Egyptian J. Desert Res., 54, No.1, 101-119 (2004)

DETECTION OF LAND COVER CHANGES BY PRINCIPAL COMPONENTS ANALYSIS OF SPOT HRV DATA CASE STUDY: HOUD EL-REMAL COASTAL AREA, EL-BEHEIRA, EGYPT

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The pressure of population on land and its limited resources is a major factor affecting sustainable development in Egypt. Whether by over- exploitation or mismanagement, changes in land use, and therefore land cover, are taking place at an unprecedented rate that makes these lands prone to degradation. Principal components analysis (PCA) has proved to be a powerful tool for detection of change and monitoring rates of land cover changes. The present paper demonstrates the application of PCA on high-resolution satellite image data (SPOT-HRV) to detect land cover changes that have occurred in Houd El-Remal area, El-Beheira governorate, on the northern coastal desert of Egypt. This area was subjected to agricultural reclamation activities by continuous sand filling of its lowlands using the sand of the dunes that exist in the vicinity, and irrigation using the deltaic untreated drainage water. This untreated drainage water is highly saline and is not re-drained again after irrigation. When salinity develops as a consequence of the above situation, lands are refilled again by transporting sand from the dunes and adding thick layers of sand for re-ultivating the land. SPOT satellite imagery of two time frames, 1986 and 1995, were analyzed using comparative classification and spectrally-based PCA to examine the status of the major land cover classes of Houd El-Remal area and to monitor the rate of change in agricultural and urban extensions. The land cover changes observed were: changes in structure of the dunes habitat due to human activities, soil salinization due to irrational land reclamation, and urban sprawl due to expanding population. It was concluded that the methodology adopted for analyzing SPOT-HRV imagery was useful in assessing and monitoring land cover changes and provided valuable information to planners and decision makers in formulating land use policies, and in allocating resources in the area under study. The study also demonstrated the immense human impacts on natural coastal habitats and loss of its natural resources, mainly sand dune. This calls for careful use of these ecologically fragile habitats and the need for conserving its biodiversity.

Keywords: land use, land cover change, principal component analysis, Edku, Houd El-Remal, urban expansions.

Land is a shorthand for the terrestrial bio-productive system that comprises man, soil, water, and ecological processes that operate within the system. Degradation means reduction (or loss) in the capacity of land to meet human socio-economic expectations. This has been quoted by Kassas (1995) in his review paper on desertification. Land use is a product of interaction between a society cultural background, skills and its physical needs on one hand, and the natural potential on the other.

The pressure of population on land and its limited resources is a major factor affecting sustainable development in Egypt. Whether by over-xploitation or mismanagement, changes in land use, and therefore land cover, are taking place at an unprecedented rate that makes these lands prone to degradation. Ecologists and resource managers need a reliable procedure mechanism to assess the consequences of human pressures on the environment, by detecting, monitoring and analyzing land use changes. Land-cover changes are always related to land use change, which in turn is associated with demographic and economic change. The overall goals in change detection and monitoring are: (1) to compare spatial representation of two points in time by controlling all variances caused by differences in variables not of interest (i.e. variation in orbital and platform altitudes, illumination, etc.) and (2) to measure change caused by differences in the variables of interest and the effect of these changes on the environment and natural resources.

Currently, change detection, monitoring and updating rely primarily upon two types of techniques: map-to-map comparisons and image-to-image comparisons (Green *et al.*, 1994). With the introduction of GIS, map-to-map comparisons can be performed digitally. This type of comparison is risky because changes between maps or GIS coverages can be caused by factors other than actual differences in land use/cover (e.g. difference in classification systems adopted, mapping techniques applied). Image-to-mage comparisons using remotely sensed imagery and/or field examination has proved to be a more powerful method for assessing land use/cover change (Verbyla, 1990). Digital Thematic Mapper (TM) and multispectral scanner (MSS) data have been used for urban-suburban change detection (Jensen and Toll, 1982; Adeniyi, 1985) and SPOT data have been used to monitor land conversion at the urban-rural interface (Martin and Howarth, 1989; Ehlers *et al.*, 1990; Dimyati, 1996).

Landsat data have been used to differentiate crop types and monitor crops over time (Odenweller and Johnson, 1984; Wagner, 1992) and SPOT data have been used to differentiate between various crop types manually (De Gloria, 1985). Image differencing (Hame, 1986; Yocota and Matsumoto, 1988) and Principal Component Analysis (PCA) and/or tasseled crop transformation (Kauth and Thomas, 1976; Toll *et al.*, 1980; Crist and Cicone, 1984; Richards, 1984; Fung and LeDrew, 1987; Byrne *et al.*, 1990) are the two image-to-image comparisons used most often. However, like map-to-map comparison, image-to-image comparisons also require that variation caused by factors other than land cover be understood and where possible controlled.

This is an ecological study of human impacts on coastal ecosystems, and an attempt to explore a technique that makes the detection of environmental and human-induced changes possible to measure in terms of extent and magnitude of change and to estimate the impact of change on the environmental conditions. The remote sensing work presented here aims at assessing environmental temporal changes in a coastal area of Lower Egypt through the analysis of multi-date high-resolution satellite imagery using principal components analysis (PCA) and classification methods.

STUDY AREA AND PRESENT ENVIRONMENTAL CONDITION

Location

The study area - Houd El-Remal - is located in El-Beheira governorate and includes the city of Edku. As depicted in figure (1), Edku sub-region forms the northwestern edge of the governorate, east of Alexandria. It is a coastal area located between the Mediterranean Sea on the north and Edku Lake on the south. The Edku village was claimed a city in 1963, and since then, the whole sub-region has shown an increasing population and tourism attraction (Fig. 2). The activities of the local inhabitants are influenced by location and were confined to fishing in the sixties and early seventies. However, recently, and with expansion and demand of population growth, land reclamation for agriculture has become a widely common activity.

The total area of Houd El Remal is about twelve thousand feddans (feddan =4200 m^2), for three thousand land holders. The size of land holding ranges between three to ten feddans. Titles of land tenure are partly steeled for almost fifty percent of land holders. Land reclamation and leveling have tremendously increased after the sixties and have become a common practice.

Environmental Problems Encountered

Houd El-Remal, which is a sand dune coastal area, was subject to reclamation activities by continuous sand filling of its lowlands by using the sand of dunes in the vicinity. These reclaimed lands are irrigated using the deltaic untreated agriculture drainage water, which is saline (measured salinity = 2500 - 3500mg/l) and is not re-drained again after irrigating. When salinity develops as a consequent of the above situation, lands are refilled again by transporting sand from the dunes and adding thick layers for re-ultivating the land. The cultivation stratification consists of three layers and produces remarkably high yields of fruit trees and vegetables. This success has attracted investors to extend the reclamation and cultivation processes. Because of this success, as well as settlement expansions, significant reductions in the dune ecosystems have occurred. Adding to that, the governmental plans for tourism development in the area, where it is expected that, in about 10 years, the sand dunes will be completely exploited and the area will suffer from permanent salinization, loss of natural habitats, and decline of its visual and environmental quality.

MATERIALS AND METHODS

Field Investigations

Several field visits were made before and after satellite image analysis, for reconnaissance, habitat description and sample collection. All the features that appear on the satellite image were identified and traced in the field. Field crops were identified and soil samples were collected from different depths (0-120cm) in which standard chemical analysis was carried out. The following properties were measured: pH, EC, TSS, organic carbon and organic matter. Crops in the agricultural fields were also identified.

Satellite Data

In order to assess the environmental temporal changes in the area under study, multi-spectral satellite imagery of high resolution (20x20) acquired from the French Satellite "SPOT" were analyzed. The SPOT data used were acquired from the HRV-1 sensor for two dates; August 1986 and 1995, with a time difference of 9 years.

This time difference assures that the trend of changes can be clearly established. The area under study was covered by the multi-spectral (XS) frames identified by KJ 109/288. Topographic maps produced by the Egyptian Surveying Agency (1986) of scale 1:25,000 were used as base maps for the preliminary interpretation of the satellite imagery. Continuous field checks for complete interpretation and validity were carried out. A

Trimble "Ensign" GPS was used during these field checks to identify and locate ground control points and landmarks. The image processing work was caried out at the unit of Remote Sensing and GIS at the Department of Environmental Sciences, Faculty of Science, University of Alexandria, on ERDASI/Imagine software version 8.2 runing on windows NT platform. IDRISI software was also used for particular image processing (cross-classification processing).

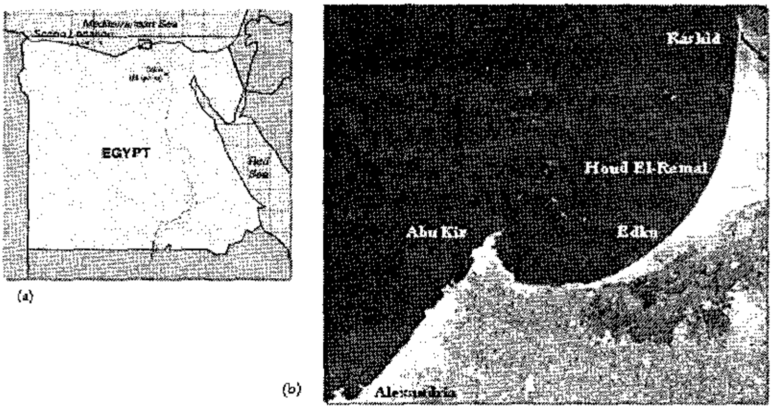


Figure (1). (a) General map of Egypt showing the location of the SPOT frame KJ 109/288,
(b) SPOT HRV full scene of the study area (El-Beheira governorate).

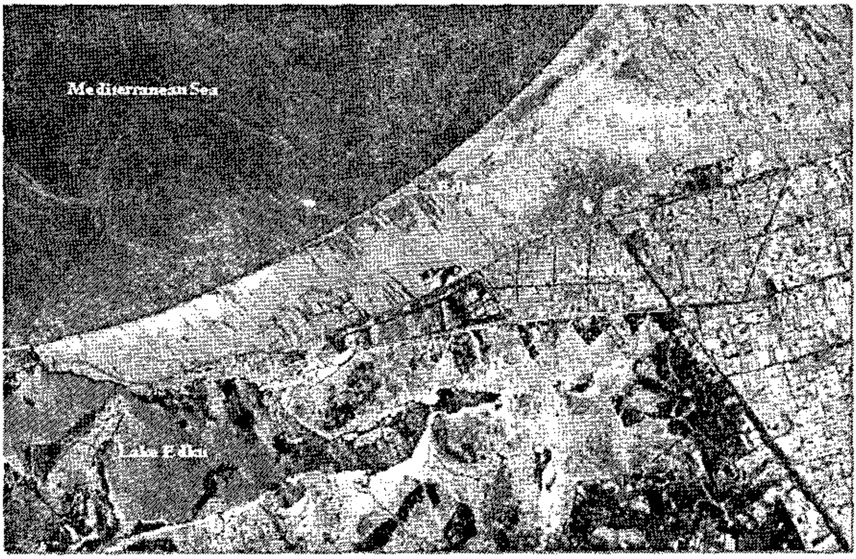


Figure (2). Basemap of Houd El-Remal subscene, scale: 1/125 000

Preprocessing Analysis

The corresponding two SPOT frames of the study area for the two dates were rectified georeferenced, in order to assess temporal changes and identical subscens, to the same reference system (UTM) such that they fit when overlaid onto each other. The rectification process was carried out using five ground control points that represent the four image corners and the center. The latitude/longitude data of these points were provided in the data sheet of each SPOT frame. The root mean square (RMS) error results were 0.68. The rectification process of the two SPOT frames was followed by locating the area of interest in a separate subscene; Edku subscene and vicinities, which included (1) the coastal area of Hod El- emal to the north, and Edku Lake and city, and (2) a fully cultivated area (Mayah village) to the south.

Because of the difference in habitat characteristics and features in the above subscene, Hod El-Remal coastal area was manually isolated (on screen) in an individual subscene for each date to ensure the homogeneity of features and stabilize the background effect. The two resultant Houd El-emal subscenes for 1986 and 1995 were then subjected to image processing analysis for temporal change assessment. Figure (3) is an illustrative representation of the above. It is also worth mentioning that linear regression analysis was conducted for Houd El-Remal subscenes of the two dates in order to match the digital data of the two dates.

Change Detection Analysis

Principal Components Analysis

The image processing analysis carried out in this step is based on the principal components analysis (PCA) technique that is conducted simultaneously on the two Houd El-Remal subscenes (1986 and 1995) on a band-based manner. This was achieved by putting together similar individual SPOT spectral bands from the subscenes of the two dates to form three spectral sets (green, red and near infrared) of subscene combinations. Each set consists of a combination of a pair of images of the same spectral band for the two dates 1986 and 1995. The three spectral sets of subscene combinations (each containing two images) were subjected to PCA individually, to produce two PC images (PC1 and PC2) for each spectral set. Figure (4) is an illustration of the above procedure.

The first component (PC1) of each set is tantamount to a total brightness of the spectral band and contains all the common information in the two image dates (unchanged features), while the second component (PC2) contains the less common contrasted information in this particular band (spatial changes). Unifying scenes, dates (months), projection, sensor and spectral bands in the above analysis ensured that the difference images represented by the three PC2 images were due to changes in spatial characteristics rather than to exogenous differences. Each PC2 difference image for a particular spectral band was examined separately to detect the Temporal changes in ground features that reflect in this band. The three PC2 difference images were then combined using the following equation to produce one difference image for the study area:

$$PCCHANGE = \sqrt{(PC2BAND1)^2 + (PC2BAND2)^2 + (PC2BAND3)^2}$$

Classification

To assess the effectiveness of the previous PCA technique in mapping and detecting change, the two subscenes of Houd El-Remal for the two dates 1986 and 1995 were classified individually to the major land cover classes that dominated in each date. The classification procedure was based on the unsupervised clustering analysis, where four classes were produced and identified. The resulted classified images for the two dates were cross-tabulated for comparison and detecting change.

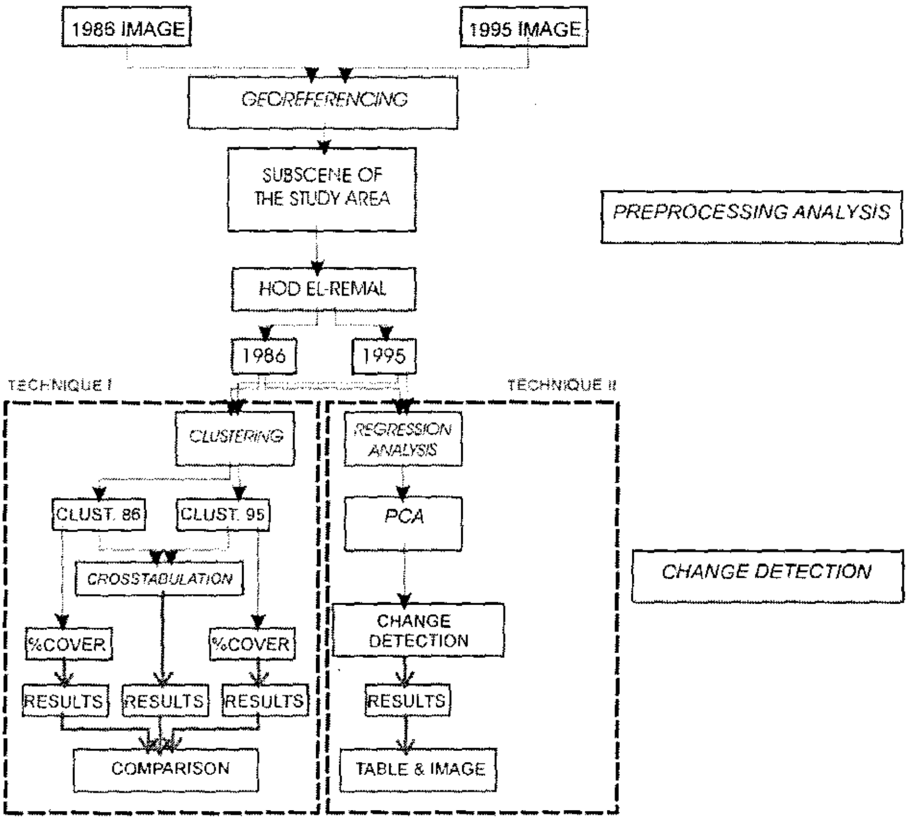


Figure (3). Illustrative presentation of the preprocessing and change detection analysis.

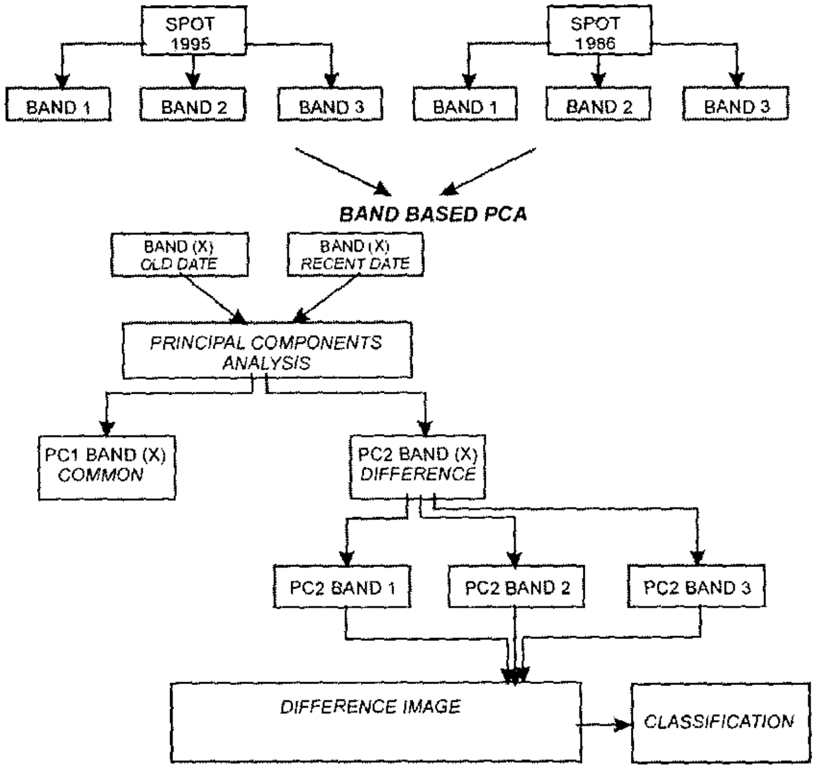


Figure (4). Illustrative presentation of the principal components analysis procedure.

RESULTS

From field visits, it was observed that rapid developments have taken place in the area in urban and agriculture expansions. Urban expansions are sprawling at the expense of agriculture lands and agricultural expansions are sprawling on the basis of land reclamation, and sand filling of salinized lands, at the expense of natural ecosystems. The aspects of urban sprawl observed were: spreading of new residential and services buildings replacing cultivated lands, construction of new roads and new facilities. The prevalent agricultural lands have different types of soils (light sandy to loamy) with varied production capacities and potentials.

The commonly grown crops in the studied communities include cotton, rice, wheat corn, clover and vegetables. The variations of average yields between basins in different communities are due to variations in soil properties, adequacy of irrigation water and the quality and conditions of drainage systems. Soil analysis results showed that in almost all basins, soil is characterized by salinity of 5.1mmhos/cm and high concentrations of carbonates which increased the alkalinity (pH 8.3) of the soils. The total organic matter in different basins were generally lower (0.11-0.34%) in deep layers than superficial layers. This is mainly due to continuous cultivation without good aeration and ploughing. The soil is very compact which prevents root penetration to deeper layers. The main results of water analysis indicated high concentration of total soluble salts and that it can be used for irrigation with caution, and for crops that are resistant to salinity.

From the PCA analysis, the interpretation of each PC2 image was aided by the information extracted from the eigenvalues and vector matrix provided in tables (1 and 2).

TABLE (1). The eigenvector matrix produced from the PCA conducted on the three sets of band combinations.

Band 1 (Green)	PC1	PC2
1986	0.9939624149	0.1097210903
1995	0.1097210903	-0.9939624149
Band 2 (Red)		
1986	0.9716203451	0.2365457776
1995	0.2365457776	-0.9716203451
Band 3 (Infrared)		
1986	0.4348876191	0.9004847354
1995	0.9004847354	-0.4348876191

TABLE (2). The eigenvalues produced from the PCA conducted on the three sets of band combinations.

	BAND 1 (Green)	BAND 2 (Red)	BAND 3 (Inf. Red)
PC1	541.26727522	753.62642924	993.91635151
PC2	176.10794432	314.43160181	235.66179592

Figure (5) is a representation of the three PC2 difference images for the three multi-date band combinations. The combined difference image of the three PC2 images was also classified to produce an overall presentation of the change / no change areas (Fig. 6).

The classification analysis carried out on the two subscenes produced four classes, each of which were checked with the ground truth data and proved to be fitting with the overall changes observed in the field. Each of the resultant classified images was also used as a reference for the difference images produced by PCA (previous technique), and the general comparison between the results of classification and PCA was followed. Figure (7) represents the four land cover classes produced from the clustering analysis for the two dates, where dark tone represents the spatial distribution of each class. Table (3) represents percent cover of each class, on the two dates and a comparative estimate in hectares. Table (4) gives the cross-classification table results.

The percent cover classes (Table 3) reflected the magnitude of environmental changes that have occured in the 9 years' time difference. From table (3), it is clear that the dense plantation areas (class 1) and the agricultural fields of less plant cover (class 2) increased by about 608 ha, and 165 ha, respectively from 1986 to 1995, with an estimate rate of increase of about 86 ha/year. The reverse was observed in the dune and bare areas (class 4) that exhibited a tremendous decrease that reached about 991 ha between the years 1986 and 1995 with a rate of decrease of about 110 ha/year. The built up and disturbed areas (class 3) showed an increase of about 219 ha between 1986 and 1995, where these areas were confined to in and around Edku city. These changes were observed visually by comparing the two False Colour Composite images of the two image dates, and were also observed during the field visits. Table (4) gives the conversion areas of each of the land cover classes in 1986 in relation to the other classes of 1995. It can be considered as an indication of the land transformation practices in the area under study.

DISCUSSION

El-Beheira governorate represents about one sixth of the cultivated lands in Egypt (Kishk, 1997) . Historically, the early settlers in this region earned their living through fishing and rain-fed farmimg in limited areas of land or around sand dune areas. Common crops in early times included water melons, tomatoes and date palms. Encouragement to expand cultivated areas in Houd El Remal occurred through leveling land and adding sand to the soil to combat salinization. Among the important problems facing agriculture in the region are: lack of suitable water and reliance mainly on mixed draining and fresh water for irrigation, which is suitable only for salt-tolerant crops and palms, higher level of ground water, increasing costs of farm requisites and farm labour, and absence of an efficient drainage system.

The extraction of information on land cover from remotely-sensed data is a fundamental activity, necessary for a variety of applications including land use planning and monitoring, ecological monitoring of vegetation communities, agricultural and forest monitoring and the calculation of land capabilities (Townshend, 1992). It is well established that remotely-sensed imagery can be used to monitor changes in land surface conditions. A large variety of methods of change detection have been proposed and applied, many of which are reviewed by Singh (1989).

Nelson (1983) examined the value of image differencing in detecting gypsy moth defoliation using Landsat MSS data. A difference of the MSS7/MSS5 (near-infrared / red) ratio was found to be more useful in delineation of defoliated areas than any single band-pair difference or ratio. Muchoney and Haack (1994) examined several approaches to detect defoliation, including merged Principal Components Analysis (PCA) (Byrne *et al.*, 1980; Fung and LeDrew, 1987), image differencing, spectral-temporal change classification and post classification differencing. Classifications of PCA and of the difference images were found to yield generally higher classification accuracies than other methods (Collins and Woodcock, 1996). Coppin and Bauer (1994) examined forest change detection by comparison of vegetation indices for different dates of imagery. The vegetation indices included the Kauth-Thomas (KT) indices of brightness (B), greeness (G) and wetness (W), as well as NDVI, green ratios and mid-infrared ratio.

Several studies indicate a strong ability to detect environmental and urban changes using satellite data (Ingebritsen and Lyon, 1985; Coppin and Bauer 1994). A number of the image analysis approaches to change detection can be referred to as linear techniques, meaning that land cover change at each image location is associated with some linear transformation of a bi-temporal spectral vector (quoted by Collins and Woodcock, 1996). The best linear change detection technique is multi-date PCA, where the eigenvector matrix is a determinant of the temporal changes. The major components images from PCA tend to account for the variation in the image data that is not due to land cover changes and are termed stable components. Minor components tend to enhance contrasts between two dates, and are termed change components. PCA, however, can automatically apply a first-order calibration to account for exogenous differences (such as differences in illumination, sensor calibration and atmospheric conditions) to the extent that these differences have an overall linear effect on the remotely sensed signal (Chavez and MacKinnon, 1994; Collins and Woodcock, 1994). All change detection methods use image values which one knows a priori should be identical for both dates, but which are not identical due to exogenous differences. These data are used to calibrate a regression equation by which the pixel values in the "subject" image are made to match those in the radiometric "master" image. Coppin and Bauer (1994) use radiometric matching as a part of a data optimization procedure which also includes transformation of sensor data to reflectance units, as well as haze removal.

In this study, satellite imagery, thematic maps and field surveys were used to detect human activities in Houd El-Remal area by two complementary techniques; PCA (band-based) and classification (clustering). The detection of the areas of change and no change from the PCA analysis was interpreted visually by analyzing the PC2 image of each spectral band and the associated eigenvector value tables. It was found that:

1. PC2 difference image of the green spectral band accounted for the land cover changes in features that reflect in this visible band, that is, urban and disturbed areas (class 3) as well as sand dunes (class 4)

2. The red spectral band accounted for the land cover changes in vegetated areas, that is, cultivated fields of dense plantations and less plant cover (classes 1 and 2)
3. The infrared band accounted for the land cover changes in water bodies and infrastructure, that is, canals, flooded areas and roads.

The combined PC2 difference image of Houd El-Remal, represented the overall change in the three bands in terms of location and area. On the other hand, the classified image (clustering analysis) identified the land cover types. The resulting percent cover classes reflected the magnitude of environmental changes that have occurred in the 9 years time difference.

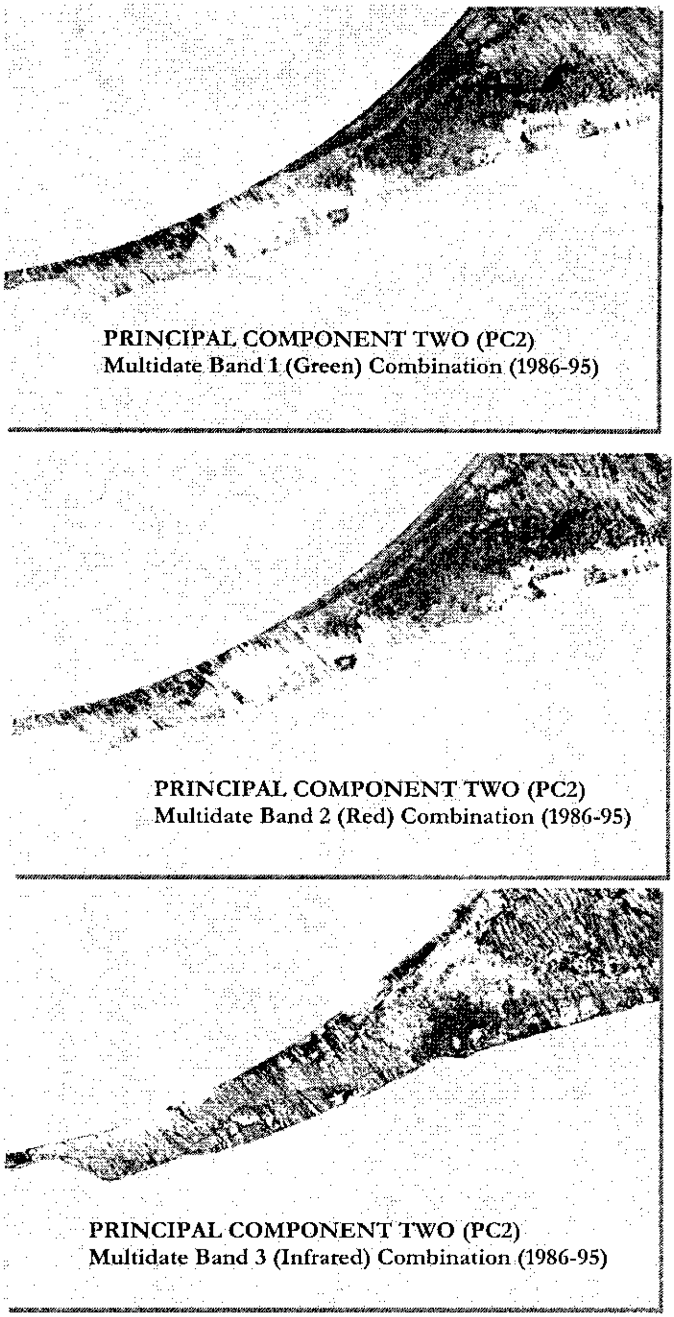
From this analysis of land cover change, it is concluded that most of the induced changes are due to anthropogenic effects. These effects are summarized in the following:

1. Pressure of increasing population and urban expansions
2. Eradication of dune ecosystems and its unsustainable exploitation.
3. Irrational reclamation and exploration of lands, in an absence of adequate planning schemes.
4. Irrigation practices that is based on untreated discharged irrigation water.

The impact of these anthropogenic practices would led to salinization of lands, decrease in the productivity of reclaimed lands, loss of the natural dune habitat and the associated deterioration in the visual landscape quality. The high soil salinity has been indicated by laboratory soil analysis. Although it is argued by local farmers that they can combat soil salinity by sand filling and addition of Gypsum, however from the environmental point of view these remedies are unsustainable and as a result, the overall environmental condition of the study area is suffering a decline in terms of quality and development potentialities. This case calls for sound environmental planning measures for sustainable development of coastal areas.

Table (3). Percent cover in hectares, resulting from the unsupervised classification (clustering) of SPOT-HRV images for the years 1986 and 1995.

Class No.	Name	Area 1986	Area 1995	Difference (1995-1986)	Difference as % Total Area	Rate of Change
1	Dense Plantations	898.08	1505.92	607.84	12.95	85.84 ha/year (total gain)
2	Agricultural Fields of Less Plant Cover	869.52	1034.2	164.68	3.51	
3	Built up + Disturbed Areas	946.56	1166.00	219.44	4.67	24.38 ha/year (gain)
4	Dunes + Bare Areas	1977.52	985.56	-991.96	21.14	110.22 ha/year (loss)
Total		4691.68	4691.68			



(a) (b) (c)

Figure (5). Principal Component two (PC2) difference images of the three multidate band combinations; (a) Green band, (b) Red band, and (c) Infrared band.

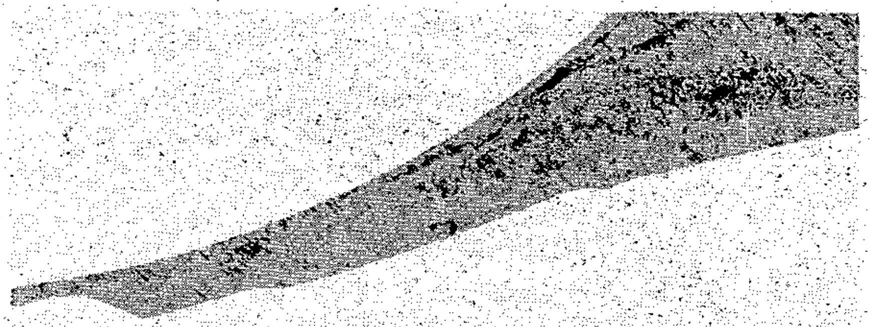


Figure (6). Areas of change and no change based on the unsupervised classification of the combined difference image of the three PC2 images.

Table (4). Cross tabulation of classes percent cover of houd el-remal in the two years 1986 (columns) against 1995 (rows).

	Dense Plantations	Agricultural Fields of Less Plant Cover	Built up + Disturbed Areas	Dunes + Bare Areas	Total
Dense Plantations	13.9 **43.3**	13.04 **40.60**	2.99 **9.31**	2.16 **6.72**	32.18 **100**
Agricultural Fields of Less Plant Cover	3.33 **15.10**	4.67 **21.17**	7.83 **35.5**	6.26 **28.3**	21.03 **100**
Built up + Disturbed Areas	1.39 **5.58**	0.668 **2.68**	7.35 **28.58**	15.46 **62.13**	24.88 **100**
Dunes + Bare Areas	0.54 **2.56**	0.159 **0.75**	2.03 **9.65**	18.26 **86.8**	21.03 **100**
Total	19.15	18.5	20.17	42.21	100%

Bold numbers: Percent cover using the 1995 classes as a reference

GENERAL CONCLUSION

The change detection analysis of the study of the coastal region revealed that:

1. In Edku city the only temporal change observed was of increase of human settlement density (fusion of urban patches forming larger conglomerations).
2. In Houd El-Remal, agricultural lands have extended due to reclamation and continuous sand filling of the lowlands using the sand of the dunes in the vicinity. The irrigation of the new reclaimed land is based on untreated drainage water that is highly saline. Various changes in the sand dunes habitat structure occurred due to human activities followed by wind erosion. However, no significant shifts in the dune boundaries were observed.

3. It is the salinization, irrational reclamation of the sand dune areas and urban sprawl around Edku city and its vicinity that accentuated land degradation which is apparent in the 1995 satellite image.

Accordingly it may be concluded that both the satellite imagery used and the methodology adopted were useful in assessing and monitoring land cover changes and provided valuable information to ecologists and decision makers in formulating land use policies, and in allocating resources in the area under study.

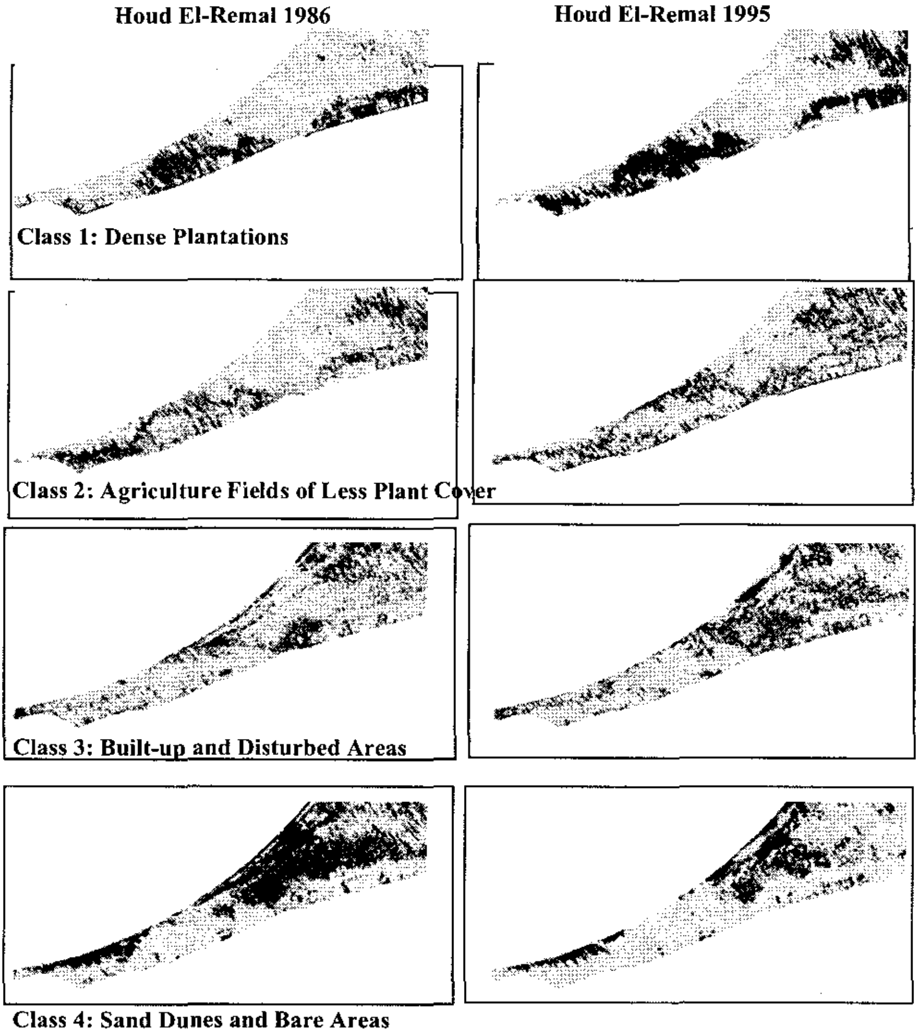


Figure (7). Unsupervised classification of Houd El-Remal area for 1986 scene (left column) and 1995 scene (right column), dark tone represents the spatial distribution of each class.

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Received: 17/04/2004
Accepted: 08/06/2004

تقييم تأثير أنشطة الإنسان على النظم الساحلية الطبيعية والمنزرعة بحوض الرمال – محافظة البحيرة بتطبيق تحليل المكون الأساسى للاقمار الصناعية "سبوت".

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توضح هذه الدراسة تأثير أنشطة الإنسان على منطقة حوض الرمال بمحافظة البحيرة لمنطقة ممثلة للساحل الشمالى الشرقى لمصر. وقد استخدمت تقنيات الاستشعار عن بعد لاختيار الحالة الراهنة لتغطية الأراضى واستخداماتها السائدة، ورصد مدى التغيير الذى حدث بالموائل وذلك بمقارنة صور الأقمار الصناعية ذات الدقة العالية "سبوت". وقد تم تطبيق طريقة خاصة من تحليل المكون الأساسى على صور الأقمار الصناعية وذلك لتحديد مدى التغير والتى تضمنت تقلص الكثبان الرملية واستغلالها بطريقة غير رشيدة، الاستصلاح غير المرشد للأراضى وممارسة نظم الرى باستخدام مياه صرف غير المعالجة، والامتداد العمرانى غير المخطط. وقد نتج عن ذلك تملح لبعض الأراضى الزراعية، فقد لموائل الكثبان الرملية وما تحتويه من موارد طبيعية ونباتات فطرية، وتدهور جودة النسق البريه المرئية.

أما التأثيرات طويلة المدى على المنطقة فهى تدهور بجودة الأراضى ومواردها الطبيعية بصفة عامة بالرغم من المنافع قصيرة المدى التى قد يجلبها الإنسان من البيئة.