Journal of Coastal Research	14	2	502–510	Royal Palm Beach, Florida	Spring 1998

Environmental Sensitivity Analysis of Potential Oil Spill for Ras-Mohammed Coastal Zone, Egypt

A.F. Abdel-Kader†, S.M. Nasr‡, H.I. El-Gamily‡, and M. El-Raey‡

†Department of Geology
Mansoura University
Egypt

‡Department of
Environmental Studies
Institute of Graduate Studies
and Research
University of Alexandria,
Egypt

ABSTRACT

ABDEL-KADER, A.F.; NASR, S.M.; EL-GAMILY, H.I., and EL-RAEY, M., 1998. Environmental sensitivity analysis of potential oil spill for Ras-Mohammed coastal zone, Egypt. *Journal of Coastal Research*, 14(2), 502–510. Royal Palm Beach (Florida), ISSN 0749-0208.

Ras-Mohammed National Park, on the southern tip of Sinai peninsula, is a valuable tourist resource that should be carefully conserved. It has been recently threatened by numerous anthropogenic activities, including oil spills from tankers passing through the Gulf of Suez. The objective of this paper is to carry out an environmental sensitivity analysis of this coastal environment, and to derive an environmental sensitivity index map of the area. Integration of remote sensing and GIS techniques has proved a powerful tool for analyses of the environmental sensitivity for potential oil spills. In this work, SPOT-XS images were used to derive information about various resources of the area, especially the shallow submarine coral reef communities. Topographic and field survey data were combined to produce the required sensitivity map. Ten major natural classes, along the shoreline and foreshore resources and habitats, were identified and analyzed. Their environmental sensitivity to potential oil spill were rated from low to high. The lowest sensitivity was assigned to the sea cliff and the highest to shallow coral reefs. Using GIS functions and analyses, it was possible to produce land use/land cover; shoreline sensitivity; foreshore sensitivity and critical natural resources maps. This information was used to determine protection priority, to propose access and protection planing, and to derive an environmental sensitivity index map of Ras-Mohammed.

ADDITIONAL INDEX WORDS: *Remote sensing, GIS, Red Sea, coastal hazard, oil spill, environmental pollution, coral reefs.*

INTRODUCTION

The coastal zone of Ras-Mohammed is characterized by its sensitive natural resources and habitats (*e.g.* ORMOND, 1982). This area is one of the most important recreation and tourism sites of Egypt. The study area (Figure 1) is located at the southern tip of Sinai, between 35°05′00″ to 34°20′00″E and 27°42′20″ to 27°52′20″N. It covers the main part of Ras-Mohammed National Park.

Natural resources in this area are threatened by numerous human activities. Potential oil pollution from tankers crossing the Gulf of Suez, phosphate pollution from industrial activities in the north, in addition to the impact of various tourist activities, are the major sources of danger to this coastal environment. The sensitive coastal ecosystems including coral reefs, rare species of migrating birds, crystal clear water and sunny golden beaches, are all under risk.

The main objective of this study is to carry out an environmental sensitivity analysis of the area of Ras-Mohammed, to derive the environmental sensitivity index map of the area, that assists decision makers and planners to plan, develop and manage these resources efficiently.

95061 received 4 May 1995; accepted in revision 10 July 1996.

The different physical environmental parameters which characterize the area such as weathering, wind, land and sea breezes, humidity, cloud cover, rainfall, currents, and tides are given in EDWARDS (1987). Reef structure, corals, fauna and flora on Ras-Mohammed National Park were reviewed by IUCN/UNEP (1988) and EL-GAMILY (1994).

Oil pollution throughout the coastal environment of Red Sea and both gulfs was documented by a number of workers *e.g.* OTTERMAN *et al.* (1974), BARRATT (1982), LOYA and RINKEVICH (1987), DICKS (1987), IUCN/UNEP (1988) and ABDEL-KADER (1990). Coastal zone geomorphology of Ras-Mohammed was discussed by NASR *et al.* (1996). EL-RAEY *et al.* (1996) discussed the use of remote sensing and GIS techniques to produce an oil spill contingency plan for Ras-Mohammed.

Work related to environmental sensitivity of coastal areas was discussed by several authors. Environmental sensitivity index (ESI) mapping for oil spills using remote sensing and GIS technology is carried out by JENSEN *et al.* (1990). The ESI system of mapping oil sensitive coastal environments and information on wildlife resources was developed to guide spill-response coordinators in evaluating the probable hazards associated with oil spills and to plan spill control operations effectively (GUNDLACH *et al.*, 1981). KENCHINGTON

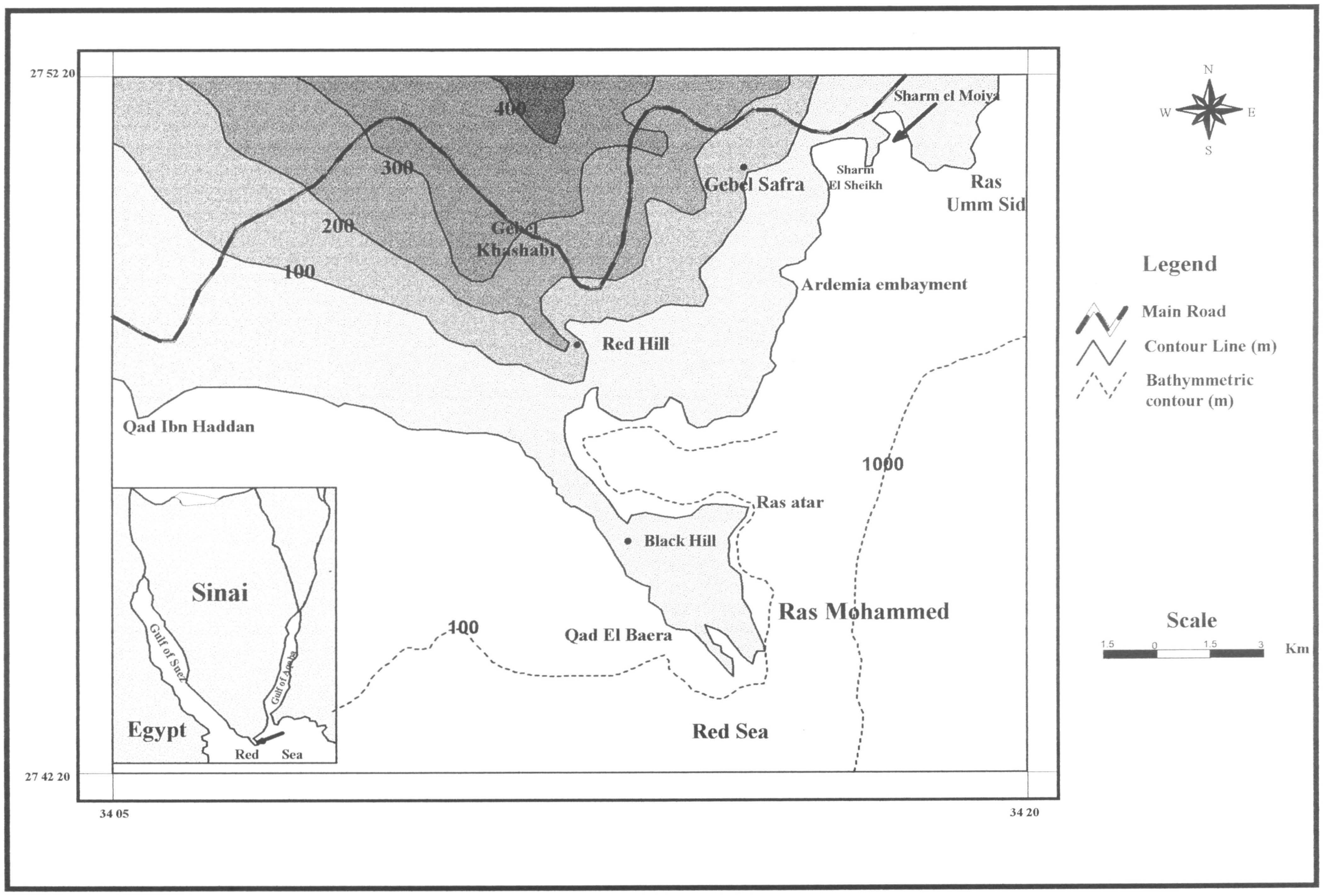

Figure 1. Ras Mohammed study area. Elevation and bathymmetric contours are indicated.

and HUDSON (1984) determined the method of constructing a coral reef management plan. The use of remote sensing for coastal zone management was reviewed earlier (*e.g.* RAJAMANICKAM *et al.* 1990, and HENRIQUE, 1991). These results were useful for defining the approach to the present work.

METHODOLOGY

The approach used in this study was based on the integration of information derived from digital image processing of SPOT data, computer digitizing of relevant maps, informa-

Table 1. *The Sensitivity criteria (1—least sensitive, 10—most sensitive), (based on* KENCHINGTON *and* HUDSON*, 1984).*

Criteria Classes	Sensitivity for Oil Pollution (1–10)	Cultural and Social Value (1–10)	Economic/ Recreation Value (1–10)	Scientific Value (1–10)	Environmental Consideration (1–10)
Sea cliff	1	3	2	3	2
Submerged coral reef	1	8	10	10	9
Sheltered sea cliff	2	3	2	3	2
Rocky and residual beach	3	2	2	2	2
Sheltered rocky and residual beach	4	2	2	2	2
Sabkha	5	2	3	5	3
Sandy beach	6	8	10	3	5
Sheltered sandy beach	7	8	10	3	5
Intertidal beach flat	8	6	7	8	8
Mangrove	9	8	7	8	10
Shallow coral reef community	10	8	10	10	10

Table 2. *Weighting factors (1), (2) and (3) of sensitivity and total relative response (based on KENCHINGTON and HUDSON, 1984).*

Criteria Classes	Sensitivity for Oil Pollution Weight (3)	Cultural and Social Value Weight (1)	Economic/ Recreation Value Weight (1)	Scientific Value Weight (2)	Other Environmental Considerations Weight (3)	Total Response
Sea cliff	3	3	2	6	6	20 (3.5%)
Submerged coral reef	3	8	10	20	27	68 (11.7%)
Sheltered sea cliff	6	3	2	6	6	23 (4.0%)
Rocky and residual beach	9	2	2	4	6	23 (4.0%)
Sheltered rocky and residual beach	12	2	2	4	6	26 (4.5%)
Sabkha	15	2	3	10	9	39 (6.7%)
Sandy beach	18	8	10	6	15	57 (9.8%)
Sheltered sandy beach	21	8	10	6	15	60 (10.3%)
Intertidal beach flat	24	6	7	16	24	77 (13.3%)
Mangrove	27	8	7	16	30	88 (15.2%)
Shallow coral reef community	30	8	10	20	30	98 (16.9%)

tion derived from air photos interpretation and supporting field investigations. Digital image processing and GIS analysis were carried out using IDRISI low cost software.

The available digital data for this study is SPOT-1 HRV1-XS digital scene acquired on 8 October 1986. SPOT digital tapes were processed to level 1-B (SPOT image, 1988). The following maps were available for this study: topographic maps of Sinai 1: 50,000 (sheet numbers NG 36 06 c and NG 36 06 d, EGYPTIAN MILITARY SURVEY, 1987) and Geomorphological map of Ras-Mohammed (NASR *et al.,* 1996), derived from aerial photos and field survey. Other valuable data were collected from documented papers and books, in addition to personal communication with specialists and local inhabitants.

Image processing techniques were used to produce the landuse/landcover map of the study area. The combination of supervised and unsupervised classification (hybrid) was used to take advantage of the characteristics of each. Functions of GIS techniques, such as vectorization, rasterization and overlaying, were used in connection with the digital image processing techniques.

Table 3. *Summary of the results of the hybrid classified image.*

Classes no.	Class Identification	Area km^2	Coverage %
1	Coralline limestone (massive & fragments)	84.48	18.12
2	Aeolian calcareous sand heaps	8.05	1.73
3	Acidic igneous and calcareous sand	32.12	6.89
4	Water	213.02	45.70
5	Arkose and sandstone	25.31	5.43
6	Living coral reef	17.84	3.83
7	Ferrogenous sandstone, shale, limestone, gypsum and conglomerate	15.62	3.35
8	Fossiliferous coral reef	20.42	4.38
9	Wet sabkha	8.54	1.83
10	Acidic basement	8.59	1.84
11	Seagrasses low density	8.45	1.81
12	Seagrasses high density	7.46	1.60
13	Shallow bottom sediments	5.49	1.18
14	Intertidal beach flat	4.53	0.97
15	Evaporites with algal sediments	6.18	1.33
Total		466.15	99.99

(1) Environmental Sensitivity Analysis

The following procedures were used to determine the environmental sensitivity of the area:

The shoreline of the topographic base map of south Sinai was digitized and stored in a separate file. The classified image, the geomorphological raster map and the matched groundtruth, were used to produce the vector files of the landuse/landcover map. The digitization process was carried out, for every land-use/land cover class, from screen. All vectors were then converted into raster format. All raster layers were then overlaid to produce the landuse/landcover map.

(2) Shoreline Sensitivity Criteria

The following criteria were adopted to determine the degree of shoreline sensitivity for the oil pollution based on information derived from SPOT data, aerial photographs, field survey and literature.

(a) Nature of Shoreline and Grain Size

The shoreline sediments of Ras Mohammed were classified into three classes, solid and rocky, fine sediment, and coarse sediment shorelines. In view of the difficulties and expenses encountered in cleaning oil spills, these shorelines are considered low, moderate and highly sensitive, respectively.

(b) Slope

Steep rocky shorelines are less sensitive than gentle slope shorelines. The slope of Ras Mohammed shorelines are divided into three types, sea cliff (steep slope), gentle slope (nearly horizontal), and medium slope (in-between).

(c) Open and Sheltered Shoreline

Sheltered shorelines are more sensitive than open ones, because of the long duration of possible impact of oil spills. Sheltered shorelines are identified from SPOT satellite (1986), aerial photos and field observations, as those of bays, tidal (mangrove) channels and embayments.

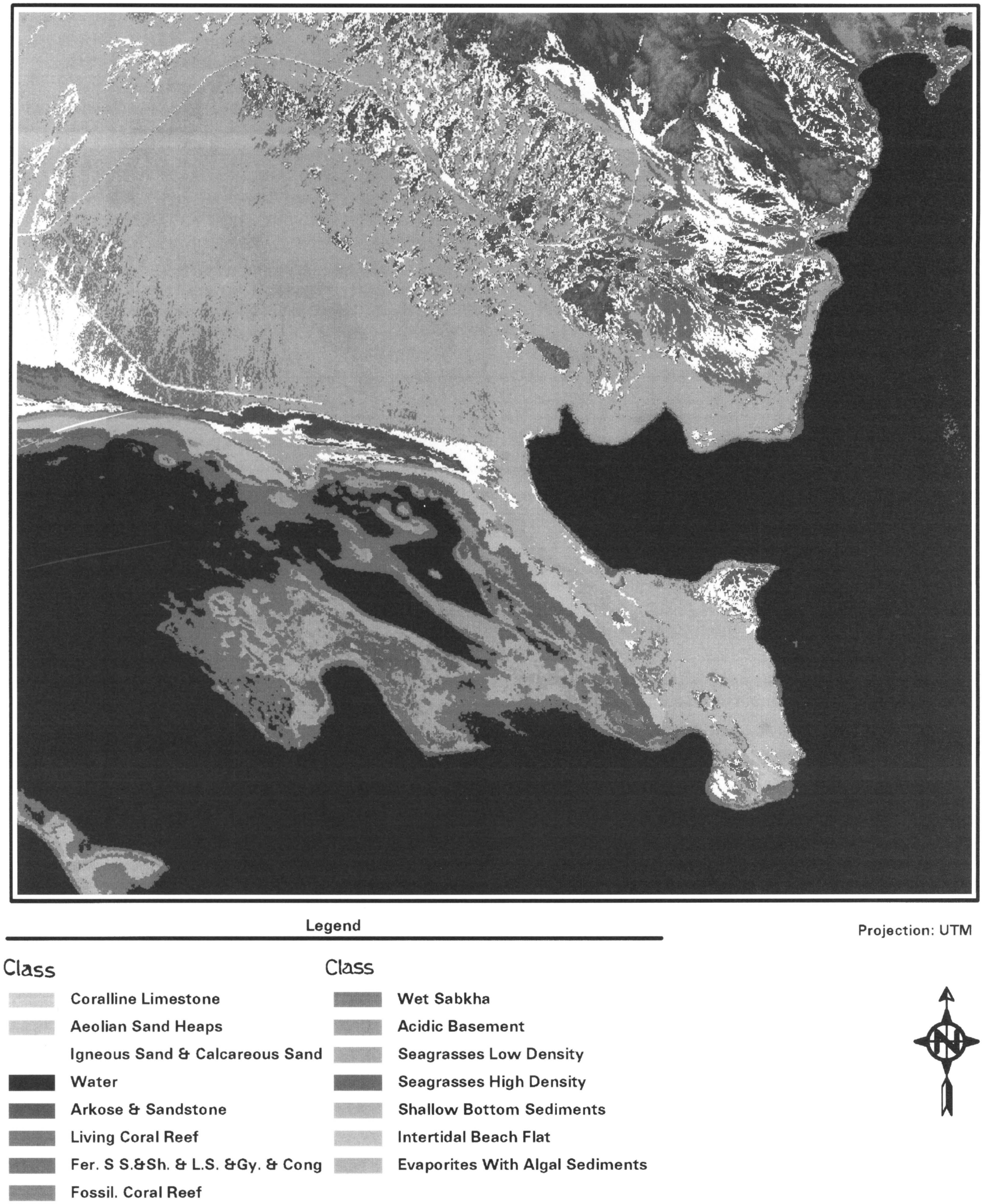

Figure 2. Hybrid classified Image (Maximum Likelihood classification {MLC}) of Ras Mohammed.

Table 4. *Contingency table of the classification accuracy.*

Classes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	Percentage Correct %
1	3,733	431	0	2,973	0	0	0	11	0	0	0	0	0	0	13	7,161	52.13
2	1	111	0	0	0	0	0	0	0	0	0	0	0	0	0	112	99.11
3	3	0	1,873	0	23	0	0	7	0	0	0	0	0	0	0	1,906	98.27
4	0	0	0	4,648	0	89	0	0	0	0	1	0	0	0	0	4,738	98.00
5	0	0	5	0	1,019	0	0	0	0	0	0	0	0	0	0	1,024	99.51
6	0	0	0	0	0	2,066	0	0	0	2	35	2	3	0	0	2,108	98.01
7	0	0	0	0	7	0	591	0	2	0	0	0	0	0	0	600	98.50
8	1	0	2	0	0	0	0	715	0	0	0	0	0	0	0	718	99.58
9	0	0	0	0	0	0	0	0	299	1	0	0	0	0	0	300	99.67
10	0	0	0	0	0	0	0	0	4	262	0	0	0	0	0	266	98.50
11	0	0	0	0	0	1	0	0	0	0	293	0	2	0	0	296	98.99
12	0	0	0	0	0	0	0	0	0	0	3	567	3	12	0	585	96.92
13	0	0	0	0	0	0	0	0	0	0	0	0	456	0	0	456	100
14	0	0	0	0	0	0	0	0	0	0	0	1	0	844	0	845	99.98
15	0	0	2	0	0	0	0	0	0	0	0	0	0	0	289	291	99.31
Average																	95.77

(d) Cleaning and Reclamation

The shoreline becomes less sensitive, by increasing the possibilities and capabilities for cleaning and reclamation. For example, the cleaning and reclamation of Sabkha is prohibiting, so it is highly sensitive.

Using those criteria, the sensitivity of a shoreline could be determined. The classified image and geomorpholological raster map were used to produce vector files for every level of shoreline sensitivity. A buffer zone from the shoreline was created. Then, the limit of every level of sensitivity was digitized from the screen. Each vector file was then converted to a raster format. Finally, the shoreline sensitivity map was produced by overlaying the various shoreline sensitivity layers.

(3) Foreshore Sensitivity Criteria

To determine the level of sensitivity of the foreshore habitats and natural resources for oil pollution, the following criteria were used:

(a) Duration and Speed of Damage

The foreshore sensitivity becomes higher at longer duration and faster speed of damage.

(b) Possibility of Reclamation, Restoration and Preservation of Habitats and Natural Resources

The sensitivity increases by decreasing this possibility.

(c) Rate of Growth of Species of the Community

The sensitivity of habitat and natural resources decreases by increasing the rate of growth of species.

(d) Dependence of Species on the Exposed Natural Resources

For example, the shallow coral reef is highly sensitive to oil spills because other members of the community are dependent on it.

Taking this into account, we used the satellite classified image and the geomorphological raster map to create the foreshore sensitivity map. By using on-screen digitizing, the vector file of submerged coral reef, intertidal beach flats, sheltered mangroves and the shallow coral reef communities were created. Subsequently, the foreshore sensitivity map was created as in the case of the shoreline sensitivity map. According to the sensitivity index of the shoreline, (of scale 1–10), the foreshore sensitivity of the inter tidal beach flats, sheltered mangroves and the shallow coral reef community ranged from 8 to 10 respectively, whereas the sensitivity of submerged coral reef equals one. The natural resources map was created by using vector files of the shoreline and foreshore which have a sensitivity rating of more than five. These vectors were converted to a raster format, and overlaid to obtain the critical natural resources and habitats map.

On the basis of information drawn from KENCHINGTON and HUDSON (1984), a sensitivity criteria table for various sensitive classes was established in this study (Table 1). To produce the protection priority map for the oil spill, we assigned weighting factors for sensitivity criteria (Table 2), and produced a rating for each class. Protection priorities, according to the sum of ratings, were then classified and grouped into three levels. The highest level for classes having a sensitivity of more than 70%, the medium level for classes have sensitivity range from 35% to 70%, and the lowest level are those of sensitivity less than 35%. Vector files for classes of every priority level were collected in one file and converted into raster format as one layer. Then a protection priority map was constructed by overlaying protection priority layers.

To produce access and protection map, the road network inside Ras Mohammed National Park was digitized from the topographic base map, and converted into raster format. The protection priority map and the road network were then used to determine potential sites of oil spill response centers. These have been used in the contingency planning in response to potential oil spills for Ras Mohammed (EL-RAEY *et al.,* 1996).

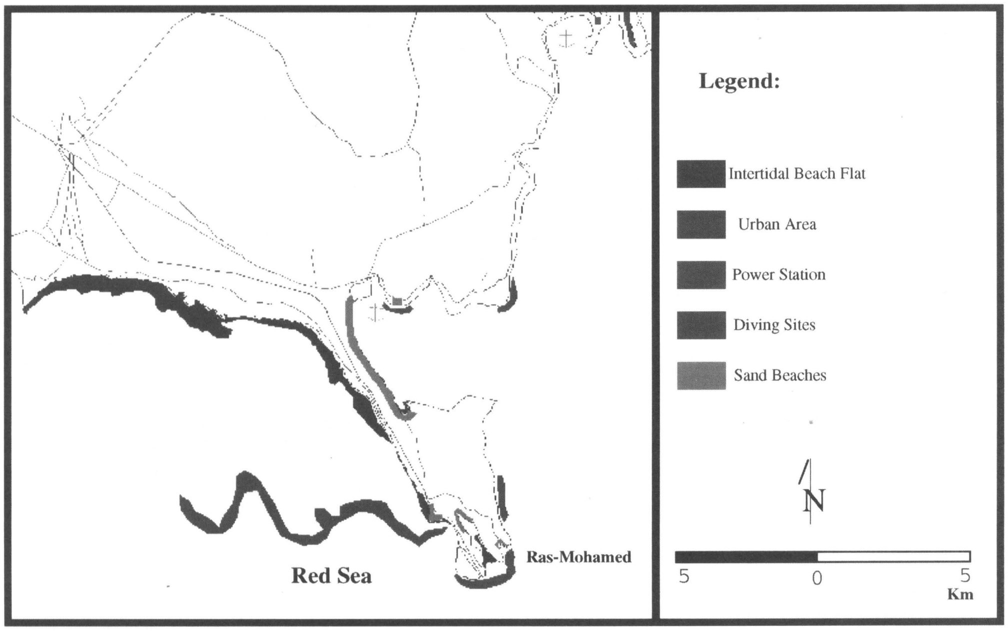

Figure 3. Landuse/Landcover map of Ras Mohammed area.

The potential sites map was stored in a vector file, and then converted into a raster format. The overlay of road network and potential response centers were used to produce an access and protection map. Finally, the environmental sensitivity index map was produced by overlaying the shoreline sensitivity map, foreshore sensitivity map and access and protection map.

RESULTS, INTERPRETATION AND DISCUSSION

Classes, areas and percentage coverage of each class, obtained from analysis of satellite image are listed in Table (3). A zoning sequence of sand, sea grass and living coral reef were found to be predominant through Ras-Mohammed foreshore habitats. It was also found that most classes from the

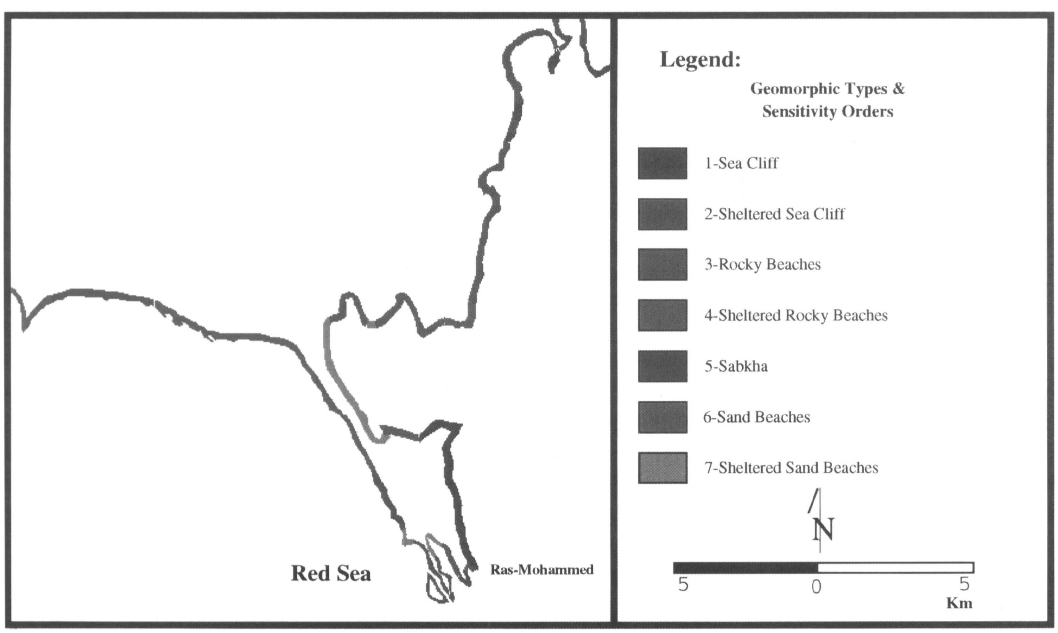

Figure 4. Shoreline sensitivity map of Ras Mohammed area.

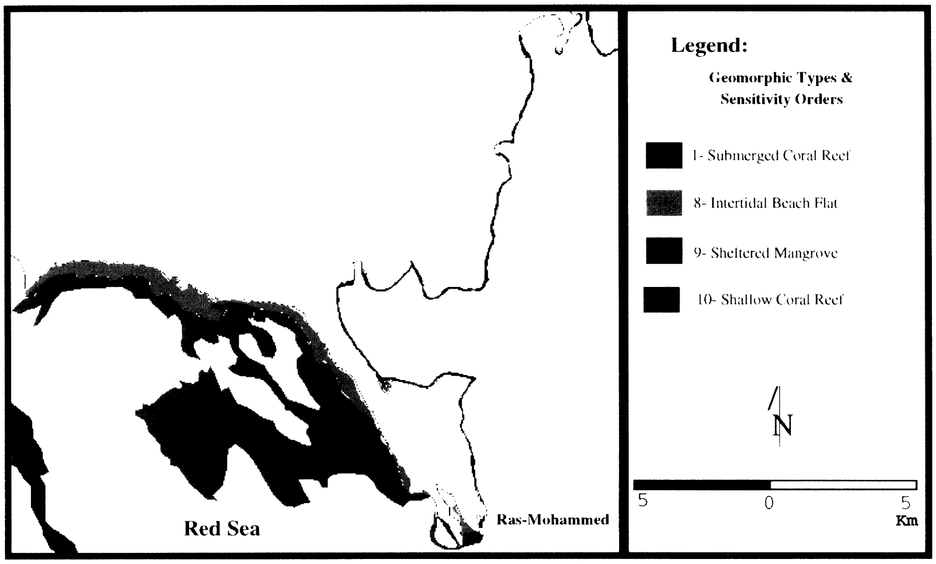

Figure 5. Foreshoreline sensitivity map of Ras Mohammed.

upland sector are mixed classes of calcareous sand, coralline limestone and acidic igneous sand. Several spectral signatures from upland classes, were found to be close to each other, in the feature space. These were particularly separated from field visits and spectral signatures. Figure(2) shows the classified image of Ras Mohammed.

To measure the overall accuracy of the classified image based on ground truth comparison, a contingency table (Table 4, was produced. The overall accuracy achieved is found to be equal to 95.8%. The accuracy of class-1, which represents the water body is the lowest one. This is because of the differences in water quality and depths.

The landuse/landcover map (Figure 3) shows that most human activities are concentrated at the southern tip of Ras Mohammed peninsula. Hotels, offices and shopping centers are located at the north eastern margin, outside Ras Mohammed National Park.

The shoreline sensitivity map (Figure 4) rated the sensitivity into seven levels or classes, the lowest is the sea cliff and the highest is sheltered sandy beaches. They are arranged

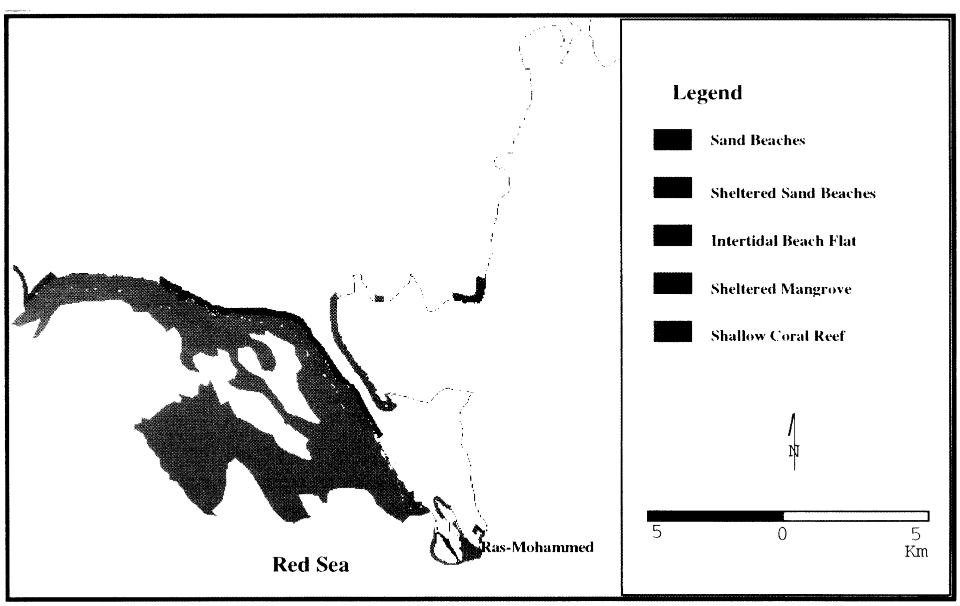

Figure 6. Critical natural resources map of Ras Mohammed based on sensitivity citeria.

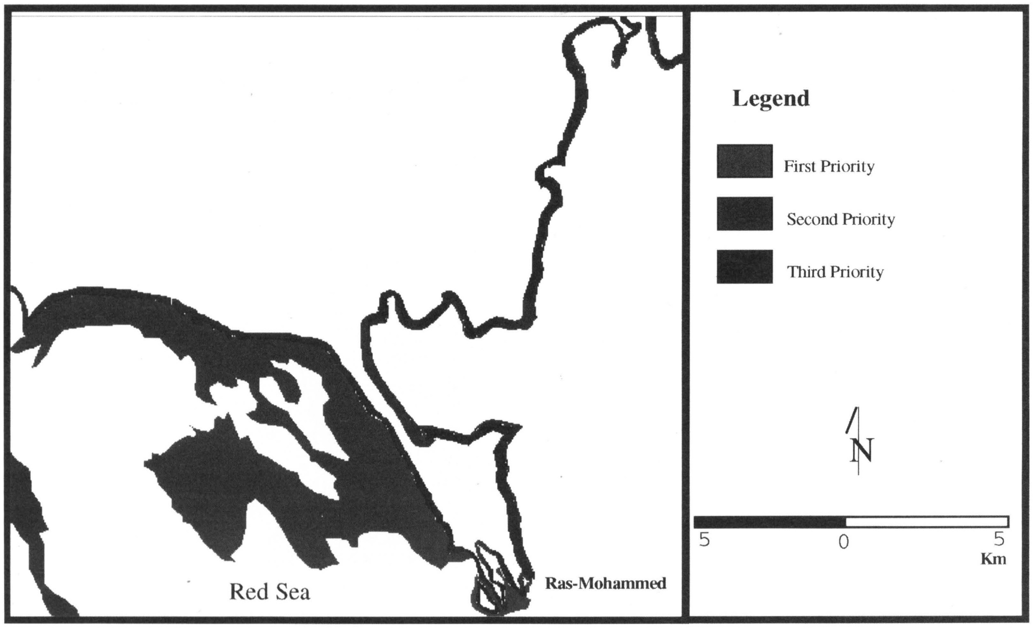

Figure 7. Protection Priority map of Ras Mohammed area.

from the lowest to the highest as follows: sea cliff; sheltered sea cliff; rocky beaches; sheltered rocky beaches; sabkha; sandy beaches; and sheltered sandy beaches. The sensitivity of foreshore habitats and natural resources (Figure 5) are arranged from lowest to highest as follows: submerged coral reef; inter tidal beach flat; sheltered mangrove; and shallow coral reef community.

The critical natural resources map (Figure 6) shows that, various types of sandy beaches, intertidal beach flat, mangrove trees and shallow coral reef community are the most critical natural resources in the study area. Environmental protection of these natural resources and habitats from potential oil spills, is a must.

The protection priority for the natural resources and habitats is documented in (Figure 7). The determination of optimum sites for oil spills response centers and tools were selected by the aid of the protection priority map and the predominant oceanographic parameters. It is noticed that, the southern tip of Ras Mohammed, in addition to the western shallow coral reef community and intertidal beach flat, have highest priority for protection.

Finally, the environmental sensitivity index map (Figure 8) includes the sensitivity of shoreline and foreshore natural resources and habitats, the road network and the sites of the oil spills response centers. Environmental sensitivity index maps are known to be used extensively to allocate most im-

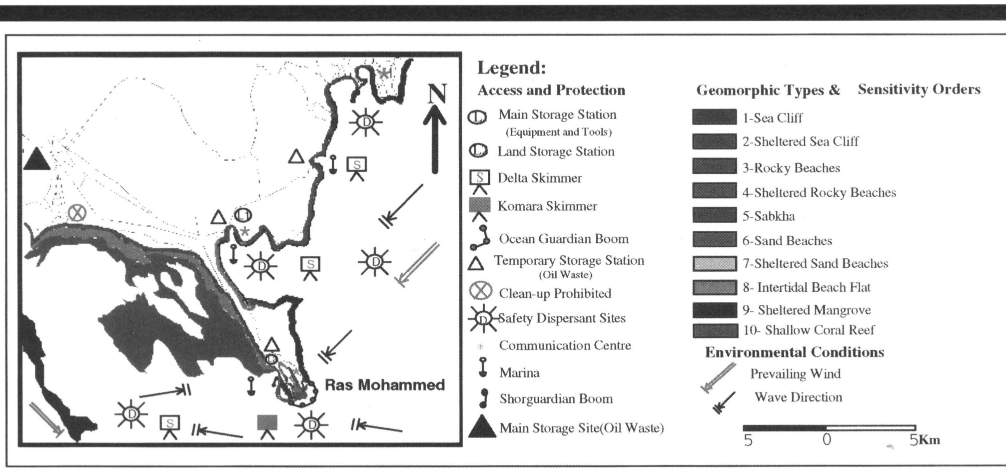

Figure 8. Environmental sensitivity index map of Ras Mohammed area.

portant natural resources and habitats during oil spills and the relevant response. This index map would help decision makers to protect the important, rich, and sensitive coastal zone environment of Ras Mohammed.

CONCLUSIONS

Ras Mohammed coastal area is a sensitive coastal environment threatened by numerous anthropogenic activities which may lead to serious environmental consequences. SPOT-xs satellite images, supported by field surveys and GIS analysis were found to be useful tools to analyze and evaluate environmental sensitivity of such area. Landuse/landcover, shoreline sensitivity, critical natural resources, protection priority, access and protection and environmental sensitivity index maps, were all produced and analyzed.

ACKNOWLEDGEMENT

The authors wish to express deep thanks to Dr. L. Barratt and Mr. D. Vousden, Hunting Aquatic Resources, University of York, United Kingdom, for their sincere help and technical support offered during this work. This work has been carried out at the Remote Sensing Laboratory of the Institute of Graduate Studies and Research. It has been partially supported by a grant from Islamic Educational and Scientific Organization (ISESCO).

LITERATURE CITED

ABDEL-KADER, A.F., 1990. Geological Studies on Southern Sinai Using Satellite Data. Ph.D. Thesis, Mansoura University.

BARRATT, L., 1982. Scientific Report of the Joint Services Expedition to the Egyptian Red Sea. University of York, Coral Reef and Tropical Marine Research Unit. United Kingdom, 47p.

DICKS, B., 1987. Pollution. *In:* EDWARDS, A.J. and HEAD, S.M., (eds.), New York: *Key Environments: Red Sea.* Pergamon pp. 383–404.

EDWARDS, F.J., 1987. Climate and Oceanography. *In:* EDWARDS, A.J. and HEAD, S.M., (eds.), New York: *Key Environments: Red Sea.* Pergamon, pp. 45–69.

EGYPTIAN MILITARY SURVEY, 1987. Topographic Map of Sinai (Sheet Number NG 36 06 C and NG 36 06 d).

EL-GAMILY, H.I., 1994. Remote Sensing and GIS Analysis of Environmental Sensitivity. Case Study: Southern Tip of Sinai. M.Sc. Thesis, Institute of Graduate Studies and Research, Alexandria University.

EL-RAEY, M.; ABDEL-KADER, A.F.; NASR, S.M., and EL-GAMILY, H.I., 1996. Remote Sensing and GIS for An Oil Spill Contingency Plan, Ras-Mohammed, Egypt. *International Journal of Remote Sensing,* 17(4), 2013–2026.

ESRI, 1992. ARC/INFO Marine spill GIS. *ARC News,* 14 (3); 3p

GUNDLACH E.R; HAYES, M.O., and GETTER, C.D., 1981. Sensitivity of Coastal Environments to Oil Spills. *In:* THOMOPOULOS, A.A. (ed.), *Proceedings of the Petroleum Industry and the Nigerian Environment.* Lagos: The Petroleum Inspectorate Nigerian National Petroleum Corporation, pp. 82–88.

HENRIQUE, 1., 1991 Remote Sensing and the Coastal Management in Brazil. *Proceeding of the Symposium on Coastal and Ocean Management,* 1, 187–192.

IUCN/UNEP, 1988. Coral Reef of the World. Vol. 2:Indian Ocean, Red Sea and Gulf. Nairobi, Kenya: UNEP, Gland, Switzerland: IUCN

JENSEN, J.R; RAMSEY, E.W; HOMLES, J.M; MICHE, J.E; SAVITSKY, B., and DAVIS, B.A., 1990. Environmental Sensitivity Index (ESI) mapping for oil spills using remote sensing and geographic information system technology. *International Journal of Geographical Information Systems,* 4(2), 181–201.

KENCHINGTON, R.A. and HUDSON, B.E.T., 1984. Coral Reef Management Handbook. UNESCO Regional Office for Science and Technology for South-East Asia, Indonesia, 18p.

LOYA, Y. and RINKEVICH, B., 1987. Effects of petroleum hydrocarbons on corals. *In:* SAIVA. B., (ed.),*Human Impacts on Coral Reef: Facts and Recommendations.* Antenne Museum, French Polynesia, pp. 91–102

NASR, S.M.; ABDEL-KADER, A.F.; EL-GAMILY, H.I., and EL-RAEY, M., 1996. Coastal zone geomorphology of Ras-Mohammed area, Red Sea, Egypt. *Journal of Coastal Research.*

ORMOND, R.F.G., 1982. Scientific report of the marine environment and tourism in the Egyptian Red Sea. University of York, United Kingdom.

OTTERMAN, J.; OHRING, and GINZBURG, A., 1974. Multidisciplinary Data Analysis of ERTS-1 Imagery, *Remote Sensing of Environment,* 3, 133–148.

RAJAMANICKAM, G.V.; LOVESON, V.J., and SINGARAM, N. 1990 Remote sensing approach to coastal environmental assessment and management in and around Vedaranyam, Tamil Nadu, India. *International Geoscience Remote Sensing Symposium,* 101–104.

SPOT IMAGE, 1988. SPOT *Newsletter,* No. 10, (Toulouse, France).