# IMPACT ASSESSMENT OF HUMAN ACTIVITIES ON COASTAL ZONES OF EASTERN SAUDI ARABIA USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS TECHNIQUES

Y. Al-Otaibi [a], M. Ait Belaid [b*], A. Abdu [b]

Arabian Gulf University, College of Graduate Studies, Desert and Arid Zone
Sciences Programme, P.O. Box: 26671, Kingdom of Bahrain,
Tel.: 973-39 026 030; Fax: 17 239 552; Email: belaid@agu.edu.bh

[a] Presidency of Meteorology and Environment (PME), Jeddah, Kingdom of Saudi Arabia.
[b] Desert and Arid Zones Sciences Programme, College of Graduate Studies, Arabian Gulf University (AGU)
P. O. Box: 26671, Manama, Kingdom of Bahrain, belaid@agu.edu.bh

**KEY WORDS:** GIS, Remote Sensing, Human Activities, Impact Assessment, Coastal Zones, Saudi Arabia.

**ABSTRACT**

The objective of this study is to survey natural resources and to assess environmental changes induced by human activities (industrial, socio-economic, and recreational) and the associated impacts on Manifah and Tanagib coastal zones in eastern Saudi Arabia. A review of the relevant literature was carried out at both the local and regional levels, in order to define the characteristics of the coastal zones and their vulnerability to pollution and environmental stress.

To achieve the main objective of this study, the scientific techniques of Remote Sensing (RS) and Geographic Information Systems (GIS), along with a field survey were used to gather data, investigate, assess and determine the main environmental problems and trends associated with development activities over time. In order to develop an environmental database including land use changes, existing data and field observations, the multi-temporal study was based on two sets of satellite imagery, Landsat-TM of 1991 and 2000. Furthermore, environmental impacts of the human activities were assessed using Leopold Matrix method.

The land use changes occurring during the last nine years in the study area indicate that the coastal zones of Manifah and Tanagib were experiencing many environmental problems, due mainly to the following factors:

- Persistence of Oil spill area (which has affected the study area in 1991).
- Decrease of Sabkha area and Salt Marsh area.
- Increase of sea waters and sand areas.
- Degradation of the coastal biodiversity due to various activities including land-based, as well as marine-based sources.

Similarly, the application of Leopold Matrix indicates that oil spills were the main source of pollution, followed by municipal and industrial solid waste, construction sites, oil pipelines, airport location, and land filling and coastal reclamation.

**RÉSUMÉ**

Le but ultime de cette étude est d'inventorier les ressources naturelles et d'évaluer les changements environnementaux induit par les activités humaines (industrielles, socio-économiques, et touristiques) ainsi que les éventuels impacts sur les zones côtières de Manifah et Tanagib à l'est de l'Arabie Saoudite. Une revue bibliographique détaillée a été faite au niveau régional et local, en vue de déterminer les caractéristiques des zones côtières ainsi que leur vulnérabilité à la pollution et aux pressions environnementales.

Les techniques scientifiques de télédétection et des systèmes d'information géographique, de concert avec les observations de terrain ont été utilisées pour acquérir les données, faire des investigations, évaluer et déterminer les principaux problèmes environnementaux, et les tendances associées aux activités de développement dans le temps. En vue de développer une base de données environnementale, incluant les cartes d'occupation du sol, les données classiques (le climat, la topographie, les ressources naturelles, les zones urbaine et industrielles, le réseau routier), et les observations de terrain, l'étude multi-temporelle a été basée sur deux images du satellite Landsat-TM de 1991 et 2000. Enfin, les impacts environnementaux des activités humaines ont été évalués en utilisant la méthode basée sur la Matrice de Leopold.

* Corresponding author

Les changements de l'occupation du sols intervenus durant les neuf dernières années dans la zone d'étude indique que les zones côtières de Manifah et Tanagib ont connu beaucoup de problèmes environnementaux, dû essentiellement aux facteurs suivants :

- Persistance de la surface des taches d'huile de pétrole qui ont affectées la zone d'étude durant la guerre du Golf en 1991.
- Réduction de la surface des Sabkha et disparition de la végétation salée.
- Augmentation de la superficie de l'eau de mer et celle du sable.
- Dégradation de l'écosystème naturel côtier due aux diverses activités humaines incluant celles provenant de la mer ainsi que celle provenant de la terre.

De façon similaire, l'application de la Matrice de Leopold indique que le déversement de l'huile de pétrole est la source principale de pollution, suivie par les déchets solides industriels et municipaux, les travaux de construction, etc.

## 1. INTRODUCTION

### 1.1 General Context

The Arabian Gulf is a semi-enclosed sea with a limited exchange of water with the open Indian Ocean. Situated in a semi-arid area of the Middle East, the Gulf is bordered by eight countries. The Arabian Gulf has a number of unique natural productive coastal ecosystems particularly in view of prevailing environmental conditions. However, discovery of oil resources and subsequent socio-economic developments has subjected these ecosystems to various types of stress (Khan et al. 2000).

The oil boom triggered unprecedented coastal development and growth in coastal population. Most of the population growth took place in the urban and industrial centres located on the coasts of the Arabian Gulf Cooperation Council countries (GCC) (ROPME, 2004).

Dredging and land reclamation in coastal and marine areas in GCC countries intensified during the last two decades, particularly along the coastal areas of the Eastern Province of Kingdom of Saudi Arabia, where the study area is located. These human activities were attributed mainly to the accelerated socio-economic development, which induced large scale land and coastal reclamation to build industries, ports, refineries and recreational facilities to meet growing urbanization and population increase (ROPME, 1999; 2004).

However, scientific evidence indicates that most of these activities are putting heavy pressures on the environment and the coastal ecosystems. These indicate that wildlife habitat and wetlands are being degraded and levels of pollution associated with oil exploration, production, processing and transportation are increasing. There is evidence that pristine habitats are being lost, reduction of fish catch, sedimentation, degradation of coral reefs and acceleration of land use changes and conflicts.

Furthermore, the strategic significance of the region has fuelled three wars (the Iran-Iraq War of the 1980's, the first and second Gulf Wars of the 1991 and 2003). These wars caused devastating effects to the marine and coastal environments especially those located on the west coast including the study area (MEPA, 1991; ROPME, 2004).

The study areas of Manifa and Tangib are located north of AL-Damam city, in the Eastern Province of Saudi Arabia, situated on the western coast of the Arabian Gulf. It is a semi-arid area with an average annual temperature of 26 °C rainfall of 120mm and high rates of evaporation. Although the total population of the area is not large, yet it is increasing at an annual growth rate of 9.3% (Al-Otaibi, 2005). Due to the accelerated rates of economic development, there have been a number of impacts and stresses associated with these rates that include (PME, 2003):

- Increasing rates of pollution due to petroleum hydrocarbons from refineries, oil terminals, oil spills from ships and oil-contaminated ballast waters.
- Coastal dredging, infilling and reclamation leading to physical alteration and degradation of habitats.
- Contamination from municipal solid wastes, untreated industrial effluents and dumping of litter from both land and sea-based sources.
- Stresses from recreational and tourist activities.
- Contamination of sediments with high levels of trace metals and heavy metals.
- Discharge of concentrated and hot brines from desalination plants and other sources.

The coastal ecosystems of the study area have also experienced extensive damage due to the three wars that have devastated the whole region. There have been long term impacts on the marine resources including the fisheries, coastal habitats and land use patterns (PME, 2003; PME/UNEP, 1989; ROPME, 2004).

### 1.2 Objectives

It is proposed here that the present study will be based on the modern techniques of RS (Lillesand and kiefer, 2000) and GIS (Demers, 2000) to collect the relevant data to structure a framework of a plan to rehabilitate the degraded coastal ecosystems of the area and develop them on sustainable basis.

The aim of this study is to formulate a framework towards an integrated planning and management of the coastal areas that will contribute towards the control and mitigation of the environmental, health and the adverse economic impacts of pollution. Thus it specifically aims to Survey the natural resources, design and develop an environmental database, and to establish a general framework for proper planning and management of coastal zones.

## 2. METHODOLOGY ADOPTED

To achieve the objectives of this study a combination of different methodologies were adopted, according to the following main steps.

### 2. 1 Literature Review

Literature review of the existing scientific reports and data sources (ecosystem components, socio-economic conditions, natural resources) was conducted to establish trends, indicators and conditions. Furthermore, the review focused on the application of RS/GIS techniques in the assessment of environmental impact in the gulf region (Ait Belaid and Mufareh, 2002; Al-Mannai, 2005; Ait Beladi, 2006) and particularly in the study site (Al-Otaibi, 2005).

### 2. 2 Satellite Data Acquisition and Field Survey

Satellite imagery (Landsat-TM) is required for land use mapping and it has to be available in the catalogue at the appropriate time and of excellent quality. For the purpose of the study, two recent satellite images (Landsat-TM) were taken for 1991 (during the event of gulf war) and 2000 (9 years after the event). A field survey was also conducted in order to evaluate the areas of habitats and ecosystems, human activities and sampling of sediments and contaminants, using ARC PAD device and GPS receiver (Kennedy, 1996) for data collection and determination of data locations.

### 2. 3 Land Use Mapping Using RS

Two satellite images of Landsat-TM were used to cover the study site in two different periods of time. The adopted analysis and interpretation techniques are (ERDAS, 1999): the combination of the two standard supervised (Maximum Likelihood Rule) and unsupervised (ISODATA Algorithm) classification techniques assisted by computer. The whole process is guided by ground truthing and local knowledge. The ground truthing process aims at localizing and characterizing land use categories using GPS instrument and ARC PAD device. The result of the classification process is a digital coverage layer containing the different land use categories.

### 2. 4 Data Analysis Using GIS

The results of the previous section 2.3 are two land use maps for 1991 and 2000 in the format of digital layers, in which polygons represent different land use categories. A full database is attached to this coverage, in which every polygon is characterized by many attributes like, the category number, area and perimeter of polygons (Booth and Mitchell, 1999). This is done by converting the digital file in raster format polygon format, using GIS tools. The analysis of these two ArcGIS Layers results produced in the previous section allows us to realize the pair-wise comparison of these two land use maps, as well as their statistical inventories, in order to detect possible changes in terms of area. Furthermore, we can investigate the impact of oil spill on other land use categories and vice-versa. Finally, the "Evolution Matrix" is built-up for the two period of times, providing all possible changes involved and the corresponding areas in terms of extension, regression and net evolution for all land use categories.

### 2. 5 Environmental Impact Assessment Using Leopold Matrix

Application of Leopold Matrix method to assess the environmental impact of development activities. In this matrix, the concept of Impact is broken into "magnitude" and "importance" components, each with a scale from 1 (Least) to 10 (Maximum). The project actions identified are arranged horizontally, while environmental characteristics and conditions are arranged vertically. The corresponding boxes are slashed and the determined numbers are inserted indicating the magnitude in the upper left-hand corner and for the importance in the lower right-hand corner. The numbers are used to identify concerns arising from the interaction of project activities with the environment (Mitchell, 1979; PME/UNEP, 1989; Ghurayba and Al-farhan, 2000).

## 3. RESULTS AND DISCUSSION

The application of the adopted methodology to the study site using remote sensing and geographic information systems analysis tools, along with ground survey leads to the following results (Figure 1 illustrating the land use map for 1991):

- Two land use maps were produced for the two periods of time 1991 and 2000, providing an exhaustive assessment of different land use categories in terms of areas and geographical locations.
- The equivalent scale of the maps elaborated is 1/100,000, which corresponds to the Landsat-TM satellite imagery with 30 m spatial resolution.
- The typology used allows characterizing the land use categories in five main classes: Sea Water, Oil Spill, Salt Marsh, Sabkha, and Sand.

The evolution matrix (Table 1), which has been developed to illustrate the whole changes occurring during the nine years intervals, confirms that:

- Oil spill area has decreased by 4030.2 hectares (ha), followed by sabkha area decreased by 2143.2 ha and salt marsh area by 257.8 ha.
- On the opposite, sea water area increased by 3534.4 ha and sand area by 2896.8 ha.
- Oil spill area has known two opposite changes: decease by 4399.7 ha (releasing sea water, sand and sabkha) and increase by 369.5 ha, impacting all other categories. Furthermore, Salt marsh area has completely disappeared.

| 1991 / 2000 | Water | Oil | Marsh | Sabkha | Sand | Ext. | Evol. (ha) |
|---|---|---|---|---|---|---|---|
| Water | --- | 3740.5 | 2.3 | 3.8 | 3.1 | 3749.7 | +3534.4 |
| Oil | 158.3 | --- | 32.2 | 71.6 | 107.4 | 369.5 | -4030.2 |
| Marsh | 0 | 0 | --- | 0 | 0 | 0 | -257.8 |
| Sabkh | 3.7 | 267.0 | 169.9 | --- | 2385.9 | 2824.5 | -2143.2 |
| Sand | 53.3 | 392.2 | 55.4 | 4892.3 | --- | 5393.2 | +2896.8 |
| Reg. | 215.3 | 4399.7 | 257.8 | 4967.7 | 2496.4 | xx | xx |

Ext. (Extension): Increase of the Area in hectares.
Reg. (Regression): Decrease of the area in hectares.
Evol. (Evolution): Extension minus Regression.

Table1. Land use changes (Evolution Matrix in hectares) for Manifah and Tanagib coast during 1991-2000.

The Evolution matrix (Table 1) gives the whole changes occurring in the study site between 1991 as a year of reference and 2000 as recent year. The columns of the matrix represent the land use statistics in 1991 and the rows represent the situation in the year 2000. The sum of the changes over a row gives the extension of the corresponding land use category (e.g. oil spill), and the sum over a column gives the regression of the corresponding land use category (e.g. sea water). The last column gives the net evolution of the land use categories considered, and it is calculated by subtracting regression row from extension column (Ait Belaid, 2003).

The application of the Leopold Matrix to the study area, for the purpose of environmental impact assessment in terms of magnitude and importance, reveals similar results than the evolution matrix below (Al-Otaibi, 2005):

- The most pollutant factor of human activities is oil spill, followed farley by industrial waste, water depletion, etc.
- In the opposite, the most impacted component of the ecosystem is soil, followed by sea water, coastal zones, vegetation area (plants), sabkha and landscape.

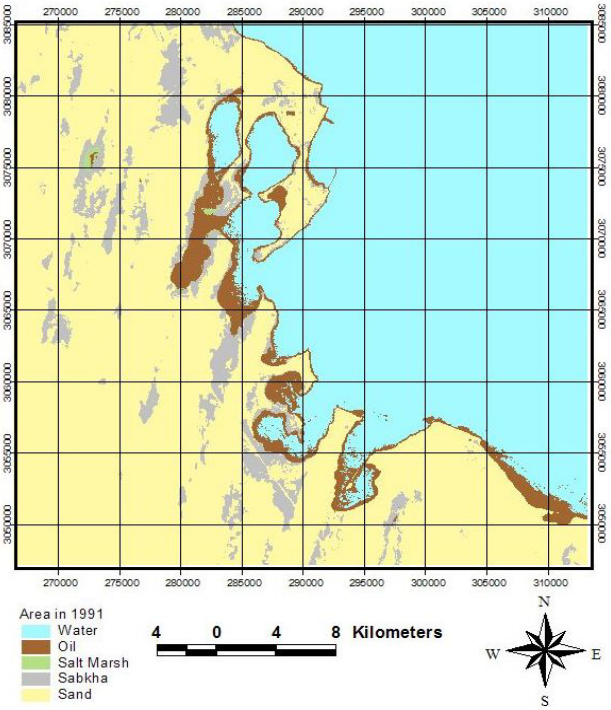


Figure 1. Land use map of Manifah and Tanagib coast for 1991
© EOSAT Copyright 1991, KACST/Processed at AGU

A comprehensive ground survey has been conducted in the study area, in order to validate and control the remote sensing results. For that purpose: twenty samples were taken in the year 2004 and analysed in the laboratory. Each sample corresponds to a cylinder with a diameter of 50 cm and a deep of 1 m. Two parameters were extracted to characterize each sample: deep of oil spill layer, and the concentration of polluted oil in Milligrams per Kilogram. The results show that the deeps are ranging from 20 cm to 1.5 m, and the concentration from 100 to 34000 Milligrams per Kilogram, which means that the impact of oil spill is still present in sand sediment at different deeps and in different concentration levels (Al-Otaibi, 2005).

## 4. CONCLUSIONS

Coastal zones were mapped out and monitored over time using (remote sensing, geographic information systems along with global positioning system) tools and appropriate land use change and analysis techniques, implemented in ERDAS Imagine and ARCGIS software (Ait Belaid, 2003).

Furthermore, the same techniques were applied to produce the evolution matrix (Table 1) and Leopold matrix, which present the whole changes occurred during 9 years interval of time and the assessment of the corresponding environmental impact of human activities on the coastal natural ecosystem.

As a final results the following fact are outlined:

- Oil spill phenomenon is the main factor affecting the whole components of the ecosystem.
- Sabkha area has deceased and Salt Marsh has disappeared.
- General degradation of the coastal fragile ecosystem due to over-fishing activities, solid waste, airport, oil pipeline, land filling and reclamation.

Finally, oil spill area which was estimated in 1991 at 6083.4 ha has decreased by 4030.2 ha (66.3%), and in the year 2000 we still have 2051.3 ha (33.7%) of oil spill to mitigate. This oil spill phenomenon has impacted mainly sabkha area (degradation), salt marsh area (disappeared), and also sea water and sand areas.

The cartographic and statistical results derived from the two land use maps produced successively during the event of gulf war (1991) (Figure 1) and after the event (2000) of oil spill are valuable tools for the protection and planning of marine and coastal zones of Manifah and Tanagib, which are vulnerable to various human activities and climate stress.

## REFERENCES

Ait Belaid, M.., 2003. Urban-Rural Land Use Change Detection and Analysis Using GIS and RS Technologies. 2nd International Federation of Surveyors (FIG) Regional Conference, Marrakech, Morocco http://fig.net/conference (accessed 2 Jan 2004).

Ait Belaid, M., 2006. Remote Sensing of Desert Cities and Urbanization Management in West Asia Region. Map Middle East 2006, March, 26 – 29, Paper Reference MI06PN 037, Dubai, United Arab Emirates.www.mapmiddleeast.org/2006/ (accessed 8 April 2006).

Ait Belaid, M. and Mufareh, M.A., 2002. Investigation of the impact of Urbanization on Agricultural Lands in AL-Ahsa Oasis Using Geographic Information Systems and Remote Sensing Technologies. 6th Annual Environmental Science and Research Institute (ESRI) Middle East & Africa User Conference, Dubai, www.gistec.com/mea2002 (accessed 20 Dec. 2003).

Al-Mannai, A., 2005. Investigation and Analysis of the Impacts of Urbanization on the Coastal Areas of Doha City Using Remote Sensing and Geographic Information System Techniques. Master Thesis, College of Graduate Studies, Arabian Gulf University, Bahrain, 127 p.

Al-Otaibi, Y., 2005. Impact Assessment of Human Activities on Manifah and Tanagib Coast Using Remote Sensing and Geographic Information System Techniques. Master Thesis, College of Graduate Studies, Arabian Gulf University, Bahrain, 110 p.

Booth, B. and Mitchell, A., 1999. Getting Started with ArcGIS. Environmental Scientific Research Institute (ESRI). Redlands, USA, 253 p. www.esri.com (accessed 1 March 2005).

Demers, M., 2000. Fundamentals of Geographic Information Systems, Second Edition. John Wiley & Sons, Inc, USA, 498 p.

ERDAS, 1999. ERDAS Field Guide, Fifth Edition. ERDAS Inc, Atlanta, Georgia, USA, 672 p. www.erdas.com (accessed 1 March 2005)

Ghurayba, S. and Al-Farhan, Y., 2000. Introduction to the Environmental Sciences. Amman, Jordan, 450 p.

Kennedy, M., 1996. The Global Positioning System and GIS: An Introduction. Ann Arbor Press, Inc., Michigan, USA, 268 p. www.trimble.com (accessed 1 March 2005).

Khan, N.Y., Munawar, M. and Price, A.R.G., 2000. The Gulf Ecosystem Health and Sustainability. Kuwait Institute for Scientific Research (KISR) and Backhuys Publishers, 494 p.

Lillesand, T.M. and Kiefer, R.W., 2000. Remote Sensing and Image Interpretation, Fourth Edition. John Wiley & Sons, Inc, USA, 724 p.

MEPA, 1991. Gulf War Oil Spill: Shoreline Clean-up Plan and Cost Estimate. The Meteorology and Environment Protection Administration (MEPA), Kingdom of Saudi Arabia, 350 p.

Mitchell, B., 1979. Geography and Resource Analysis. Longman, New York, USA, 399 p.

PME, 2003. Oiled Shoreline Survey in Support of the Marine and Coastal Damage Assessment. The Presidency of Meteorology and Environment (PME), Kingdom of Saudi Arabia, 293 p.

PME/UNEP, 1989. Environmental Impact Assessment- Basic Processes. The Presidency of Meteorology and Environment (PME) and United Nations Environmental Programme (UNEP), PME Press, Jeddah, 45 p.

ROPME, 1999. Regional Report of the State of the Marine Environment. The Regional Organization for the Protection of the Marine Environment (ROPME), Kuwait, 173 p.

ROPME, 2004. State of the Marine Environment Report, 003. The Regional Organization for the Protection of the Marine Environment (ROPME), Kuwait, 217 p.

## ACKNOWLEDGEMENTS

We would like to express our acknowledgements to the King Abdul-Aziz City of Science and Technology (KACST), particularly its Space Techniques Institute, for providing satellite imagery and the Presidency of Meteorology and Environment (PME) for providing classical and historical data and the Arabian Gulf University (AGU) for providing geographic information systems and remote sensing laboratory facilities.