Combined Use of Satellite Remote Sensing and GIS to Support Land-Use Planning and Management of At-Tif-AlFaza Coastal Area, Red Sea, Yemen

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Abstract. The objective of this study is to support sound planning and sustainable development of the At-Tif to AlFaza coastal area along Red Sea, Yemen. This area is characterized by its unique coastal ecosystems and rich benthic habitats for example coral reef, seagrasses and algae. Multidate landsat imagery acquired by Enhanced Thematic Mapper Plus (ETM+) and other preceding sensors (MSS and TM) during the period from 1972 to 2009 were used as a source of information for mapping and extraction of different thematic geo-environmental information on the study area. A field survey was conducted in August 2010 to gather information on study area and to verify some existing remotely sensed elements. Results obtained from remote sensing analysis and ground survey were used to build an environment database and GIS layers for the study area. These layers and other gathered information on geology, grain-size distribution of the coastal sediments, bathymetry and possible natural hazard, were used to build an environmental sensitivity model for the study area.

An environmental sensitivity index was prepared, this sensitivity was classified into the high, medium and low environmental sensitivity on the basis of sensitivity to anthropogenic activities. The medium and low environmental sensitivity, land use land cover, shoreline Slope and DEM have been used for the delineation of the suitable sites for potential sustainable development. The best suitable sites for the sustainable ecotourism development were determined in the north of At-Tif village, AlFaz and At-Tif spit.

Keywords: geoenvironment, sensitivity, model, coast, suitability, GIS, remote sensing.
Introduction

More than two-thirds of the world's population lives on the coast (Johnin, 2000). The human activities are growing quickly in coastal areas, especially adjacent to coral reef habitats and exert great impacts on coastal resources. The Red Sea hosts some of the richest ecosystems and resources in the world. Although the Red Sea is still one of the least ecologically disturbed seas relative to other enclosed water bodies, it is threatened by growing risk of marine pollution, and environmental degradation from rapidly expanding maritime activities (Sagheer 2008). It is necessary to maintain the fragile balance through the identification and monitoring of problematic areas and to propose sustainable practices for the human welfare. Remote sensing data, geographic information system (GIS) and modeling techniques are very useful tools for sound planning of coastal area sustainable development (Naser et al., 2003).

The study area is located along the Yemen’s Red Sea coast, 17 km south of Hodeidah city. It lies between longitude 42º 53' 30" to 43º 03' 26" E and latitude 14º 20' 23" to 14º 38' 07" N (Fig. 1). Main prominent features of the study area include fish harbors and villages, sand spit and bars, tidal flat, sabkha, coastal dunes and reefal limestone stack. The study area also hosts rich coral reef and seagrasses communities.

The study area is an almost flat to slightly undulating coastal plain and occasionally is cut by several wadi channels. Commonly the east boundary of the coastal area is marked by a zone of perennial vegetation. The climatic condition is characterized by hot summer and warm winter, very sparse rain, high humidity and weak wind speed. The marine water is characterized by semi-diurnal tide, average salinity 37.9‰ and the temperature about 27.5°C and 38°C in winter and summer respectively.

The application of the remote sensing technique is very important for monitoring of possible changes of the geomorphological features, natural resources and land use /land cover of the study area. It was found that Geographic Information System (GIS) and modeling techniques are very useful tools for sound planning for the sustainable development of the coastal area. Naser et al. (2003) studied the environmental modeling using remote sensing and GIS for sustainable ecotourism development of Ras Banas area, Red Sea of Egypt; also Effat and Hegazy (2007) discussed a GIS- based tool for a coastal Highway's sensitivity index of the Mediterranean coastal highway in Egypt.
Fig. 1. Location map showing the study area.
The GIS in a narrow definition is a computer system for the input, manipulation, storage and output of digital spatial data. In a more broad definition, it is a digital system for the purposes of planning, administering and monitoring the natural and socioeconomic environment (Jankowski et. al., 1997 and Hussain, 2004). There are many GIS models used for scientific investigations of resources, coastal zone management, assessing environmental conditions and development planning (Ayad, 2005 and Suryanarayana and Amit, 2006). Hussain, (2004) discussed the GIS and modeling for coastal zone management case of Lake Burullus in Egypt. There are two different approaches to model environmental processes by GIS. The first is the cartographical modeling that works within the GIS program according to Abdel-Kader et al. (1998), Naser et al. (2003), Fall et al. (2006) and Ellik and Moshe (2007). The second approach is the mathematical modeling which uses the GIS as a cooperating technology (Kemp, 1997). This study the present work uses GIS technology and modeling to examine the influence of a number of natural and man-made factors on the conservation of the ecosystem on the study area and their impact on potential best suitable sites.

Materials and Methods

1-Source of Data

The data used for the present study include multi-date landsat (Table 1), ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), topographic maps and admiralty charts. The ASTER image is located by 42-43 E and 14-15 N. The topographic maps published by the Ordnance Survey in UK and the Yemeni Survey Authority in 1980 has a scale of 1:50000. The admiralty chart has scale of 1:50,000 and published at Taunton, UK in 2006.

<table>
<thead>
<tr>
<th>Type satellite</th>
<th>Date</th>
<th>Landsat Number</th>
<th>WRS Bath/Row</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSS</td>
<td>October 13, 1972</td>
<td>Landsat-1</td>
<td>179/050</td>
</tr>
<tr>
<td>TM</td>
<td>September 20, 1989</td>
<td>Landsat-4</td>
<td>166/050</td>
</tr>
<tr>
<td>ETM+</td>
<td>December 23, 2000</td>
<td>Landsat-7</td>
<td>166/050</td>
</tr>
<tr>
<td></td>
<td>September 18, 2009</td>
<td>Landsat-7</td>
<td>166/050</td>
</tr>
</tbody>
</table>
2-Grain Size Analysis

The grain size analysis of sediments has been carried out using the method described by Folk (1980). The sand and gravel fractions were sieved at diameters of 4, 2, 1, 0.5, 0.25, 0.125 and 0.063 mm screens. The mud (silt and clay) fractions were determined by the pipette method. Cumulative curves were produced by plotting the cumulative percentages against phi-diameters on arithmetic probability graph paper using SEDSTAT program. The grain size classes (gravel- sand- mud) proposed by Blair and McPherson (1999) were used to describe the texture of the collected samples.

3-Remote Sensing Analysis

The programs ERDAS IMAGINE 9.1 and Arc GIS 9.2 software were used to conduct the analysis data. A GPS unit was used to collect ground truth data during May 2011. Remote sensing data require pre-processing to remove geometric and radiometric flaws. The registration process transforms each pixel of a raw satellite images into a new coordinate system in a specified map project. The image thus was rectified and registered using Universal Transverse Mercator (UTM) projection following the cubic convolution technique. The root mean squares error for the registered images 1972 was 0.33 pixel.

In this study, both enhancement techniques (principal components) and ratio image method (band 4 of date1989/1972, 2000/1989 and 2000/2009) are used to emphasize changes between eroded and accreted areas. Because of the low reflectivity of water at near-infrared (NIR) region of the electromagnetic spectrum. A maximum likelihood supervised classification technique is applied in the ETM+ image (date 2009) to determine land use /land cover classes. These classes are: Shallow marine, coral reefs, tidal flat (some spot covered by seagrasses and algae), sabkha, coastal dune, sparsely vegetated plain and cultivated land (Fig. 2).

4-Description of the Utilized Data

The main source of data required to establish the GIS database includes:

- Distribution of the coastline sediments map
- Digitized coastline
Fig. 2. Thematic map for main land coverage pattern of the study area.
- Digitized the hazard map (coastal dune movement and coastline change) from band ratio and superclassification of landsat images.
- Contour line and bathymetric (source topographic map, admiralty chart and ASTER, Fig. 3)
- Digital elevation model (DEM) and slope maps
- Land use/land cover map

Fig. 3. Bathymetric and topographic map of the study area.
The classification of the grain size sediments in the coastline were used to analyze and identify the gravels, sand and mud distribution. Digitization of the coastline was based on ETM+ image acquired on 2009. An accurate digital elevation model (DEM) of the study area was developed using topographic map, admiralty chart and ASTER image, where the contour lines and the spot heights were digitized (Fig. 3). Each point was assigned the correct elevation at its accurate coordinates. Subsequently, a grid was interpolated from the contour lines and elevation points to produce the DEM. By processing the DEM, the slope has been derived as it is expressed by degrees from the horizontal (Fig. 4).

Fig. 4. Slope degree map of the study area.
The data integration involved a wide range of raster, vector and tabular data components for display, comparison, and analysis. As the GIS becomes established, it is possible to apply a model to combine the thematic layers to generate new information.

**Model Construction and Results**

A cartographic model is a set of interacting ordered map operations act on raw data, as well as derived and intermediate map data, to simulate a spatial decision making process (Tomlin, 1990). A preliminary mathematical model has been developed in combination with the established GIS to manipulate the concerned gathered layers and parameters. The direct target of this model is to construct an environmental sensitivity index (ESI) map and to determine the best suitable sites.

**1- Environmental Sensitivity Index Map**

The environmental sensitivity index map is very important for land use planning, for example in deciding best areas for ecotourism development (Sagheer 2008). Two kinds of information are needed to produce the environmental sensitivity index map; these are the characteristics of the coastline zone and natural resources. The grain size distribution of the coastline sediments in the study area can be classified into four coastline units 1) gravelly-sand 2) sandy gravel 3) muddy-sand and 4) sandy mud (Fig. 5). The distribution of the sediments along the coastline show sand gravelly concentration in the spit and sand islands while along the coastline of At-Tif is sandy mud and muddy sand. Four variable criteria of the coastline characteristics (slope, sheltered-exposed, pollution and scientific /social) are used to influence the Environmental Sensitivity index (Table 2). The steep slope (greater than 10°) is less sensitive than flat area (e.g. tidal flat) (El-Gamily 2001). Also, the sheltered coastline zone and the fine sediments are more sensitive to oil pollution than the exposed coastline zone, coarse sediments and beach rock respectively. Accordingly, the natural resources and sedimentary environments are of high scientific and social importance. Furthermore the relative sensitivity of the natural resources criteria such as sabkha, tidal flat, (seagrasses and algae) and coral reef are used as indicators for the level of the environmental sensitivity (Table 3).
Fig. 5. Grain size distribution of Coastline sediments.
Table 2. Different weights criteria for the coastline sensitivity.

<table>
<thead>
<tr>
<th>Coastline textures</th>
<th>Slope</th>
<th>Sheltered- exposed</th>
<th>Pollution</th>
<th>Scientific &amp; Social value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;5</td>
<td>5-10</td>
<td>&gt;10</td>
<td>Sh</td>
</tr>
<tr>
<td>Muddy Sand and Sandy mud</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Sandy gravels</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Gravelly Sand</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3. Different weights assigned to the natural resources criteria.

<table>
<thead>
<tr>
<th>Natural resources criteria</th>
<th>Description</th>
<th>Weight</th>
<th>Natural resources criteria</th>
<th>Description</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sabkha</td>
<td>Not exist</td>
<td>0</td>
<td>Coral reef</td>
<td>No exist</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Dry sabkha</td>
<td>1</td>
<td></td>
<td>Low</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Wet sabkha</td>
<td>2</td>
<td></td>
<td>Medium</td>
<td>6</td>
</tr>
<tr>
<td>Tidal flat</td>
<td>Not exist</td>
<td>0</td>
<td></td>
<td>High</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Small area exist</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large area exist</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A simple operations model has been designed according to the following steps (Fig. 6):

- Digitizing the coastline and coastline zone sediments of the study area from the image processes (date 2009) result.

- Building a GIS environment with the essential derived layers and the different weights criteria (Table 2).

- Assigning different weights to the individual elements according to their influences, through a study of image processing experts and as shown in Table 3.

Applying and testing the following equations to divide the coast into areas of different environmental sensitivities:

\[
\text{ESI of sabkha} = \text{weight value of sabkha} \times \text{total weight value of coastline zone sensitivity}
\]

\[
\text{ESI of tidal flat} = \text{weight value of tidal flat} \times \text{total weight value of coastline zone sensitivity}
\]

\[
\text{ESI of coral reef} = \text{weight value of coral reef} \times \text{total weight value of coastline zone sensitivity}
\]

According to this model (Fig. 6) the study of coastal areas has been classified into three environmentally sensitivity levels as follows:

Low ESI (≤15), Medium (between 15-33), High (≥33)
2-Best Site Suitability Development

The criteria or layers used in the site suitability development are hazards (coastline changes, coastal dunes movements and main wadi), elevation and slope, environmental sensitivity index and the current land use. Each layer has a very specific and unique theme that is representative of a single parameter or group of parameters. Figure 7 shows a simple mathematical model block diagram that attempts to combine and integrate the above mentioned criteria to derive areas that satisfy the following conditions:-

- Away from the hazards criteria by making a buffer zone (coastline changes, coastal dune and main wadi) Table 4.

- The suitable site is less than 30 m in elevation and less than 10° of slope.

- Areas of the Low environmental sensitivity.

- Away from current land use by making a buffer zone (Table 4 urban communities, cultivated land, national security sites, main roads).
This assumption was made to highlight the areas suitable for building coastal tourism villages and other human activities. Figure 8 shows the results of the model that used the above conditions and represents the best areas for suitable development in study area.

Table 4. Estimated buffer zones distances from criteria.

<table>
<thead>
<tr>
<th>No</th>
<th>Criteria (layers)</th>
<th>Buffer zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Urban communities (very small villages)</td>
<td>&gt; 300 m</td>
</tr>
<tr>
<td>2</td>
<td>The cultivated lands &amp; Main roads</td>
<td>&gt; 100 m</td>
</tr>
<tr>
<td>3</td>
<td>National security sites</td>
<td>&gt; 1000 m</td>
</tr>
<tr>
<td>4</td>
<td>Main wadis</td>
<td>&gt; 100 m</td>
</tr>
<tr>
<td>5</td>
<td>Coastal dunes</td>
<td>&gt; 200 m</td>
</tr>
<tr>
<td>6</td>
<td>Medium and low shoreline change</td>
<td>&gt; 100 m</td>
</tr>
</tbody>
</table>

Fig. 7. Flow chart of the site suitability model.

**Conclusion**

This work described the research that has been preformed through a careful analysis of environmental parameters, to develop an integrated mathematical model that give a comprehensive insight into the best suitable areas for sustainable development in At-Tif to AlFaza Red Sea coastal area of Yemen.

Based on the processing of the satellite image, field survey, geological setting, physico-chemical characteristics of the coastal sediments and the evaluation of the both natural hazards (e.g. coastline change, coastal dune movement, and wadi channels), and various miscellaneous anthropogenic activities hazards, two models have been
constructed; namely: environmental sensitivity model and site suitability model. The environmental sensitivity index was determined as high, medium and low grade. The high environmental sensitivity was located in the north of At-Tif spit and northern west of Al-faz village. The best suitable sites for the sustainable ecotourism development were determined in the north of At-Tif village, AlFaz and At-Tif spit.

Fig. 8. Map show the sites suitability development of the study area.
References


تطبيق الاستشعار عن بعد ونظم المعلومات الجغرافية
لدعم خطة استخدام وإدارة منطقة الطائف - الفازة الساحلية،
البحر الأحمر، اليمن

عbuff علي عبدالله
قسم الجيولوجيا البحرية، كلية علوم البحار والبيئة، جامعة الحديدة، الحديدة، اليمن

المستخلص. الهدف من هذه الدراسة هو دعم خطة علمية صحيحة للتنمية المستدامة لمنطقة الطائف الفازة الساحلية على امتداد البحر الأحمر اليمني والتي تتميز بنظام بيئي وأراضي رطبة ساحلية فريدة. تم استخدام بيانات لعدم أربع صور للقمر الصناعي لإنشاء لانسات للأعوام 1989 و 2009 لإنتاج الخرائط الرقمية للمنطقة واستخراج معلومات جيوبينية. وكان النزول الحلكي في شهر أغسطس 2010 لمسح المنطقة وتأكد من نتائج تحليل صور الأقمار الصناعية. نتائج تحليل صور الأقمار الصناعية والزراعة الحقيقية تم استخدامها في بناء قائمة بيانات بيئية على هيئة طبقات بواسطة نظم المعلومات الجغرافية. هذه الطبقات تضم الجيولوجيا وتوزع حجم الحبيبات والأنظمة البيئية وطبغرافية ومورفولوجية المنطقة الساحلية والمخاطر البيئية. تم استخدامها من أجل بناء نموذج دليل الحساسية البيئية لمنطقة الدراسة.

قُسم نموذج دليل الحساسية البيئية إلى ثلاثة أقسام تشتمل مناطق عالية الحساسية البيئية ومتوسطة ومنخفضة. تضمن إنشاء نموذج تحديد أفضل مناطق التنمية الساحلية مستدامة عدة طبقات هي مناطق متوسطة ومنخفضة الحساسية البيئية ودرجة الميل ومعدل تغير خط الشاطئ وحركة الكثبان الرملية والطرق والقرى ومواقع المنشآت الوطنية. وقد تركزت مناطق التنمية المستدامة الناتجة من النموذج في لسان الفازة البحري وشمال قرية الفازة وجنوب منطقة الطائف.