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A Remote Sensing Approach for Detecting Agricultural Encroachment on the Eastern Mediterranean Coastal Dunes of Turkey

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Abstract: The aim of this study was to develop an effective procedure for detecting land use/land cover (LU/LC) changes resulting from agricultural encroachment on eastern Mediterranean coastal dunes by using remote-sensing techniques. Historic LU/LC information was extracted from aerial photos taken in 1976 and IKONOS imagery was acquired in 2002 to determine the current LU/LC pattern. The remotely sensed aerial and satellite data were classified by integrating spectral information with measures of texture, in the form of statistics derived from the variance, co-occurrence matrix and variogram. The performance of these classification approaches was evaluated in terms of error matrices. The accuracy of the classification was greater when using the variogram texture measure and spectral data together than when using spectral data alone or incorporating with co-occurrence matrix texture for both image classifications. Co-occurrence texture measures did not result in a significant increase in accuracy with the maximum likelihood classifiers in the classification of IKONOS imagery. The addition of variogram texture information in particular, with variogram lags of 1, 2 and 3 pixels, increased the overall classification accuracy by 11.3%. The principal conclusion of this paper is that the accuracy of agricultural land cover and semi-natural vegetation classification can be maximised by incorporating textural information with remotely sensed spectral data in the Mediterranean coastal environment.

Key Words: Land use/land cover changes, remote sensing, coastal dunes, IKONOS, image texture, monitoring.

Türkiye'nin Doğu Akdeniz Kıyı Kumullarındaki Tarımsal Yayılımın Belirlenmesi İçin Bir Uzaktan Algılama Yaklaşımı

Özet: Bu çalışmanın amacı, Doğu Akdeniz Bölgesindeki sahil kumullarında tarımsal yayılım sonucundaki arazi örtüsü/alan kullanımı değişimlerinin saptanmasına yönelik etkin bir uzaktan algılama yönteminin geliştirilmesidir. Geçmiş arazi örtüsü bilgileri 1976 yılına ait hava fotoğraflarından temin edilirken, güncel durum 2002 tarihinde kaydedilen IKONOS uydu verisinden sağlanmıştır. Bu uzaktan algılanmış veriler, yansıma verileri ile görüntü tekstürü birleştirilerek sınıflanmıştır. Tekstür bilgileri varyans, tekrar oluşum matriksleri (Co-occurrence Matrix) ve variogram hesaplamalarından elde edilen istatistiklerden derlenmiştir. Görüntü sınıflama sonuçları hata matriksleri temel alınarak karşılaştırılmıştır. Her iki görüntü sınıflamasında da variogram tekstür bilgisinin yansıma değerlerine eklenmesi, yansıma değerlerinin tek veya tekrar oluşum matriksleri ile birlikte kullanımından daha yüksek doğrulukla sınıflama yapılmasını sağlamıştır. IKONOS görüntüsünün sınıflanmasında tekrar-oluşum tekstür verilerinin maksimum olabilirlik sınıflayıcısı ile sınıflanması belirgin bir doğruluk artışı sağlamamıştır. Bunun yanında variogram tekstür bilgisinin, özellikle lag 1, lag 2 ve lag 3 piksel, sınıflamaya eklenmesi toplam sınıflama doğruluğunu % 11.3 arttırmıştır. Bu çalışmanın temel sonucu olarak, Akdeniz kıyı ortamındaki tarımsal arazi örtüsü ve yarı-doğal vejetasyon sınıflamasının, görüntü tekstür bilgilerinin uzaktan algılanmış yansıma bilgisi ile birleştirilerek sınıflamaya dahil edilmesi sayesinde yüksek doğrulukla üretilebileceği ortaya konmuştur.

Anahtar Sözcükler: Arazi örtüsü/alan kullanımı değişimleri, uzaktan algılama, kıyı kumulları, IKONOS, görüntü tekstürü, izleme

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Introduction

Increasing and often conflicting demands on natural resources in protected areas call for the intensification of efforts to ensure their effective management. This is especially true in Mediterranean coastal zones where the natural resources are fragile and susceptible to degradation. The contemporary state of Mediterranean land cover is a constantly changing mosaic of cover types determined by both the physical environment and human activities. In addition to the central role in affecting the environment, many facets of human health and welfare are directly connected with land use/land cover (LU/LC) change, including biological diversity and food production. Changes in LU/LC can have profound local, regional and global consequences (Klemas, 2001; Alphan, 2002).

Environmental monitoring is required to monitor and record changes in the extent and distribution of agricultural activity patterns as accurately as possible along the eastern Mediterranean coast of Turkey, particularly in fields with land covered by sand dunes. Turkey's coastal sand dunes are of global conservation interest, but they have also been subject to loss due to changes in agricultural practices. A fundamental expression of human impact on the eastern Mediterranean coastal dunes is the use of direct reclamation to obtain new agricultural fields.

Such actions result in habitat loss and the degradation of biological diversity. Soil conditions of coastal ecosystems are very difficult to manage and yields tend to decline over time. Agricultural fields reclaimed from coastal sand dunes are dramatically abandoned after a few years of intensive use, and this promotes further destruction. Extracted sand is laid routinely on agricultural fields as salinity increases. This type of LU/LC is not compatible with wildlife conservation, especially when endangered birds, sea turtles and plant species are involved. Five hundred and sixty plant taxa were identified in the area by Çakan (2001), and the richest species diversity was observed on sand dunes. However, Kapur et al. (1999) determined that 46% of coastal sand dunes had been opened up for agricultural cultivation in the last 76 years in the Seyhan River delta. This development has had a major impact on this coastal dune ecosystem (Aytok, 2001).

While the increasingly threatening nature of the invasion of agricultural lands along coastal ecosystems has long been witnessed in this region, data concerning the extent and properties of these changes are neither complete nor consistent. The provision of adequate and consistent information on coastal resources is essential to integrated coastal zone management (ICZM). LU/LC information on coastal zones is crucial for determining changes and identifying environmental trends. Remote sensing (RS) and geographical information systems (GIS) are progressively becoming applicable tools for the identification and analysis of landscape spatial patterns (Berberoğlu, 2003). RS data have been used effectively in many different applications concerning LU/LC change (Pilon et al., 1988; Singh, 1986; Ram and Kolarkar, 1993; Lenney et al., 1996). However, to date, land cover classification from satellite sensor imagery has been limited by the relatively coarse spatial resolution of the imagery available. This difficulty was alleviated by current fine spatial resolution satellite sensor imagery such as IKONOS, Quickbird and Orb View-3 that are capable of generating multispectral imagery with spatial resolutions as fine as 1-4 m (Meydan and Berberoğlu, 2002). This high-resolution, remotely sensed data increased the accuracy and detail of information provided by change detection applications (Narasimha Nao et al., 2002).

This study represents an approach for the investigation of semi-natural vegetation and agricultural LU/LC change by using airborne and satellite RS.

Materials and Methods

The study area is situated along the coastal edge of Çukurova Plain, which has widespread agricultural lands and coastal wetland ecosystems. The Tuz Lagoon, which is the westernmost lagoon on the coast, is located at the boundary of Tuzla district and lies 10 km from the Seyhan Delta.

The study area is approximately 5 x 10 km, and is predominantly engaged in agriculture, comprising peanut, tomato, wheat, and water and honey melon production. Detailed information on the soil properties of the study area was reported by Dinç et al. (1990).

The lagoon is brackish and is surrounded by extensive salt marshes and sand dunes. The floristic composition of the dunes varies according to the local environment. The fore-dune zone is a large sand plain with dominant species such as *Cakile maritima, Salsola kali, Euphorbia paralias, Eryngium maritimum, Pancratium maritimum, Elymus farctus* and *Ipomea stolonifera*. The dune slack zone has a very high ground water level. Characteristic species for this zone include *Trachomitum venetum, Imperata cylindrica, Phragmites australis, Juncus maritimus* and *Inula viscosa* (Berberoğlu, 1994; Yılmaz, 1998).

Four monochrome photographs taken in 1976 (24 x 24 cm) provide full monoscopic cover of the study area. The photoscale was 1:35,000. The current LU/LC pattern was extracted from IKONOS imagery obtained on 14 June, 2002. The IKONOS imagery has a spatial resolution of 4 m and four wavebands sensitive in the visible and near-infrared portions of the electromagnetic spectrum. In addition, land cover data were recorded on the date of IKONOS imagery acqusition by using GPS with an accuracy of 4 m.

Image processing and classification

Approximately 15 evenly distributed ground control points (GCPs) were selected from each image. The airphotos and IKONOS imagery were geometrically corrected and geocoded to the Universal Transverse Mercator (UTM) coordinate system using the nearest neighbour algorithm. The transformation had a root mean square (RMS) error of between 0.4 and 0.6, indicating that image rectification was accurate to within 1 pixel in both x and y directions. The aerial photos were spatially resampled to a 4 m ground resolution to ensure compatibility with IKONOS imagery and mosaicked to cover the whole study area.

A supervised maximum likelihood classification technique was applied using ERDAS Imagine Software. The IKONOS image was initially classified into 11 classes as opposed to four LU/LC classes, by generating seven agriculture classes (wheat, tomato, watermelon, peanut, burned stubble, bare soil, and tilled soil) rather than one. However, the final output was amalgamated into four LU/LC classes.

Texture measurement

In digital imagery, texture can be defined as patterns of spatial relationships, often quite complex, among the grey levels of neighbouring pixels. In situations where different land cover classes are not spectrally separable in remotely sensed data, the accuracy of a classification may be increased through the use of spatial (i.e. textural) information. The importance of image texture in LU/LC classification has been demonstrated by various researchers (Curran and Atkinson, 1998; Berberoglu, 1999; Berberoglu and Curran, 2000; Narasimha Nao et al., 2002). Numerous textural measures have been developed (Carr, 1996; Steel, 2000). The most commonly used set of statistical features are the second order textural measures based on Haralick's grey-tone spatial dependency matrix (Haralick et al., 1973), which has been applied in several remote sensing applications (for example, Connors et al., 1984; Augusteijn et al., 1995; Dikshit, 1996). The matrix records the number of pixels with grey scale i; these are then separated from the pixels with a grey scale j by a particular distance and direction.

A variety of statistics may be derived from the co-occurrence matrix. Haralick et al. (1973) identified 14 such measures. Five of these measures (Wood, 1996) were used in this paper

(i) Contrast,

$$\sum_{i,j} |i-j|^2 P(i,j)$$

(ii) Homogeneity,

$$\sum_{i,j} P^2(i,j)$$

(iii) Entropy,

$$\sum_{i,j} P(i,j)\log P(i,j)$$

(iv) Correlation,

$$\sum_{i,j} \frac{(ij)p(i,j) - \mu x \mu y}{\sigma x \sigma y}$$

where μx, μy, σx and σy are the means and standard deviations of px and py

(v) Dissimilarity,

$$\sum_{i,j;i\neq j} \frac{P(i,j)}{|i-j|^2}$$

where i,j are the grey levels of paired pixels and $P(i,j)$ are the probabilities of co-occurrence.

However, this technique requires large window sizes to measure the spatial variability whereas most ground cover targets do not have such large homogeneous areas in the Mediterranean landscape. It has been demonstrated that measures of spatial variability, more robust than the variogram may provide more useful information on spatial variation (Srivastava and Parker, 1989; Berberoglu et al., 2000).

The variogram is defined as half the expected squared difference between paired data values separated by the vector, lag **h**. A sample variogram is computed for the $p(\mathbf{h})$ paired observations, $z(x_i)$, $z(x_i + h)$, $i=1, 2, \ldots, p(\mathbf{h})$

$$\hat{\gamma}(h) = \frac{1}{2}\, p(h) \sum_{i=l}^{p(h)} \{z_v(x_i) - z_v(x_i + h)\}^2$$

where ν is the support (the size, geometry and orientation) of the area over which measurements are made. In the case of imagery the lag **h** is equal to a pixel (Figure 1).

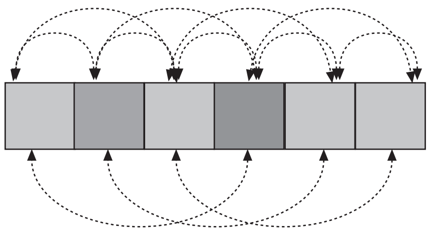

Figure 1. Lags along a transect of pixels. Lags of 1, 2 and 3 pixels are illustrated.

The variogram within a moving window has only been used to quantify texture in radar imagery (Miranda et al., 1992; Miranda et al., 1996). Miranda et al. (1992) found that variograms could be used to distinguish effectively between different land cover classes and increase the accuracy of classifications. A critical issue for calculating the variogram over an image is the size of the window. The size of the window needs to be related to the size of the objects in the scene. For example, Miranda and Carr, who have employed the variogram texture measure for image classification, used very large windows (e.g., 22 by 22 pixels) (Miranda et al., 1992), because they studied Brazilian rain forest, where the areas covered by each land cover class are large and continuous. However, Miranda et al. (1996), suggested that a 7 by 7 window size is ideal for the calculation of variogram texture in another study. Considering the fact that Mediterranean type land covers are significantly small and discontinuous, this structure limits the utility of large window sizes because such large windows increase the risk of contamination by class mixing. For this reason, in this study the smaller window size of 7 by 7 was used.

This paper aims to use co-occurrence matrix measures of texture and a new structural image texture technique, termed variogram texture measure, to classify agricultural land cover in Tuzla, Turkey.

Application of Texture

Code was written in Fortran 77 to compute the co-occurrence matrix and the five statistics described above. The co-occurrence matrix was computed for four directions: 0° clockwise from North, 45°, 90° and 135° and the five statistics derived from the average co-occurrence matrix for the four directions. The classification presented below utilised the mean value of the statistics derived for the four directions. Variograms were computed using a modified version of the of the GSLIB (first edition) variogram computer code (Deutsch and Journel, 1992).

Variogram and co-occurrence matrix texture measures were applied to IKONOS imagery. All texture measures for IKONOS imagery were extracted from the first principal component of the four wavebands to create texture waveband(s). The texture waveband(s) was combined with the image to add spatial information. Then maximum likelihood classification was applied and the outputs were compared on the basis of classification accuracies derived from the error matrix. Texture data were always used with spectral data. The texture measure that provided the most accurate classification results was utilised to quantify aerial photo image texture and investigate the further utility of this texture measure.

Error matrices provided information about the accuracy of classifiers and also confusion between classes. The overall accuracy results were derived using 817 and 300 random points for IKONOS image and aerial photos respectively.

The ground-truth for IKONOS imagery was provided by land surveys performed simultaneously alongside image acquisition. Reference data for aerial photography were obtained from the literature, visual interpretation and local people's knowledge. The number of ground control points was associated with the number of classes within the images.

Results

Various combinations of texture wavebands and spectral data were classified by using a maximum likelihood classifier and the accuracy results are presented in Figure 2.

Co-occurrence texture measures did not result in a significant accuracy increase with the maximum likelihood classifiers in the classification of IKONOS imagery. Some minor accuracy increases were achieved in entropy and homogeneity measures. The addition of variogram texture information in particular, variogram lags of 1, 2 and 3 pixels, increased by 11.3% the overall classification accuracy (Table 1).

Variogram texture measures resulted in more accurate image classification than co-occurrence matrix measures. For this reason, variogram texture measures were retained for aerial photo image classification. To further investigate the utility of variograms within aerial photo image classification various combinations of variograms at lag of 1 to 4 pixels and variance were evaluated (Table 2).

The highest overall accuracy of 84% was achieved using spectral data with variograms at lags of 1, 2, 3 and 4 pixels and variance (Table 3).

The use of variance in addition to variograms did not increase the IKONOS classification accuracy; it over-emphasised the field boundaries. However, it revealed

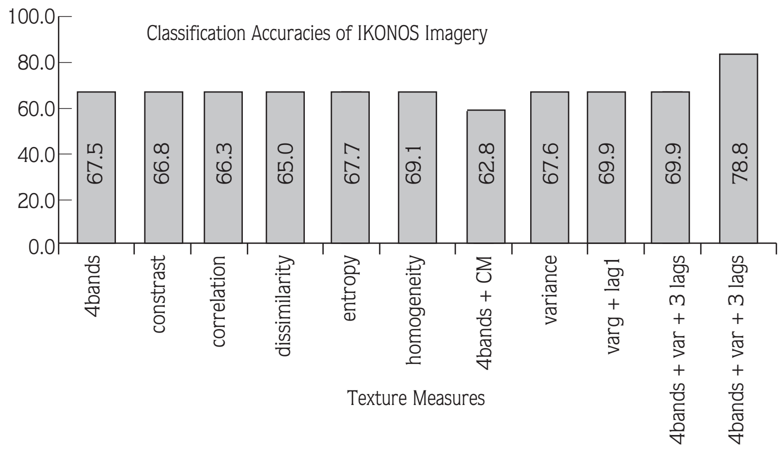

Figure 2. Overall accuracy results of the classifications incorporating texture measures. (CM: Co-occurence matrix; var: Variance)

Table 1. Error matrix of classification of the IKONOS image incorporating variogram lags of 1, 2 and 3 pixels.

	Agriculture	Sand Dune	Dune Slack	Dune Vegetation	Total	User's Accuracy (%)
Agriculture	**413**	24	4	6	447	92.4%
Sand Dune	55	**137**	1	1	194	70.6%
Dune Slack	0	0	**56**	13	69	81.2%
Dune Vegetation	57	3	9	**38**	107	35.5%
Total	525	164	70	58	**817**	
Producer's Accuracy (%)	78.7%	83.5%	80.0%	65.5%	**Overall Accuracy**	**78.8%**

Table 2. Error matrix of classification of the aerial photo image incorporating variogram lags of 1, 2 and 3 pixels and variance.

	Sand dune	Dune slack	Dune vegetation	Total	User's accuracy (%)
Sand dune	**135**	19	12	166	81.3
Dune slack	1	**73**	-	74	98.6
Dune vegetation	16	-	**44**	60	73.3
Total	152	92	56	**300**	
Producer's accuracy (%)	88.8	79.3	78.6	**Overall accuracy**	**84.0%**

Table 3. Overall classification accuracies of aerial photo image incorporating variogram lags of 1, 2 and 3 pixels and variance.

Texture variables	Overall accuracy (%)
Spectral alone	74.7
Variance + lags of 1,2,3,4	44.3
Spectral + variance + lag of 1	81.7
Spectral + lags of 1,2,3	81.3
Spectral + variance + lags of 1,2,3,4	84.0

useful information about the texture structures of land cover classes, which was very helpful for extracting information about scene conditions in an aerial photo image. An advantage of the variogram over the co-occurrence matrix texture measure is the capability to compute the measure on a lag-by-lag basis. Each lag of pixel provides different spatial information for each land cover type (Figure 3).

These responses resulted in the highest classification accuracy for both images. Variogram lags of 1, 2, 3 and 4 pixels and variance provided the highest accuracy for aerial imagery; however, the use of variance in addition to the variogram did not increase the accuracy of IKONOS. Four spectral bands and variogram lags of 1, 2 and 3 pixels produced the most accurate results for IKONOS imagery (Figure 4).

In particular, small and patchy land cover classes were classified successfully with variogram lags of 1, 2 and 3 pixels (Figure 5).

As a result of the classifications, the sizes of LU/LC areas and the rates of conversion of semi-natural vegetation to agricultural LU/LC were determined (Table 4).

Over the last 26 years, dramatic LU/LC changes have occurred in this coastal zone. Approximately 66% of the

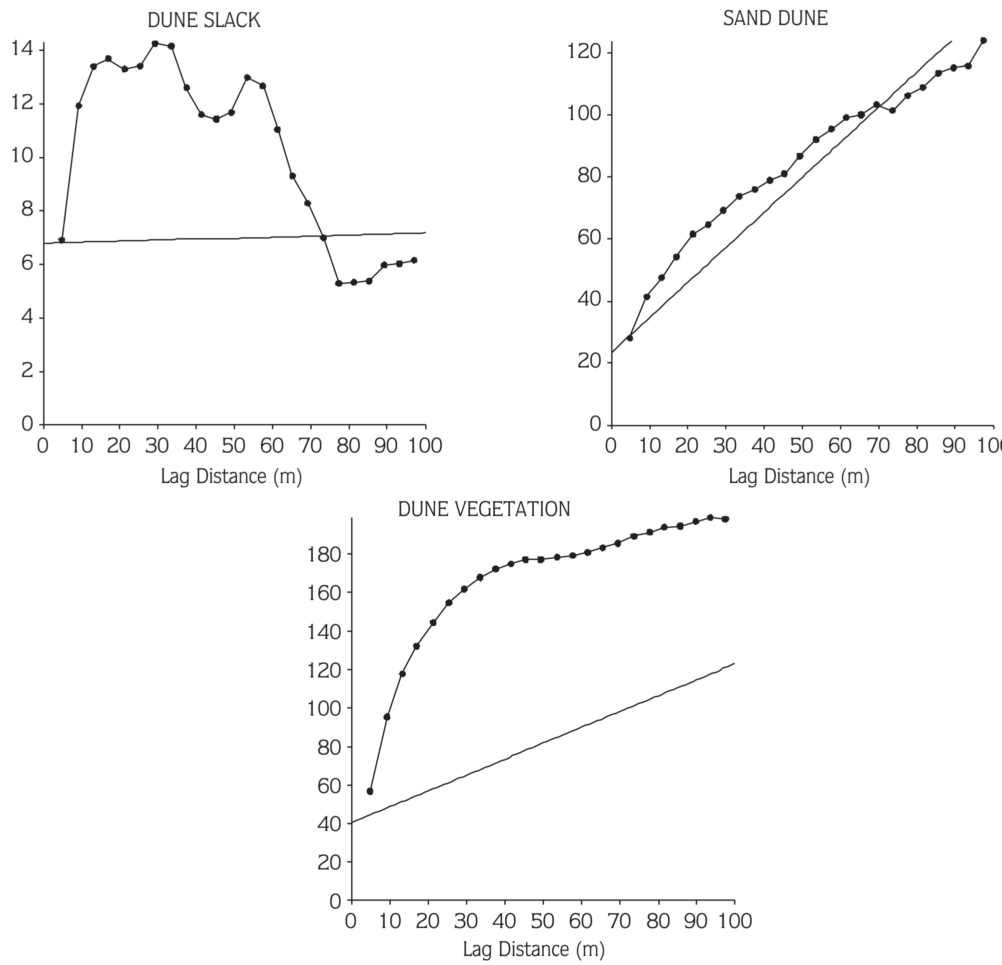

Figure 3. The measured (circles) and modelled (line) variograms from aerial photo image.

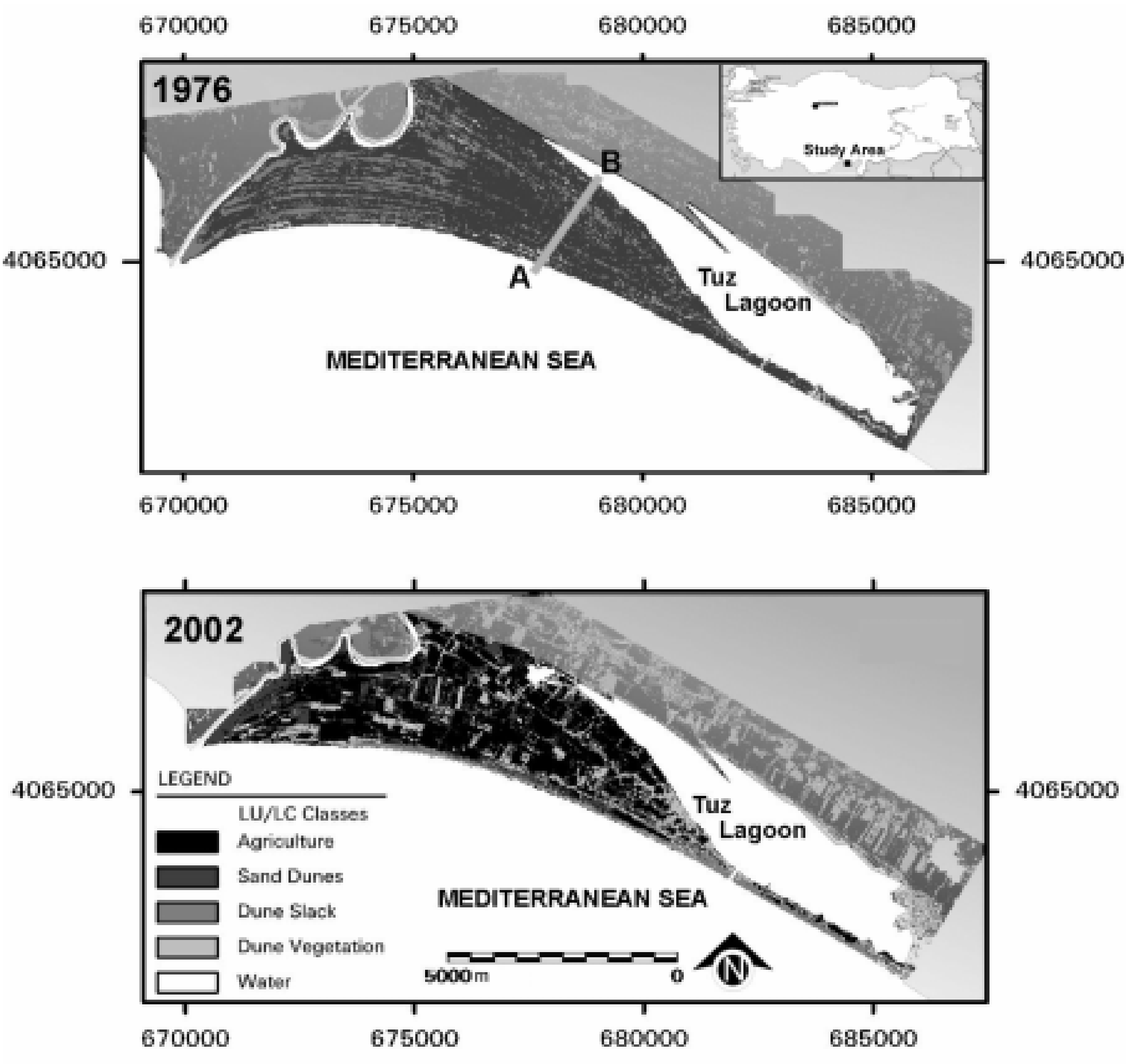

Figure 4. Classified aerial and IKONOS imagery based on spectral data and variogram texture measures.

Table 4. LU/LC changes between 1976 and 2002.

LU/LC Classes	1976 (ha)	2002 (ha)	Change (ha)
Agriculture	0	1963	+1963
Dune Slack	438	194	-244
Dune Vegetation	208	145	-63
Sand Dunes (bare)	1792	112	-1680

dune slacks, 30% of the dune vegetation and 94% of the bare sand dunes have been destroyed in the study area. The natural topography and quality of the landscape has been enormously changed (Figure 6). The total coverage of LU/LC classes decreased, as much as 24 ha, between 1976 and 2002. The differences arise from coastal erosion, which may have resulted from decreases in sediment supply due to the construction of dams in the upper basin of the Seyhan River. In addition, seasonal water level changes between the two images and the coarse resolution of the aerial photos may also have influenced this decrease.

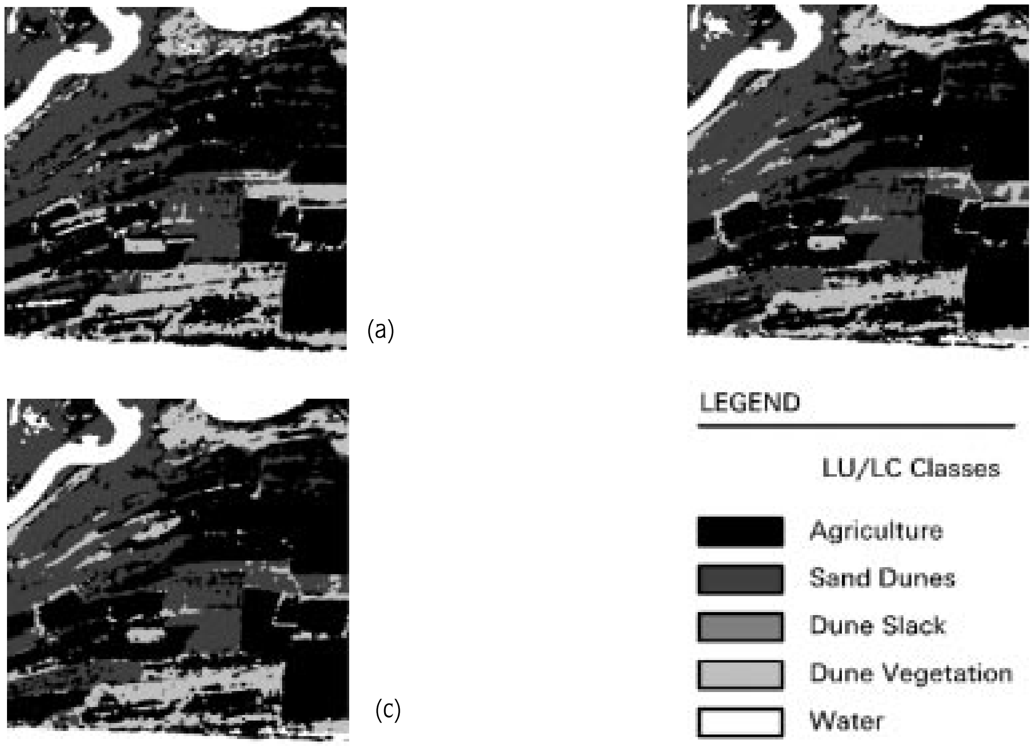

Figure 5. Classifications incorporating various texture measures for parts of the IKONOS imagery (a: variogram lags of 1,2,3 pixels; b: spectral alone; c: homogeneity).

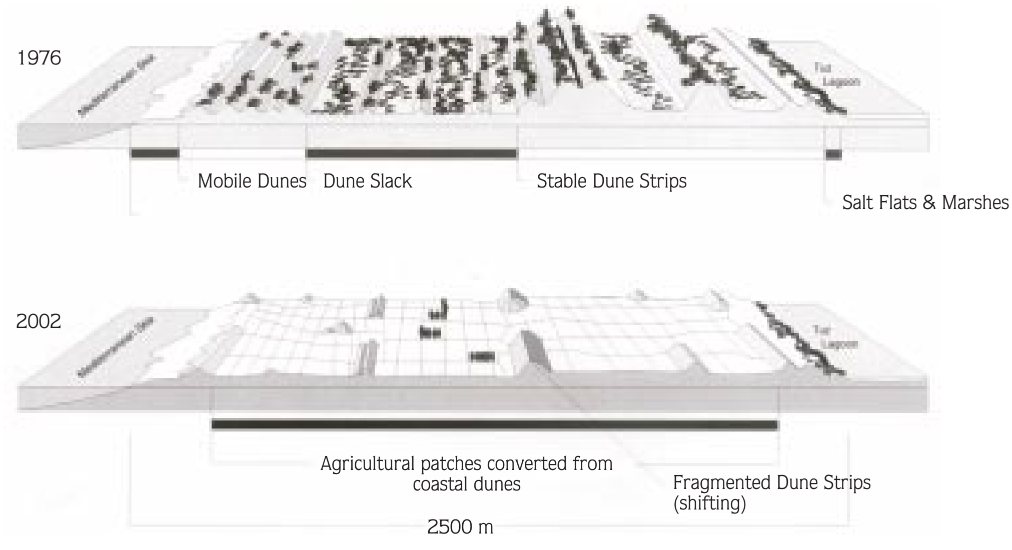

Figure 6. Profiles of the region extracted from classified images (The location is given in Figure 4).

Discussion and Conclusions

This study aimed to detect LU/LC changes by using high spatial resolution remotely sensed data. Spectral and spatial information in the form of various texture measures were integrated with the aim of increasing the effectiveness of classification (by means of maximising the percentage accuracy) with which Mediterranean coastal land cover can be classified. The spatial (textural) information included the variance, variogram and co-occurrence matrix. The Synergy of the techniques, in particular variogram texture measures, enabled more accurate classifications than those obtained using standard techniques alone. As a result of these classifications, the LU/LC changes over 26 years were determined.

Medium resolution imagery has been utilised for coastal change studies (Sanjevi, 1996) and provided better change detection results, especially in large homogeneous areas (Lupo et al., 2001; Larsson, 2002). However, finer change detection of heterogeneous environments such as the Mediterranean coastal zone requires finer ground resolution. The integrated use of aerial photography and high-resolution data with spatial (texture) information provides a basis for finer and accurate change detection. Furthermore, spatial (texture) information that quantifies variation within remotely sensed data has been widely used with medium-resolution imagery such as Landsat TM (Berberoglu et al., 2000) and radar (JERS-1 SAR) data (Miranda et al., 1996) to increase classification accuracy. This study has shown that texture techniques are more appropriate for high spatial resolution images. This is due to the fact that high spatial resolution images hold high pixel variation, which can be quantified by texture measures. In this respect, this research is novel for this region in terms of incorporating high spatial resolution imagery with texture information for coastal LU/LC change studies.

Additionally, the variogram texture measures used in this study in addition to traditional texture measures (variance, co-occurrence matrix) is relatively new in remote sensing applications. Very few publications (e.g., Berberoğlu et al., 2002) are available concerning variogram texture classification with high spatial resolution data. This study showed that variograms hold considerable potential for high spatial resolution image classification.

This novel approach can be applied to other delta and estuarine ecosystems in the Mediterranean where land use changes are rapid and pervasive. This research only focused on the spatial distribution of agricultural and semi-natural LU/LC. Considering the scale and distribution of the change, the consequences of these trends on the physical environment, such as soil, hydrology, vegetation and fauna, is subject to further field investigations. However, the scale of the aerial photos (1:35,000) limited the level of detail in the change detection procedure. Finer resolution aerial photos (e.g., 1:25,000) will likely diminish these effects.

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