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Monitoring Vegetation Change in Abu Dhabi Emirate from 1996 to 2000 and 2004 using Landsat Satellite Imagery

مراقبة التغير في الغطاء النباتي في إمارة أبوظبي للفترة من 1996 إلى 2000 و2004 باستخدام صور القمر الصناعي لاندسات

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ABSTRACT: In the fall of 2001, a study was initiated to investigate vegetation changes in the Abu Dhabi Emirate. The vast majority of vegetation present in the region is irrigated, and an analysis of vegetation change will support groundwater investigations in the region by indicating areas of increased groundwater use. Satellite-based imaging systems provide a good source of data for such an analysis. The recent analysis was completed between February and November 2002 using Landsat 5 Thematic Mapper satellite imagery acquired in 1996 and Landsat 7 Enhanced Thematic Mapper Plus imagery acquired in 2000. These assessments were augmented in 2004 with the study of Landsat 7 imagery acquired in early 2004. The total area of vegetation for each of seven study areas was calculated using the Normalized Difference Vegetation Index (NDVI) technique. Multi-band image classification was used to differentiate general vegetation types. Change analysis consisted of simple NDVI image differencing and post-classification change matrices. Measurements of total vegetation area for the Abu Dhabi Emirate indicate an increase from 77,200 hectares in 1996 to 162,700 hectares in 2000 (110% increase). Based on comparison with manual interpretation of satellite imagery, the amount of under-reporting of irrigated land is estimated at about 15 percent of the actual area. From the assessment of the 2004 Landsat imagery, it was found that the growth of irrigated vegetation in most areas of the Emirate had stabilized and had actually slightly decreased in some cases. The decreases are probably due to variability in the measurement technique and not due to actual decreases in area of vegetation.

Keywords: *vegetation monitoring, satellite imagery, Landsat, Abu Dhabi.*

المستخلص: في خريف عام 2001 تم البدء في دراسة لتحري التغير في الغطاء النباتي في إمارة أبو ظبي. تمثل الغالبيه العظمى من النباتات الموجودة في المنطقة المساحات الزراعية المروية، ولذا فإنه بتحليل التغيير في الغطاء النباتي يمكن دعم التحريات المتعلقة بموارد المياه الجوفية للإشارة إلى المناطق التي تم فيها زيادة استخدام المياه الجوفية. وتوفر صور الاقمار الصناعية إحدى المصادر الجيدة للبيانات لإجراء هذا النوع من التحليل. ولقد تم الانتهاء من هذه التحاليل في الفترة ما بين فبراير ونوفمبر 2002 باستخدام صور فضائية من راسم الخرائط الغرضي المحمول على لاندسات 5- ملتقطة للعام 1996 وصور فضائية من راسم الخرائط الغرضي المحسن المحمول على لاندسات - 7 ملتقطة للعام 2000، وفي عام 2004 تمت إضافة صور فضائية للقمر الصناعي لاندسات 7- ملتقطة في أوائل العام 2004 لهذه التحاليل. تم حساب المساحة الإجمالية للغطاء النباتي لسبعة مناطق في الإمارة باستخدام طريقة معامل الفرق الموحد للغطاء النباتي (NDVI)، وتم استخدام طريقة تصنيف قنوات الصور الفضائية للتمييز بين انواع النباتات بشكل عام. واشتمل تحليل التغير في الغطاء النباتي على مقارنة معامل الفرق الموحد للغطاء النباتي بين الازمنة المختلفة وتصنيف مصفوفة التغيرات للغطاء النباتي. أشارت حسابات المساحة الكلية للغطاء النباتي لإمارة ابوظبي إلى زيادة في هذه المساحة من 77,200 هكتار في عام 1996 إلى 162,700 هكتار

في عام 2000 (110% زيادة). وبناءاً على المقارنة اليدوية لتفسير الصور الفضائية تبين أن نقصان الأراضي المروية حسب التقارير بلغ حوالي 15 ٪ من المساحة الفعلية. ومن تقييم صور لاندسات للعام 2004، تبين بأن نمو الزراعة المروية في معظم مناطق الإمارة قد استقر بشكل عام، وفي بعض الحالات سجل انخفاضا طفيفا، إلا أن هذا الانخفاض في المساحة عزي على الارجح إلى التغيير في أسلوب القياس، وليس بسبب انخفاض حقيقي في مساحة المزروعات .

كلمات مدخلية : *رصد الغطاء النباتي، صور فضائية، لاندسات، أبو ظبي.*

INTRODUCTION

Remotely sensed imagery can be used effectively in hydrologic studies, such as where ground water is being used for irrigation. By knowing the location and type of new areas of irrigated vegetation, hydrologists can better understand how the ground water may be affected in that area. Different crop types use different kinds and amounts of groundwater. Acacia forests can tolerate more brackish water and use relatively less amounts of water. Grass fields require larger amounts of fresh water. An investigation in the use of satellite imagery to determine areas of irrigated vegetation and rates of change was conducted in the Abu Dhabi Emirate in 1997, using Landsat 5 Thematic Mapper satellite imagery acquired in 1987 and 1996 (Sohl, 1999). The 1997 study focused on examining ways to monitor vegetation change and suggested the most applicable change detection technique to be used by the GWRP staff.

The goal for this study was to extend the vegetation change analysis to the 1996 to 2000 and 2004 timeframe. Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite imagery was acquired for the winter 2000 timeframe and analysis was conducted to delineate areas of vegetation to compare with the 1996 results. Further analysis was performed, where possible, to describe the kinds of vegetation present, according to a simple land-cover classification scheme.

DESCRIPTION OF THE STUDY AREAS

With approximately 59,200 km^2 (square kilometers) of land area, the Abu Dhabi Emirate is the largest of the seven emirates that make up the United Arab Emirates. Located on the Arabian Peninsula, the United Arab Emirates is bordered by the Kingdom of Saudi Arabia to the west and south, the Sultanate of Oman to the east, and the Arabian Gulf to the north.

Most of the Abu Dhabi Emirate is underlain by nearly flat-lying sequences of sedimentary rocks, with the uplifted Oman Mountains and associated thrust zone in the east of the Emirate. Alluvial deposits eroded from the Oman Mountains are found on flood plains radiating from the mountain front. More recent deposits of wind-blown sand cover much of the current land surface (Moreland, 1988). The climate is arid, with average annual rainfall less than 10 cm. No perennial streams are present in the Emirate. Appreciable amounts of groundwater can be found, however, in dune sand deposits, alluvial deposits, and shallow sedimentary formations. Groundwater quality differs with location and depth from fresh, to brackish, to saline.

For the purposes of this study, the vegetative cover was categorized into five main classes: (1) Forests - primarily acacia trees planted in uniform plots; (2) Date palms - dense, well-established groves of palm trees; (3) Vegetable fields - small fields laid out in a patchwork fashion, containing a wide variety of vegetable plants; (4) Grass/fodder fields - both small (4 hectares) and large (800 hectares) fields growing grasses typically used for animal feed; and (5) Dry grass - not a true vegetation type, but this refers to fields of cut grass laid out to dry. These fields of drying grass were distinctive in the multi-spectral imagery. Mixed classes, such as date palms/grass, trees/grass, and scattered acacia, also were used during some of the image classifications. Irrigation of all these vegetation types is supplied by groundwater.

Areas of irrigated vegetation are located primarily east of the city of Abu Dhabi, in a large area around the city of Al Ain, and in the Liwa region. Three Landsat scenes cover nearly the entire area of irrigated vegetation. To improve the results of the image classification and to allow for easier handling of the data sets, the scenes were divided into seven study areas. Each study area covers a separate region of irrigated vegetation in the Abu Dhabi Emirate. The imagery for the Abu Dhabi, Al Hayer, Al

Khazna, and Al Ain study areas was contained in Landsat scene 160/43. The imagery for the Ghayathi study area was contained in scene 161/44. The locations of the study areas within the Abu Dhabi Emirate are presented in Figure 1.

DATA SOURCES

Landsat Scenes

The Landsat 7 ETM+ scenes were ordered from the USGS EROS Data Center in Sioux Falls, South Dakota. Each scene was georeferenced to the UTM projection/coordinate system, zone 40, was terrain corrected, and was in GEOTIFF format. Each scene covers an area approximately 180 km on a side, or 32,000 km^2. The data sets were loaded onto local computer disks at the GWRP and were converted into ERDAS Imagine files and reprojected into the Transverse Mercator projection. The 1996 Landsat 5 imagery had been acquired earlier for the 1987-96 change analysis (Sohl, 1999) and already had been transformed into the appropriate projection/coordinate system. A browse image of a full Landsat 7 ETM+ scene (path 160, row 43), in natural color (bands 3,2,1 – red, green, blue), which contains the area from the city of Abu Dhabi in the west, to Al Ain in the east, and Dubai to the north is presented in Figure 2.

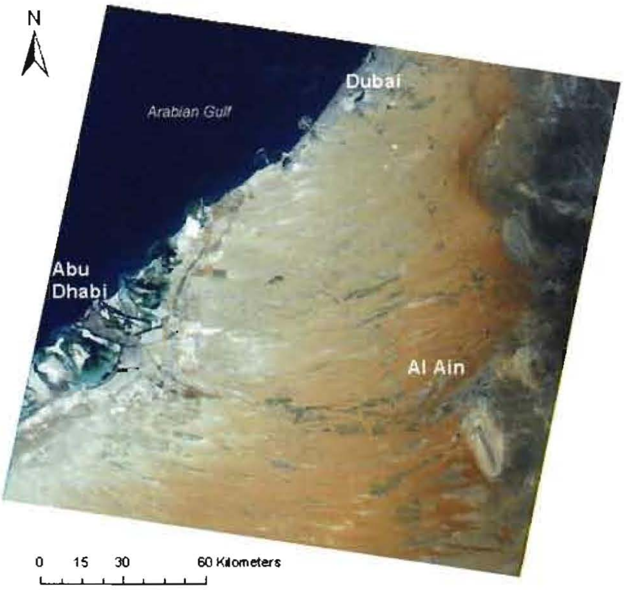

Fig. 2. Study areas in Abu Dhabi Emirate.

METHODS AND PROCEDURES

The following sections describe the methods and procedures used for determining vegetation change using Landsat imagery in the Abu Dhabi Emirate, from 1996, 2000 and 2004.

Overview of Multi-spectral Imagery

Remote sensing essentially is the act of measuring a characteristic without physically encountering the subject. Remote sensing of the

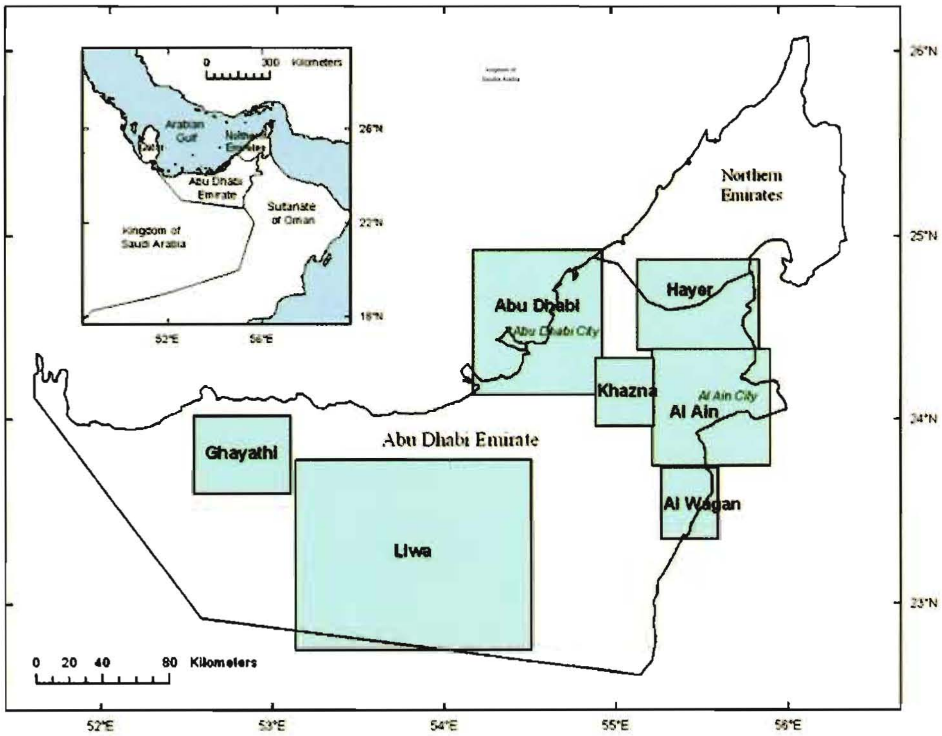

Fig. 1. Study areas in Abu Dhabi Emirate.

earth using satellite imagery measures electromagnetic energy (typically the light from the sun) after it has been reflected from the earth's surface. Different materials on the earth's surface interact with sunlight in different ways by reflecting or absorbing wavelengths of light in different intensities. These differences allow drawing conclusions about what type of material was present. Vegetation reflects light the strongest in the green and infrared ranges of the electromagnetic spectrum. In other words, vegetation absorbs light mostly in the blue and red wavelengths. Because of this result, vegetation typically is seen as green. How a given material reflects the range of wavelengths of light is called its spectral reflectance curve, or its spectral signature. Multi-spectral sensors were designed to measure the intensities of reflected light in multiple wavelengths. Landsat 7 ETM+, for example, detects reflected light energy in six different wavelengths, (plus one panchromatic band and a thermal band) (Jensen, 2000). Having reflectance values for a given surface type in six different wavelengths allows the plotting of the reflectance curve with six data points. More data points (more image bands) allow the curve to be more precisely defined. Many variables can affect the way light is reflected or absorbed. Sun angle, moisture levels, topography, atmospheric conditions, surface heterogeneity, and many other factors can change the intensity of light reflected by a given surface type. Because of this characteristic, satellite remote sensing only can give indicators of surface type.

Data Preprocessing

Within ERDAS Imagine, the import utility was used to convert the .tif files into .img files. For each scene, bands 1, 2, 3, 4, 5, and 7 were stacked into a single .img file using the layerstack utility. This stacking allowed for easier file handling. The original data are stored as unsigned 8-bit data, meaning that each pixel can have a value up to 8 bits in size (2 to the 8^{th} power = 256 possible values). Bands 6(1) and 6(2) are thermal bands (the detectors were sensitive to wavelengths of light in the thermal infrared range) and generally are not useful in these applications. Band 8 is a high-resolution panchromatic image. The detectors have a higher spatial resolution (15 m as compared to 30 m for the other bands and 60 m for the thermal), and a broad spectral resolution (sensitive to a wide range of spectral wavelengths). As the working projection used in the GWRP is Transverse Mercator, the imagery was reprojected from UTM. This reprojection was done using Imagine's reproject utility. The output projection was defined as: Transverse Mercator, Clarke 1880 spheroid, Nahrwan UAE datum, scale factor 0.9996, central meridian of 54 degrees longitude, origin of latitude of 0 degrees, and 500,000 m false easting. A second-order polynomial equation provided sufficiently accurate results (sub-pixel RMSE). Nearest neighbor resampling was used as it retains the original pixel values without any averaging.

Determination of Vegetated Areas

The first step in analyzing the vegetated areas in the Abu Dhabi Emirate was to create Normalized Difference Vegetation Index (NDVI) images for each study area. The index is created by subtracting band 3 from band 4, and normalizing that value. Because healthy vegetation reflects light strongly in the infrared frequency (band 4), and not strongly in the red (band 3), the presence of high values in the difference image usually indicates green vegetation. ERDAS Imagine software has a built-in function for the creation of NDVI data sets. The year 2000 NDVI greyscale image for the Al Khazna study area is shown in Figure 3.

Fig. 3. Normalized Difference Vegetation Index greyscale image of the Al Khazna study area, 2000.

The NDVI images created were 8 bit, with 256 possible pixel values. These images were converted to thematic images (as opposed to continuous images), and displayed in pseudocolor mode. Using the inquire cursor and the raster attributes display, pixel values were chosen that best defined the threshold between vegetation and not vegetation. The image was converted into a binary file where pixels can have one of only two possible values, representing vegetation or not vegetation. For example, it may be decided that original pixel values lower than 81 do not represent vegetation, and pixels with values 82 and above do represent vegetation. This determination is made after viewing the image at four or five threshold levels. The display color of the pixels was changed from grey-level values to either black or white, with white representing vegetation. There was a threshold value, which varied from image to image, and included all the vegetation in the image, but did not include too many "noise" pixels. Noise pixels, or pixels incorrectly classed as being vegetation, were kept to a minimum. This was difficult in some images, as some of the faint vegetation, such as widely spaced acacia trees, would not be classed as vegetation before large areas of noise would start to be included. For the most part, however, a reasonable distinction could be made between areas of vegetation and no vegetation.

After a determination of a threshold value had been made, the NDVI image was recoded using the raster recode utility in the Imagine software. Values below the threshold were recoded to 1 and values above the threshold were recoded to 2 (a background value of 0 was retained). To make the resulting images easier to interpret, a filtering algorithm was run over the image. This filtering does not make the image any more accurate (it may reduce slightly the accuracy), but it allows the user to more easily read the map results by eliminating small, isolated pixels that appear as noise. A neighborhood function filter was used, with a 3-by-3 majority window. This function applies a 3-by-3 window over the image and evaluates each pixel. The pixel value in the center of the window is replaced by the value of the majority of the pixels within the window. This process has the effect of eliminating small, isolated pixels of either category. Using the Raster Attribute Editor, an attribute column of area was added (in hectares).

One limitation of the NDVI analysis technique is that it only is sensitive to appreciable green plant-surface cover and cannot indicate those areas where the land has been prepared for irrigation (substrate preparation, laying of irrigation piping, and others) but plants were not yet visible. To be held above the NDVI threshold in this analysis, the amount of plant cover had to be appreciably greater than the background reflectance contributed by the soil/sand substrate. This result will tend to underestimate areas of irrigation as compared to amounts based on actual irrigated land, regardless of plant maturity.

IMAGE CLASSIFICATION

Supervised and Unsupervised Classification

Image classification is the assignment of thematic information (usually land cover type) to pixels based on an analysis of the reflectance values across the various spectral bands. Different surface materials interact with light in different ways by absorbing some wavelengths and reflecting others. By detecting the intensity of light reflected across a number of wavelengths, an idea of the reflected signature of the material can be made. The reflected light from a surface material can be affected by a large number of variables, including atmospheric conditions, sun angle, and moisture content. These characteristics change over time and with location, so the prediction of a given surface type based on measured light reflectance almost can never be made with 100 percent certainty.

here are two basic approaches to image classification. Supervised classification normally is used when the investigator has a good knowledge of the surface types present in the image area. The investigator points at examples of the various surface types in the image (usually drawing polygons around them) and these examples are used in computer analysis to find pixels throughout the image with similar spectral characteristics. Supervised classification techniques were used only for the Al Ain study area in 2000, because of the high level of user knowledge in this area. The second approach is called "Unsupervised Classification", and is used most often when the investigator does not have good knowledge of all the surface types present in the image. This approach was used for all the study areas in the Abu Dhabi Emirate. The spectral signatures of the pixels are examined with computer analysis and are grouped or "clustered" based on an iterative statistical analysis. The user specifies how many categories will result. Generally, it is best to specify as many as three times the number of suspected surface types. 60 classes were used in the study areas. After classifying the image into categories with the software, the user examines the resulting thematic image and tries to name each category. In ERDAS Imagine, the displayed color of the various categories can be changed using the raster attributes editor and the inquire cursor. Categories may be combined with others if they appear to define the same or similar surface type. This combination can be performed with the recode utility. In an attempt to create a better classification of images, the filtered NDVI image was used as a mask on the multi-band imagery prior to classification. This masking eliminated the non-vegetated areas in the unsupervised classification analysis.

Land-Cover Classification Scheme

Because the NDVI mask was used to exclude non-vegetated areas, only those areas representing some kind of vegetation were categorized. Land cover such as sand, bare rock, or urban areas all were combined into one category, non-vegetation. Attempts were made to discriminate vegetated areas into the following categories: forests, vegetable fields, dry grass, date palms, and grass/fodder fields. Mixed categories were also used in some cases.

Change-Detection Analysis

The change-detection analysis was conducted in two ways. The first way was the direct comparison of thresholded NDVI images. By recoding one of the output images, the 1996 and the 2000 NDVI images could be added to obtain a new image showing four possible outcomes:1--non-vegetation in both years; 2--vegetation only in 1996; 3--vegetation only in 2000; and 4--vegetation in both years. The second way was the comparison of the post-classification images. After satisfaction with the assignment of categories to the classified thematic images, an image addition was performed, similar to the NDVI change analysis. After recoding one of the images (1996 or 2000) to allow for unique outcomes, the two images were added together. The results can be displayed in a change matrix, showing the area falling into each new category. This kind of analysis gives more detail as to what kind of change is taking place than the first technique. The tables are presented as a matrix of the 1996 categories on the left and the resulting 2000 categories across the top. Therefore, for any given category in 1996, how much of that category either stayed the same or changed to a new land-cover category as in 2000, can be seen.

VEGETATION CHANGE

Total Vegetated Area for Study Areas

The results of the area calculations from the filtered NDVI image analysis are presented in Table 1. An increase in measured vegetation from 1996 to 2000 is seen in all study areas. Total area of vegetation for the Abu Dhabi Emirate as measured with the change-detection analysis shows an increase from 77,200 hectares in 1996 to 162,100 hectares in 2000 (Fig. 4). Slight decreases in vegetation for most study areas are seen in 2004.

Table 1. Total vegetation for the seven study areas, 1996, 2000, and 2004 (in hectares).

Study Area	1996	2000	2004
Liwa	13,000	28,700	27,500
Al Ain	24,900	43,200	42,500
Al Khazna	8,300	14,700	12,500
Al Hayer	6,900	14,200	13,600
Abu Dhabi	14,900	41,300	38,700
Ghayathi	7,900	12,400	9,100
Al Wagan	1,600	7,600	7,800
Total	77,500	162,100	152,000

Classification by Study Area

For the Al Ain area, the dense groves of palm trees in the oasis presented a unique signature. This category does not seem to be present in the Liwa study area, or is not easily distinguishable from other categories. The spacing of palms is important to its signature, and outside of densely planted oases, the palms tend to appear more

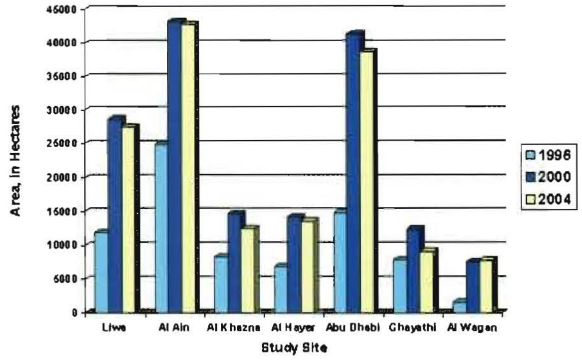

Fig. 4. Area of total vegetation for each study area, 1996, 2000, and 2004.

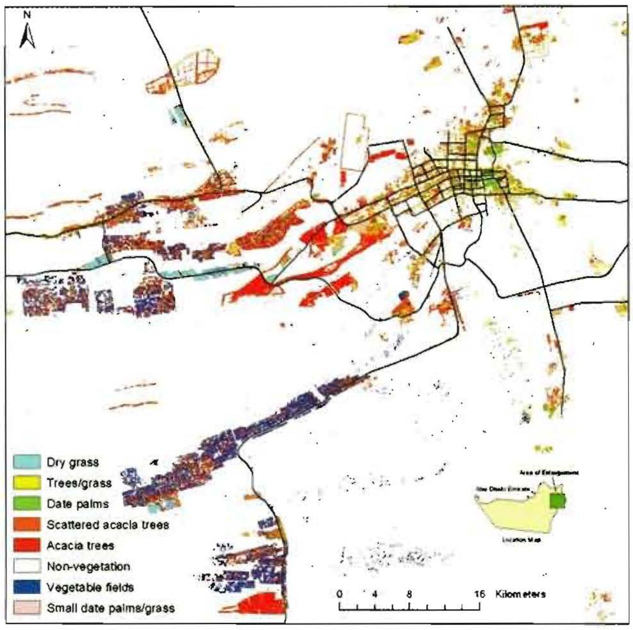

Fig. 5. Supervised classification for the Al Ain study area, 2000.

similar to other tree types. Also, the fields of drying, cut grass do not stand out in the Liwa area. While these fields were observed during a visit in March 2001, either they were not present when the Landsat scene was acquired (Dec. 27, 2000) or they are not easily separated from the other categories in this area. The results of a supervised classification for the Al Ain study area in 2000 is presented in Figure 5.

Differences by Land-Cover Category

A matrix of the 1996 and 2000 categories from the unsupervised classification of the Al Ain study area are presented in Table 2. The largest change is non-vegetation to forest.

Total Vegetation Differences

Total vegetation differences for the Al Ain study area are presented in Figure 6 and Table 3. The thematic image has four possible values: (1) was non-vegetation in 2000 or 2004, (2) was vegetation only in 2000, (3) was vegetation only in 2004, or (4) was vegetation in both 2000 and 2004

Table 2. Change matrix of the 1996 and 2000 classification categories for the Al Ain study area. (Hectares).

		Categories in 2000				
		Non-veg	Palms	Grass/veg	Dry grass	Forest
Categories in 1996	Non-veg	448,400	100	3,700	300	21,900
	Palms	50	400	50	0	200
	Grass/veg	900	700	800	200	2,800
	Dry grass	200	0	100	150	700
	Forest	6,100	300	1,600	150	9,300

Table 3. Vegetation differences (in hectares) for the Al Ain study area, 2000 to 2004.

Category	Description	Area (hectares)
1	Non-vegetation in 2000 and 2004	446,500
2	Vegetation in both 2000 and 2004	32,000
3	Vegetation only in 2000	11,000
4	Vegetation only in 2004	10,500

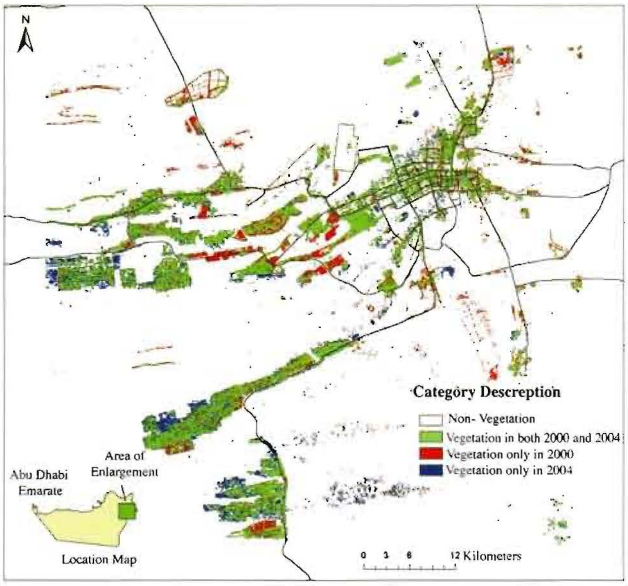

Fig. 6. Vegetation difference in the Al Ain study area, 2000 to 2004.

ACCURACY OF THE CHANGE DETECTION ANALYSIS

To gain an understanding of the accuracy of the unsupervised classifications, a set of 80 random control points was generated for the Al Ain study area and the classification values were compared to field or photo-interpreted observations. ERDAS Imagine was used to generate the randomly placed points over the vegetation classification.

An error matrix resulting from analyzing control points for the Al Ain unsupervised classification is presented in Table 4. Field observations (reference data) along the X-axis, and classification results (map data) along the Y-axis are presented in the table. The values indicate the number of points that fall into each result/reference relation. For example, 14 of the 80 points were classified with the unsupervised classification process as category 4 (Acacia trees) and they also were classified as category 4 with the reference evaluation. These 14 points would be seen as correctly classified. Alternatively, three points were classified as category 6 (Vegetable fields) by the unsupervised classification technique, but were described as category 4 (Acacia trees) from the field evaluation. This result is seen as a misclassification. Categories 2 (Scattered trees) and 3 (Grass) had appreciable overlap and it was decided to collapse them into a single category. Overall, of the 80 control points, 51 were classified the same as the reference, resulting an overall 64 percent accuracy rate.

Table 4. Error matrix for the supervised classification for the Al Ain study area, 2000.

Map data (classification results) — Category description and number	Reference data (field observations) — Category description and number: Date palms (1)	Trees/ grass (2/3)	Acacia (4)	Scattered acacia (5)	Vegetable fields (6)	Dry grass (7)	Total	User's Accuracy (percent)
Date palms (1)	4	2	-	-	-	-	6	67
Trees/grass (2/3)	1	13	2	1	4	-	21	62
Acacia (4)	-	3	14	2	3	-	22	64
Scattered acacia (5)	-	-	1	4	2	-	7	57
Vegetable fields (6)	-	3	3	1	10	-	17	59
Dry grass (7)	-	1	-	-	-	6	7	86
Total	5	22	20	8	19	6	80	na
Producer's Accuracy (percent)	80	59	70	50	53	100	na	64

A study in 1990 (Hamid and Hassan, 1993; Maddy, 1993) found that the agriculture area measured by field verification was about 50 percent greater than that measured from satellite imagery. For the Al Hayer study area, a small study was performed where the vegetation was manually interpreted from the higher resolution Landsat band 7. The resulting polygons representing manually interpreted vegetation totaled 16,600 hectares. The NDVI analysis for this study area indicates 14,200 hectares of vegetation, or 14 percent less than that measured by manual interpretation. While this is less than the 50 percent under reporting indicated by Hamid, the results of the algorithm-based satellite assessment are clearly not correctly classifying all the vegetation present in the study area.

Factors affecting the determination of accuracy include that the land cover may have changed since the imagery was acquired in 2000. This result may be true of vegetable and grass fields, but tree farms and palm oasis probably will remain stable over many years. It is speculated that the primary effect to the accuracy of measurements of total vegetation area determined during this study is the density and maturity of the plants. When relatively young, the trees are small and widely spaced. From satellite imagery, the surrounding sand has a much stronger affect on the measured reflectance than the actual tree. When performing an NDVI analysis, these areas of small trees will fall below the threshold of vegetation, causing an under reporting of vegetation in the study area.

Based on field observations, farm fields are relatively small compared with acacia forests, with a variety of trees and palms planted along the edges. At the 30 m resolution, the pixels usually contain a mixture of land cover types, making the distinction between crops and trees difficult. The typical farm field is about 190 meters square, containing 3.5 hectares. Approximately 36 pixels would cover a typical farm field. With edge effects, and the general lack of homogeneity within most fields, clear distinction between crops and trees is difficult. This difficulty is probably the primary cause of confusion between the vegetable plot class and the other categories. The small field size and heterogeneity of the vegetation types in combination with small errors in horizontal registration could also effect the correct assessment of the resulting classification.

There is clear textural and shape distinction between farm areas and forests. The farm areas show a rectangular, patterned texture, whereas the planted forests usually appear as continuous blocks of trees with sharp outside boundaries. It is possible that the use of additional rule sets and ancillary data could refine the classification of these categories.

SUMMARY AND CONCLUSION

Using Landsat 7 ETM+ satellite imagery, vegetation for the Abu Dhabi Emirate has been mapped in 1996, 2000, and 2004 and the results compared to indicate the amount and location of change. The vegetation was measured in terms of actual green vegetation growing at the time of the imagery acquisition to give total area in hectares for each study area.

Measures of actual area of vegetation in the Emirate indicate an increase from 77,500 ha in 1996 to 162,100 ha in 2000 (an increase of 109 percent). The largest increases in area of vegetation have been measured in the Abu Dhabi, Al Ain, and Liwa study areas. Area of measured vegetation is less than the area of irrigated land, because of the inability of the satellite sensor to detect small, widely spaced, or immature plants. Based on comparison with manual interpretation of satellite imagery, the amount of under reporting of irrigated lands is estimated at about 15 percent of the actual area. This amount of under reporting is much lower than that found in earlier assessments. Measurements taken from the 2004 imagery indicate that growth of new vegetated areas has slowed in most areas. Based on visual interpretation of the imagery, the small decreases in vegetated area are probably due to an inability of the measurement technique to sense certain patches of vegetation, as the extent of the fields appears to be the same as previous years. This may be due to differences in the time of year of image acquisition.

Multi-band classifications were performed successfully on the Al Ain and Liwa study areas. By area, the vegetation type most prevalent is forest cover. These areas consist primarily of acacia trees that have been planted successfully in large tracts throughout the Emirate. Category change is predominantly non-vegetated land to forest cover. Based on a comparison with 80 test points, the classification of the Al Ain study area showed an overall accuracy rate of 64 percent. Factors contributing to this relatively low accuracy rate may include the relative small size of the vegetable plots (usually about 4 hectares) and the high heterogeneity of the fields. Small discrepancies in horizontal registration could also have an effect on the accuracy of indicated land-cover categories.

Overall, irrigated vegetation has increased greatly in the Emirate, (more than 100 percent increase in 4 years), with addition of new fields slowing in recent years. By using satellite imagery to monitor changes in vegetation in the Emirate, scientists will have an efficient and valuable data source to aid them in ensuring the proper management of the groundwater resources in the Abu Dhabi Emirate.

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