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Chapter 4
Abu Dhabi Island: Analysis of Development and Vegetation Change Using Remote Sensing (1972–2000)

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Abstract Over the past few decades new cities have appeared around the world in undeveloped areas. And although development has expanded significantly and become bolder and more innovative, the above-average scale at which the countries of the Persian Gulf are growing stands one level above the rest. The United Arab Emirates obtained independence in 1971 with a GDP of 6.5 billion Dirhams (US$ 1.6 billion); this figure ballooned to 379 billion Dirhams (US$ 103 billion) in 2004. During this timeframe, the country had undergone tremendous development through petroleum exports and foreign investments. Needless to say, development has permanently changed the country's landscape. The purpose of this paper is to investigate land cover changes in the capital Abu Dhabi and surrounding regions from 1972 to 2000 using Landsat images. Two primary (land and vegetation) and two secondary (shallow and deep water) features were selected as measures of development. Remote sensing and GIS were used to perform the classification and post-classification of images and visualize the results. Results for the two primary features vegetation and land have shown an increase of 3700 and 17% respectively between 1972 and 2000. The creation of new land from the by-products of dredging activities has negative effects on seafloor habitat while the intensified artificial expansion of vegetation impacts groundwater resources, both being direct consequences of rapid development. The application of sustainable methods in development activities is crucial, particularly in this part of the world with very few natural resources other than petroleum and natural gas.

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4.1 Introduction

Monitoring changes in the environment and the prediction of future circumstances is an important factor in the developing world. The countries in the Persian Gulf are facing tremendous industrialization and their landscape is changing at a tremendous pace (Starbuck and Juanito 2006). Remote sensing plays a significant role in providing geo-information in a spatial format and also in determining and monitoring the overall capacity of the earth (Navalgund et al. 2007).

Prior to independence in December, 1971 the United Arab Emirates (UAE) was a group of loosely associated tribal sheikhdoms called the Trucial States. Petroleum was discovered in the area in 1958 and Abu Dhabi began to export offshore oil in 1962 (Library of Congress 1993). The UAE's proven oil reserves stand at 97.8 billion barrels and as a result of the petroleum wealth the country is getting rapidly industrialized (Alhameli and Alshehhi 2004). The UAE's gross domestic product was Arab Emirates Dirham (AED) 6.5 billion (US$1.6 billion) in 1972 (El Mallakh 1981), that figure swelled to AED 379 billion (US$103 billion) in 2004 (UAE-NMC 2008). In 1976, the area under cultivation in the emirate of Abu Dhabi was 28.70 square kilometers (sq.km.) which exploded to 135,000 sq.km. at the end of 1997 (MEAW 2008).

The initial study area for this project was comprised of the original Landsat scene (185 km × 185 km) covering the central portion of the UAE, however, this approached was abandoned because of the limited time available. Subsequently, the area was reduced to capital, the city-island of Abu Dhabi, and the surrounding region within an average radius of 17 km around the center of the island. This radius was selected because it represents the maximum amount of coastal alteration around the capital.

The current morphology of the island and its surroundings is the result of dredging and land reclamation operations that aim to boost economic productivity. Similarly, afforestation efforts have been extensive in order to beautify the barren landscape of the country (Issa 2008). We found it interesting to compare the change in morphology and the areal extent of vegetation cover from 1972, a year after the emergence of the UAE as an independent country to the year 2000. The rationale for selecting these time periods is that the earliest available satellite imagery for this region dates back to 1972; the year 2000 was chosen because that was when the most recent cloud-free, error-free and cost-free imagery for that particular area was found.

4.2 Data

For this study we used two cloud-free images; a Landsat 1 Multispectral Scanner (MSS) image from November 29th, 1972 and a Landsat 7 Enhanced Thematic Mapper Plus image from August 8th, 2000. Landsat was the chosen satellite because the spatial resolution and the areal extent of the scene cover the region of interest and

Table 4.1 Satellites and sensors used for the study

Satellite	Sensor	Spectral range	Bands used	Pixel Res
L 1	MSS multi-spectral	0.5–1.1 μm	1, 2, 3, 4	60 m
L 7	ETM+ multi-spectral	0.450–1.175 μm	1, 2, 3, 4	30 m

the imagery was freely available. The images were downloaded from the University of Maryland's Global Land Cover Facility (GLCF) and were orthorectified with a RMS geodetic accuracy of 50 m. The MSS image consists of a pixel size of 60 m and contains four spectral bands; the ETM+ image consists of a pixel size of 30 m and contains eight spectral bands. All MSS bands (1–4) were used while the first four ETM+ bands were used in order to work with a consistent radiometric range on both images. As previously mentioned (see Section 4.1), the August 2000 Landsat 7 image was the most recent available in terms of cost and freedom from error, this is due to the fact that Landsat 7's Scan Line Corrector (SLC) had been inoperational since May 2003 and this results in a "zigzag" effect on resultant images. About 22% of any scene is lost due to this mishap. The United States Geological Survey (USGS) provides a Gap-filled Systematic Correction with all Landsat imagery since May 2003 but this approach could not be applied for this project due to time constraints (Table 4.1).

4.3 Methodology

The methodology employed in this study involves the classification and post-classification of the satellite imagery which was adapted from the Advanced Training Course on Land Remote Sensing from the European Space Agency (ESA).

The area under analysis consists of low-lying land comprised of tidal mudflats, mangrove forests, reclaimed land made of dredge-spoil plus associated dredged channels, salt-flats, algal mats and an urban landscape. Due to the diversity of landscapes, we chose sets of contiguous pixels as the Spatial Unit of Analysis (SUA). When an image interpretation process is undertaken, one of the key issues in the delineation of discrete areal units on images is the selection of the smallest size area entity to be mapped as a discrete area, the minimum mapping unit (Saura 2002). The chosen Minimum Mapping Unit (MMU) for this study, based on the SUA, is three pixels which correspond to 0.008 sq.km.

4.3.1 Feature Identification and Selection

Due to the limited availability of ancillary data, we have relied solely on aerial imagery for feature selection and identification in the case of the Landsat 1 image. Furthermore, single bands as well as combinations of bands were applied to achieve maximum possible differentiation. On the other hand, in case of the Landsat 7 image we relied on both visual analysis and local knowledge in identifying and selecting features.

In order to make a clear distinction between the vegetation and other features in both images we employed the Normalized Difference Vegetation Index (Rouse et al. 1973) to both the Landsat images:

$$\text{Normalized Difference Vegetation Index (NDVI)} = \frac{\text{Near Infrared} - \text{Red}}{\text{Near Infrared} + \text{Red}} \quad (4.1)$$

In order to determine the areal extent of afforestation as well as to ascertain the area of reclaimed land, we found it necessary to focus on four information classes; land, vegetation, shallow water and deep water. This would give us the amount of new land created since 1972 as well we the amount of new deep-water channels created as a result of land reclamation efforts and the increase in the amount of vegetation.

4.3.2 Classification

A classification system is designed based on the user's need, spatial resolution of selected remotely sensed data, image-processing and classification algorithms available and time constraints (Lu and Weng 2007). Since this study is not focused on distinguishing between individual land classes apart from vegetation, different land forms such as urban areas, reclaimed islands, salt-flats and low-lying algal mats were aggregated into one region of interest, land. The signatures generated from the training samples are then used to train the classifier to classify the spectral data into a thematic map (Lu and Weng 2007). We used maximum likelihood, a parametric classifier. Maximum likelihood functions on the basis of computation from the records of the classes set from training samples and each pixel is assigned to the class with the highest probability based on training statistics. Polygons of training samples were collected from both images because of the wide generality of the desired classes (Table 4.2).

In the resultant images, there was a distinct "salt and pepper" effect, hence post-classification processing was necessary. For the first stage, a Sieve method was

Table 4.2 Samples collected for Landsat images (1972 and 2000)

1972 Land class	Polygons/pixels	2000 Land class	Polygons/pixels
Deep water	90/7387	Deep water	185/28,863
Shallow water	67/4204	Shallow water	124/25,738
Land	116/21,084	Land	326/110,442
Vegetation	10/39	Vegetation	139/14,458

employed for the purpose of removing the isolated pixels in the classified image. A minimum threshold of three pixels with eight neighbours were selected. Any pixels that did not meet the required parameters were deleted and replaced by unclassified values. Hence, another post-classification method was necessary to merge these unclassified pixels. Majority Analysis (Stuckens et al. 2000) was performed to convert the unclassified pixels within a single class into that class. In this method, a kernel size of 5 × 5 was specified as well as a center pixel weight of value three, which was be replaced based on the values of the kernel of the majority class. After a series of tests with other post-classification methods, this was considered to be a good choice (particularly for a classification with a persistent "salt and pepper" problem) as it is able to eliminate the noise in the classified image. Therefore, after generalization, a smoother image for both the MSS and ETM+ images was produced.

4.4 Results

Determining the accuracy of the classification was performed using a Confusion Matrix. Ground-truth region of interest (GTROI) samples were collected from each image and were assigned the desired classes. These were then entered into the Confusion Matrix and accuracy was assessed against the classified images. As previously mentioned (see Section 4.3.2) the only available ancillary data for 1972 came from aerial imagery and which were also used in the accuracy assessment. The Overall Accuracy of the Landsat 1 image was 94.2% with a Kappa Coefficient (Cohen 1960) of 0.97. The Landsat 7 image produced an Overall Accuracy of 94.07% and a Kappa Coefficient of 0.99 (Table 4.3).

The outcome of the classification displayed a significant increase in the primary features within the temporal range of the study; the final classified images in vector format are presented in Figs. 4.1 and 4.2. Between 1972 and 2000 new land areas were created in the shallow and deep water which amounts to approximately 16% of the total land area. The areal extent of vegetation increased considerably by 3700% during the same period from 3.38 to 127.92 sq.km. These figures were anticipated since the country's population increased by nearly 10-fold from 309,000 to over 2,776,000 in the 28-year period between 1972 and 2000 (Oxford Business Group 2008; UAE Ministry of Information and Culture 2004) (Figs. 4.3, 4.4, and 4.5).

Even though the study area had undergone tremendous development, some of the original land cover had been retained, for example 86.30% of the original 1972 vegetation cover (coastal mangroves) was retained, which amounts to less than 3% of total vegetation in 2000. Similarly, all the other features experienced a retention percentage of above 80% except shallow water, which had retention of 51.82% of the original areal extent. This is most probably due to the dredging activities that created new land and new deep water channels around Abu Dhabi Island (Table 4.4 and 4.5).

Table 4.3 Accuracy Assessment of the Landsat 1 and 7 images

Percentage accuracy of the Landsat 1 image classification

Class	Land (%)	Vegetation (%)	Shallow water (%)	Deep water (%)	Total (%)
Land	100.00	31.22	0.00	0.08	29.47
Vegetation	0.00	68.25	0.00	0.00	2.41
Shallow water	0.00	0.53	76.99	0.04	15.57
Deep water	0.00	0.00	23.01	99.88	52.55
Total %	100.00	100.00	100.00	100.00	100.00

Calculated producer's and user's accuracies for the Landsat 1 image classification

Class	Prod. Acc. %	User Acc. %	Prod. Acc.	User Acc.
Land	100.00	96.13	1514/1514	1514/1575
Land	100.00	96.13	1514/1514	1514/1575
Vegetation	68.25	100.00	129/189	129/129
Shallow water	76.99	99.76	830/1078	830/832
Deep water	99.88	91.17	2561/2564	2561/2809

Percentage accuracy of the Landsat 7 image classification

Class	Land (%)	Vegetation (%)	Shallow water (%)	Deep water (%)	Total (%)
Land	93.25	15.99	0.00	0.00	33.24
Vegetation	6.75	84.01	0.00	0.00	14.04
Shallow water	0.00	0.00	93.80	0.00	12.65
Deep water	0.00	0.00	6.20	100.00	40.06
Total %	100.00	100.00	100.00	100.00	100.00

Calculated producer's and user's accuracies for the Landsat 7 image classification

Class	Prod. Acc. %	User Acc. %	Prod. Acc.	User Acc.
Land	93.25	93.25	1519/1629	1519/1629
Vegetation	84.01	84.01	578/688	578/688
Shallow water	93.80	100.00	620/661	620/620
Deep water	100.00	97.91	1922/1922	1922/1963

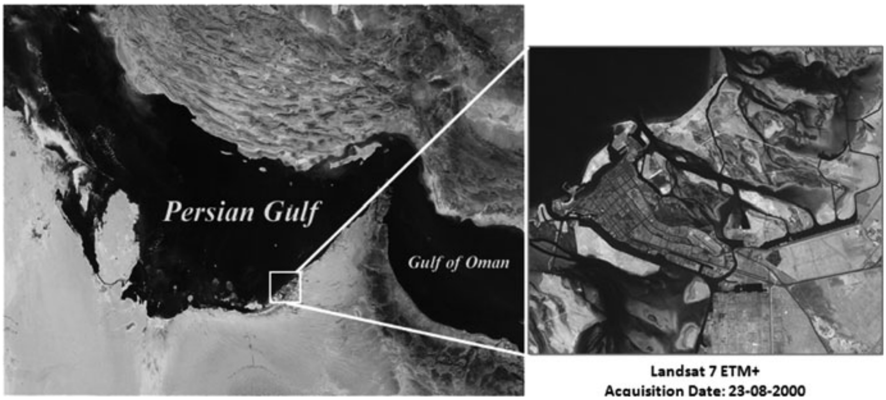

Fig. 4.1 Overview of the study area

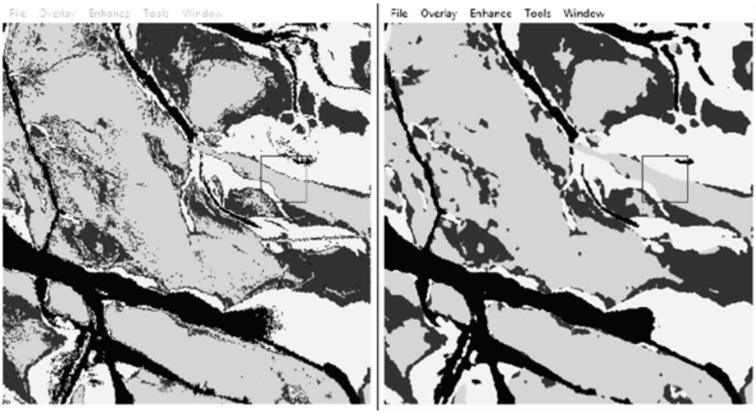

Fig. 4.2 Displays the 2000 classified image before (*left*) and after performing majority analysis

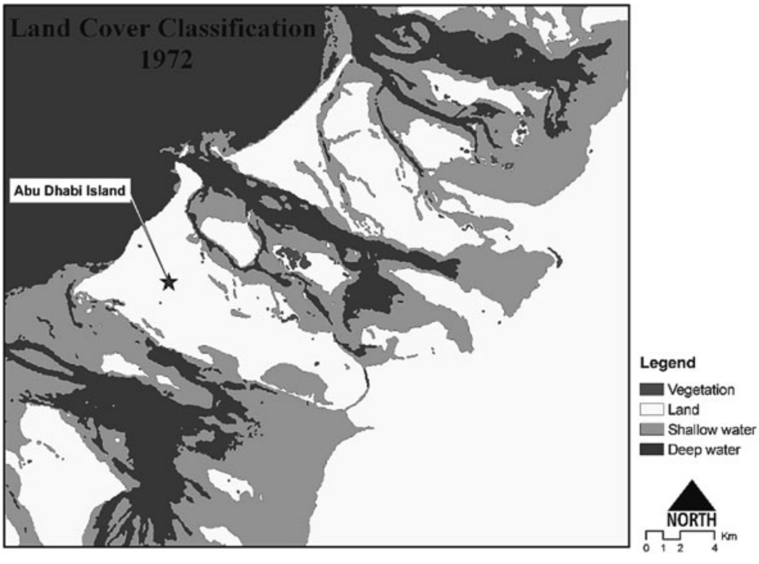

Fig. 4.3 Land cover map of Abu Dhabi in 1972

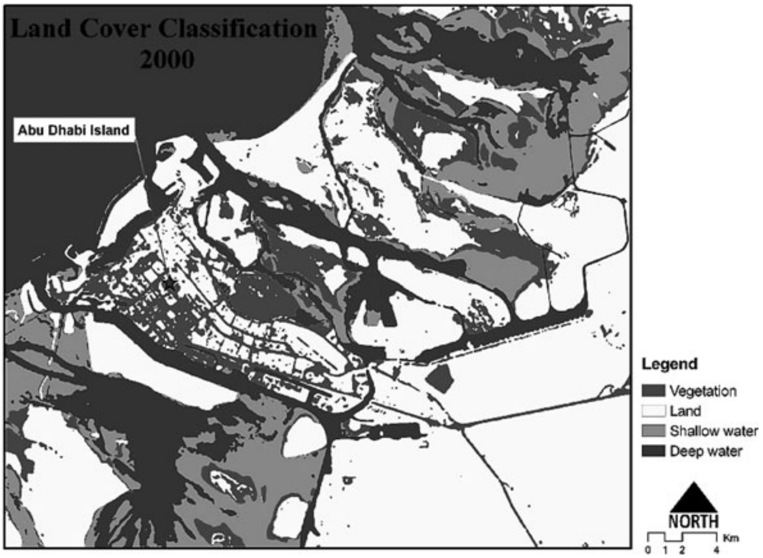

Fig. 4.4 Land cover map of Abu Dhabi in 2000

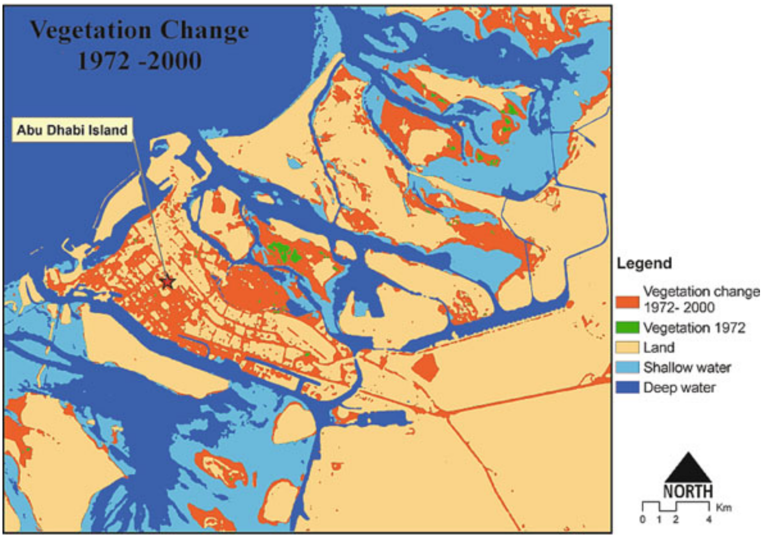

Fig. 4.5 Change in vegetation in Abu Dhabi Island between 1972 and 2000

Table 4.4 Change in different land covers between 1972 and 2000

Change of different land covers to vegetation between 1972 and 2000

1972 Land cover	2000 Land cover	Areal change (sq.km.)	Percentage based on 2000 land cover area
Vegetation	Land	0.31	0.06
Shallow water	Land	60.62	12.55
Deep water	Land	17.43	3.61
Land	Vegetation	75.51	59.07
Shallow water	Vegetation	48.18	37.69
Deep water	Vegetation	1.22	0.96

Change of different land covers to shallow water between 1972 and 2000

1972 Land cover	2000 Land cover	Areal change (sq.km.)	Percentage based on 2000 land cover area
Land	Shallow water	2.93	1.52
Vegetation	Shallow water	0.03	0.01
Deep water	Shallow water	32.60	16.93

Change of different land covers to deep water between 1972 and 2000

1972 Land cover	2000 Land cover	Areal change (sq.km.)	Percentage based on 2000 land cover area
Land	Deep water	17.21	4.93
Vegetation	Deep water	0.12	0.03
Shallow water	Deep water	37.04	10.60

Table 4.5 Amount and percentage of land cover area that was retained between 1972 and 2000

1972 Land cover	1972 Area (sq.km.)	2000 Land cover	2000 Area (sq.km.)	Areal retention (sq.km.)	Retention percentage based on 1972 land cover area
Land	500.42	Land	483.13	404.77	80.89
Vegetation	3.38	Vegetation	127.83	2.92	86.39
Shallow water	302.76	Shallow water	192.48	156.92	51.82
Deep water	344.24	Deep water	347.36	292.99	85.11

4.5 Discussion

The countries of the Persian Gulf have simultaneously outpaced their neighbors in the development and modernization since the discovery of petroleum. However, this rapid development was not monitored until recently when the science of remote sensing began to be taken up by academia and researchers in the region. We have demonstrated that remote sensing can be used to measure the amount of change over the course of several years in rapidly changing landscapes. This method can be applied to other cities in the region, and indeed worldwide, that have undergone similar levels of development. Although the scope here was to see the change in land and vegetation over 28 years, future work of interest may be the evaluation of how the urban fabric and impervious surfaces of Abu Dhabi have increased since independence and their contribution to the Urban Heat Island effect (Jones et al. 1990).

4.6 Conclusions

The area in and around the capital city of Abu Dhabi was subject to intensive development efforts that permanently altered the landscape. These drastic morphological changes have been attributed to the surge in petroleum wealth. This study has successfully produced a land cover map of the selected study area through the application of a supervised classification algorithm. This study demonstrated that remote sensing can be used in the monitoring of landscapes that quickly change in relatively small temporal scales.

Albeit the scope of this study is limited, it does provide valuable insight into the extent that which the UAE is changing. More research on development and its impacts on landscapes are needed, particularly in rapidly developing nations such as the UAE, is required and remote sensing provides an invaluable tool.

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