consulting multidisciplinary scientists to monitor oil spill.*

Keywords— *Red Sea Coast, Oil Spill, ESI, Sudan.*

I. INTRODUCTION

The Red Sea coast in Sudan is approximately 750 km in length inclusive of bays and inlets. It extends from 18º N at the Eritrean border to 22º N at the Egyptian border (Abdul-Razak *et. al.*, 2010). Red sea coast of the Sudan is characterized by distinguished marine environment of coral reef, fish species and mangrove forest. Most of Sudanese export and import passed through Port Sudan as the main seaport of the country. Sudan has begun exporting crude oil after successful exploration of the oil in 2000(WB, 2008).

An oil spill is a release of a liquid petroleum hydrocarbon into the environment due to human activity, and it is a form of pollution (USGS, 2021). It is often refers to marine oil spills, where oil is released into the ocean or coastal waters (NOAA, 2021). Oil spills include releases of crude oil from tankers, offshore platforms, drilling rigs and wells, as well as spills of refined petroleum products and their by-products, and heavier fuels used by large ships such as bunker fuel, or the spill of any oily white substance refuse or waste oil. Oil spills in the marine may cause significant physical and chemical changes in marine life. It may take months or even years to clean up (Annunciado *et al.*, 2005).

Environmental Sensitivity Index (ESI) was initiated in the mid 1970's, scientists with National Oceanic and Atmospheric Administration (NOAA) and the US Coast Guards classify numerically the sensitivity of shorelines to oil spills. The classification is based on the vulnerability index that proposed by Hayes and Gundlach (1975) and Gundlach and Hayes (1978), in which the vulnerability for oil spills depends upon the physical and geological characteristics of the coast line (RPI, 1996). It is ranked from 1(the least vulnerable) to 10(the most vulnerable). The Vulnerability Index (VI) has become a benchmark for coastal managers, planners, and scientists in determining the effects of oil on the shorelines (Gundlach and Hayes, 1978). This index has been modified and refined over time, and which led to the development of the ESI (RPI, 1996). On the other hand, according to the NOAA, the ESI systematically compiles information in standard formats for coastal shoreline sensitivity, biological resources, and human-use resources. ESI maps are useful for identifying sensitive resources before a spill occurs so that protection priorities can be established and cleanup strategies can be designed in advance. ESI have been an integral component of oil-spill contingency planning and response since 1979, when the first ESI maps were prepared days in advance of the arrival of the oil slicks from the IXTOC 1 well blowout in the Gulf of Mexico (NOAA, 2002). The ESI system has been a widely accepted system in mapping sensitive resources regarding oil spills. However, the numbers on the scales does not represent actual

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quantified sensitivity (i.e. ESI 5 is not five times as ESI 1). This led to many regional modifications, for example the six-point sensitivity index used in the coastal sensitivity Atlas of Southern Africa (IPIECA, 1994). Shore types have different sensitivities in different regions due to the variation of the local environmental conditions (Owens and Robilliard, 1981; Hayes and Michel, 1997). Therefore, the Environmental Sensitivity Index has to be modified according to the environmental conditions of a particular region. This approach has been followed in the present study; in which the local environmental and socio-economic conditions have been taken into account in performing sensitivity analysis. Typically, Environmental Sensitivity Index (ESI) mapping system deals with shoreline habitats, biological resources and human use resources (NOAA, 2002). Shoreline habitats have a high likelihood of being directly polluted when the oil spill affected the shoreline (NOAA, 2002). Mapping the entire distribution of a large number of species potentially located in an area, and showing it on the ESI map, may not be very helpful to responders setting protection priorities. Therefore, it is more reliable to identify only the types of species that tend to be vulnerable to spilled oil and the most sensitive life-stages. Human-use resources as explained by NOAA (2002) are concerned with man-made features.

At present, the Sudan has no capacity to respond to oil spills in its territorial waters. With the gradually increasing volume of shipping using Port Sudan, and the plans for the development of a new oil terminal at Gezirat Abdalla, it is important that the Sudanese authorities should establish a national system for responding to oil spills. The purpose of National Oil Spill Contingency Plan (NOSCP) is to provide such a national framework for responding to oil spills and protecting the coastal resources of the Sudan (PERSGA/UNEP, 2003). An integral component of a successful contingency plan is to determine and to map the coastal environments; those would be seriously damaged by an oil spill, so to receive priority protection. The oil spill cases in the study area, Basheir Terminal, has been reported by PETRODAR Operating Company (PDOC, 2008), 28th Dec, 2007 was first oil spill incident. The emergency control and shutdown system has malfunctioned due to the power failure during the circulation operation leading to the oil spillage through the relief system.. Second oil spill incident was reported in3rdJan, 2008. This study aimed to initialize national scale project for production of the ESI maps of the Sudanese Red Sea Coast. There is no similar study on the feasibility of such application in the Sudanese Red Sea Coast. This study aimed to produce ESI map for proper oil spill management from the available data to be further updated or modified.

II. Study Area

The study area, Marsa Bashayer Oil Terminal (II) and its surrounding area is located approximately 25km south of Port Sudan (Figure 1).

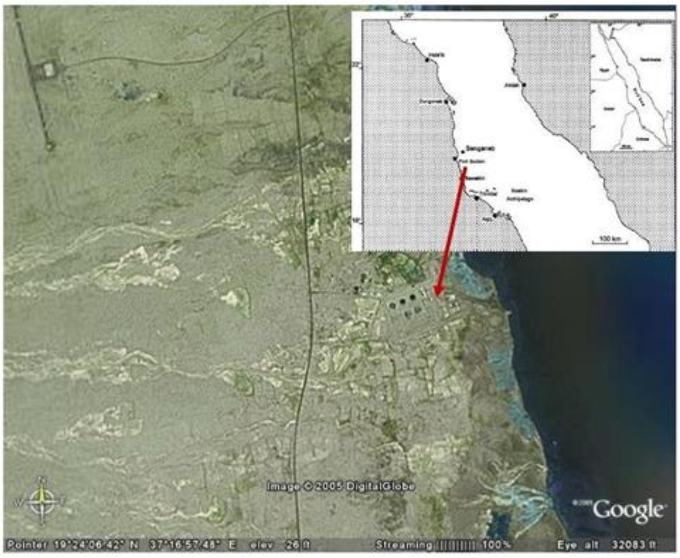

Fig. 1. The Study area

III. Materials and Methods

Spatial data include Landsat ETM+ image (2000) and Digital Elevation Model (DEM) for *Path 171 & Raw 47*that were freely downloaded from Global Land Cover Facilities (http://www.glcf.nasa.org). In addition *non-Spatia*l data was collected from previous studies, PERSGA technical report(s), UNEP environmental database and reported accident case(s) related oil spill. A GIS package produced by Environmental Systems Research Institute Inc. (ESRI); was used to perform the necessary analyses. Landsat ETM+ imagery of 2000 was displayed in RGB (321) color composite, then clipped to the area of interest using extract tool of spatial analyst toolbox. This polygon was later used to clip vector layer(s) (shapefiles). On-screen digitizing of shoreline was conducted and exposure to wind and wave flux was categorized. Distance from Bashayer terminal was estimated to the limits of the study area and this layer was later converted into vector to be intersected with other vector layers.

The final sensitivity rank of a particular shoreline segment is the integration of the four main factors (Figure 2): shoreline exposure, distance from Bashayer MT and biological productivity. The final output was the shoreline habitats classified according to their sensitivity.

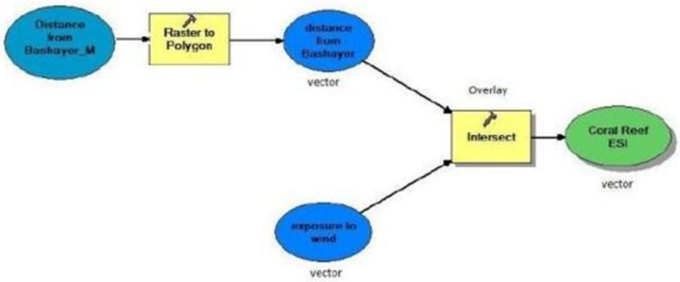

Fig. 2. Flowchart of the cartographic model for shoreline classification (Modified After Lotfy, 2004)

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IV. Results and Discussions

Coral Reefs classification was based on the secondary data that obtained from PESGA/GEF (2003), the coral reefs coverage of the cost was less than 4 (Figure 3).

Fig. 3. Classification of the coral reefs

Shoreline slope of the study area was shown in Figure (3). The study area was flat with slope < 5^0. Thus the slope factor was not used in the model and replaced with the distance from Bashayer MT (Figure 5) .

Distance from Bashayer MT was set to the limit of the study area polygon; the raster layer was converted into vector for the purpose of arithmetic overlay (all layers are in vector format) then reclassified into three classes: Closed to MT, Far from MT and Very far from MT (Figure 5).

The shoreline exposure was locally classified into three classes (Figure 6) namely: exposed, moderately sheltered and highly sheltered habitats. The sensitivity decreases with the increase in the exposure level. The exposed shore line habitats were assigned to the lowest rank and the highly sheltered were assigned to the highest rank.

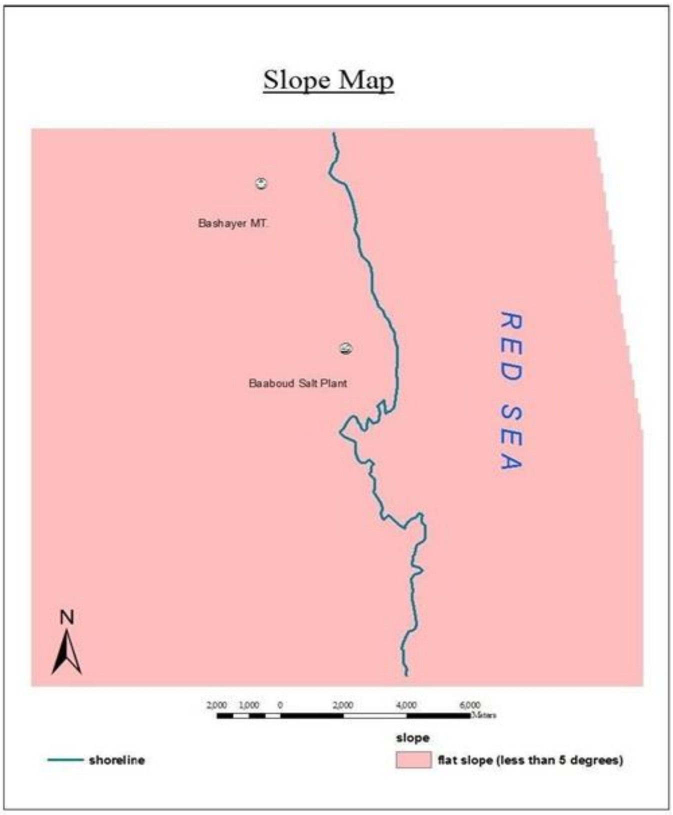

Fig. 4. Slope Map of the study area

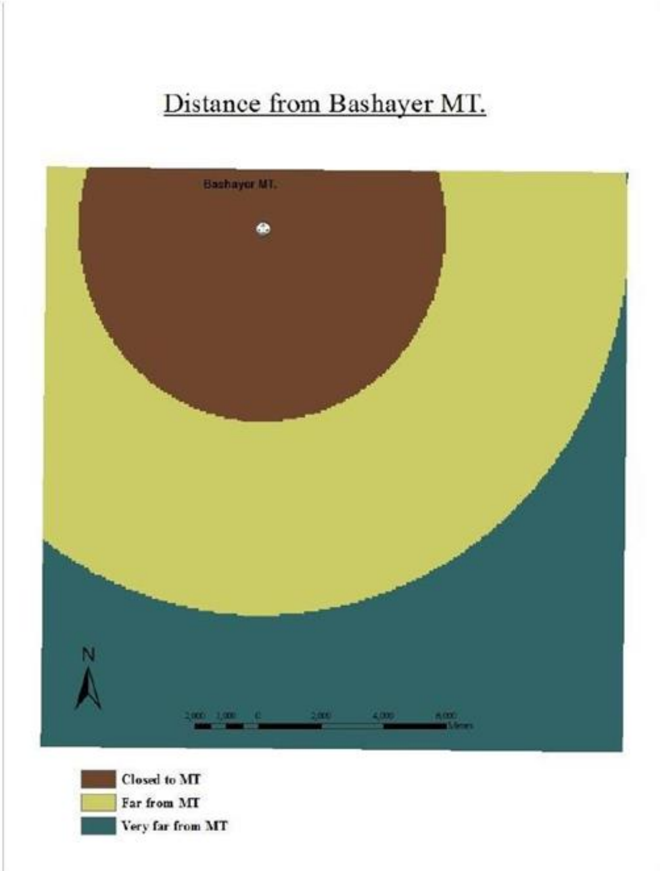

Fig. 5. Distance from Bashayer MT

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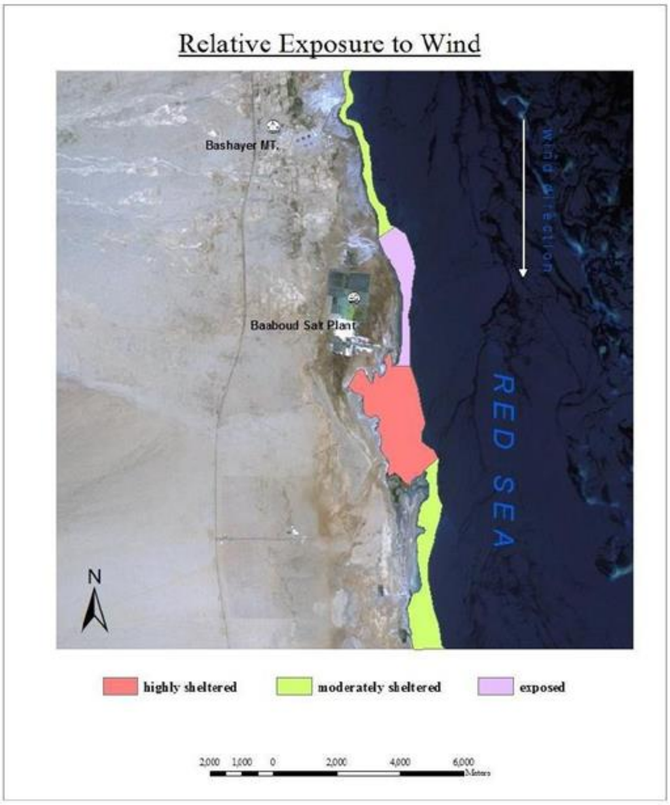

Fig. 6. Relative Exposure to the wind

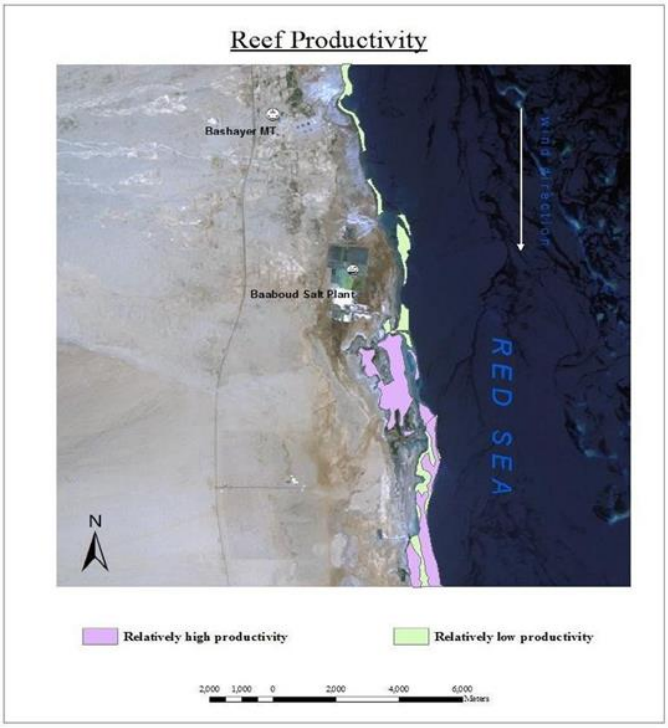

Fig. 7. Biological Productivity of the area

Biological Productivity was analyzed with reference to shoreline and closed land to shoreline. Shoreline was distinguished by presence of fringing reef that was shallow in some places as clearly interpreted from satellite image having lighter green color compared to submerged parts of dark green color. The relative biological productivity of the area was shown in Figure (7), The shallow algal coral reefs was considered as highly productive, while the other parts were low productive.

Shoreline/Coral reef sensitivity to oil spill was done for the whole reef area considering the sum of sensitivity ranks for each input layer, assuming that the greater the account is corresponding to the highly sensitive class and vice versa, the least sensitive class is that of less account. Figure (8) illustrates the main ESI ranks of the reef; table (1) ranks reef segments into ESI classes according their distance from MT and also the ease of clean-up. It shows their arrangement with respect to their degree of sensitivity. Following the concept of NOAA, all segments mapped has been matched with the class index and accordingly ranking was given on the scale of ESI- 1 to ESI-6 where ESI-6 is highly vulnerable and ESI-1 is least vulnerable.

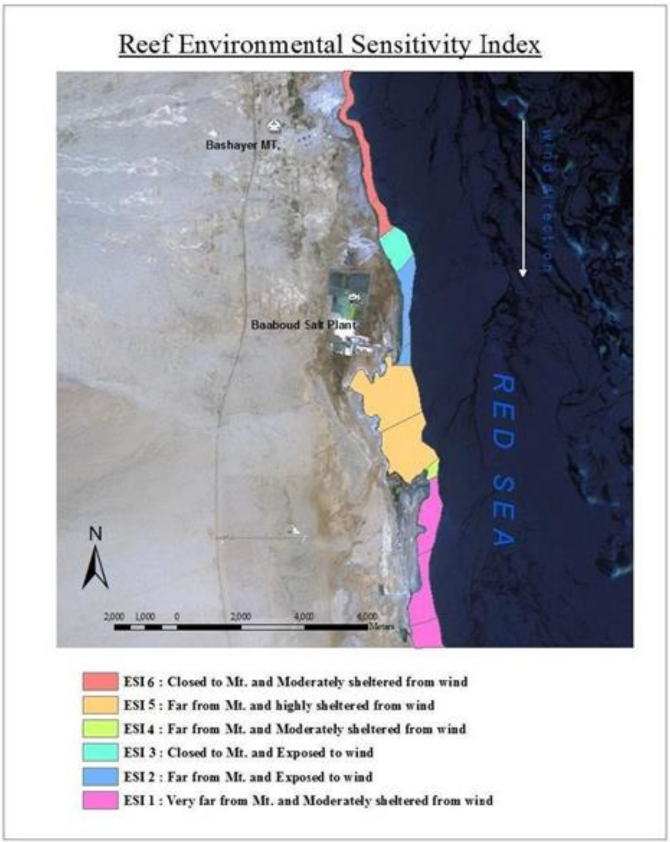

Fig. 8. Reef ESI map

TABLE 1. Reef segments ESI Ranking

Sensitivity ranking	Land use/land cover class	Sensitivity index
ESI6	Closed to MT and moderately sheltered from wind	Most sensitive
ESI5	Farfrom MT and highly sheltered from wind	
ESI4	Far from MT and moderately sheltered from wind	
ESI3	Closed to MT and exposed to wind	
ESI2	Far from MT and exposed to wind	
ESI1	Very far from MT and moderately sheltered from to wind	Less sensitive

V. Conclusion

- The study concluded that vulnerability to oil spill decreased with distance and the sensitivity ranged from medium to high. According to the adoption of distance from MT, the sensitivity of the study area may be considered as medium to high.
- This study recognized six segments that are subjected less/more to the effect of spilled oil. Three segments were far, two were close and one was very far from Marine Terminal. The farness from Mt. may decrease the vulnerability in parts of moderate or high shelter from wind i.e. spilled oil not easily washed away.
- GIS tools can facilitate decision-making and setting priorities for conservation and alerting the susceptible resources, and suggesting the proper measures of control.

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