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Monitor Land Degradation Phenomena Through Landscape Metrics and NDVI: Gördes, Kavacık, Ilıcak, Kumçay and Marmara Lake Basins (Turkey)

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Abstract: Rapid land use/cover change (LULC), land degradation and landscape fragmentation are occurring in Turkey, as a result of demographic pressure, agricultural expansion, government policies and environmental factors such as drought. This study analyzed the dynamics of LULC and land degradation as revealed in landscape fragmentation in the Gördes, Kavacık, Ilıcak, Kumçay and Marmara Lake basins based on Landsat data for 1975 and 2000. A hybrid supervised/unsupervised classification approach coupled with GIS analyses was employed to generate LULC maps. Various class-level Landscape Pattern Metrics (LPMs) were calculated using FRAGSTATS, in order to analyze landscape fragmentation. Normalized Difference Vegetation Index (NDVI) has been prepared from the satellite data to understand the vigour and density of vegetation. The results indicated that the study area had a decrease in NDVI values, which meant a decrease in the vegetation cover, land degradation and the soil moisture during the study period. Consequently, the landscape became more highly fragmented. This suggests that anthropogenic activities driven by agricultural expansion were the main causes of landscape fragmentation, leading to landscape degradation in the study area. This study demonstrates the effectiveness of the Remote Sensing (RS) and the Geographical Information System (GIS) in detection, assessing, mapping, monitoring and generating essential quantitative information on the land degradation.

Key words: Desertification, GIS, land degradation, landscape ecology, LPMs, NDVI, remote sensing, Turkey

INTRODUCTION

Land degradation and desertification are complicated global problems (Dregne *et al.*, 1991; Irshad *et al.*, 2007; Maiangwa *et al.*, 2007). The UNCCD (The United Nations Conference on Desertification) defines desertification as land degradation in arid, semi-arid and dry-humid areas resulting from various factors, including climatic variations and human activities (Irshad *et al.*, 2007). The term desertification was first used by the French geographer Andre Aubreville in 1949 for the process by which productive savannahs, grasslands and scrublands of north and equatorial Africa turned into unproductive desert. According to Dregne (1986), desertification, as impoverishment of terrestrial ecosystems under impact of man, can be measured by reduced productivity of desirable plants, undesirable alterations in the biomass and the diversity of fauna and flora, soil deterioration and increased hazards of human use. The symptoms of arid and semi-arid land degradation vary from region to region, but are generally considered to include loss in productive vegetation and erosion of soil surfaces by wind and water. General definition of land degradation was presented by Wasson (1987) as: land degradation is a change to land that makes it less useful for human beings. The underlying causes of the phenomenon of desertification are directly related to human activities; human pressures on the environment and resources; social, economic and productive organization and practice and unsustainable ways of living generated by unsustainable production and use of natural resources.

Desertification phenomenon has significantly interested all European countries of the Mediterranean basin in the last decades (Greco *et al.*, 2005). According to López-Bermúdez and García Gómez (2003), in the future, food problems in the Southern Mediterranean region due to desertification and land degradation will be a problem for the entire Mediterranean region. Causes of desertification and land degradation in the Northern Mediterranean region can be found mainly due to human activity, socioeconomic organization and land use change (López-Bermúdez and García Gómez, 2003; Greco *et al.*, 2005). Also, semi arid climatic conditions in Mediterranean region are natural parameters of desertification and land degradation (El-Bagouri, 2006). In Anatolia we can identify a series of areas that face problems of desertification and land degradation to a different extent (Atalay, 2002). The problem of desertification in Turkey is thought to be contributed to by human interference with nature; over-grazing, quarrying of sand and gravel and off-road traffic. The importance of understanding deforestation processes goes beyond the ability to quantify the changes resulting from deforestation; it is essential to understand its causes, effects on natural resources and wildlife habitat.

RS and GIS provide successful tools for land degradation detecting and monitoring (King and Delpont, 1993; De Jong, 1994). Especially, in order to monitor vegetation productivity over a long time scale and on a large spatial scale, the use of satellite imagery is the only viable option (Symeonakis and Drake, 2004). Satellite based NDVI (The Normalized Difference Vegetation Index) is the most commonly used method to monitoring vegetation change and it's mapping (Tian and Min, 1998; Parodi, 2002). NDVI responds to changes in biomass and chlorophyll content and therefore serves as a useful measure or primary productivity. Jones *et al*. (1996) evaluated the theoretical potential of NDVI to assess watershed health and hypothesized that it could indicate losses in productivity, increased erosion and losses of the buffer capacity along riparian corridors.

The majority of studies on land degradation using satellite remote sensing techniques have focused on the regional and local scale where high resolution satellite data, such as Landsat and SPOT images, can be utilized (El-Khattib *et al*., 1997; Collado *et al*., 2002). Landscape Ecology has developed a variety of landscape pattern indexes that allow us to characterize the landscape patch composition and configuration and such metrics that can be used to quantify the effects of fragmentation at the landscape scale. For this reason, landscape ecology is also a powerful tool for the study of land degradation and its changing in time, as well as forecasting ecosystem health in affected regions. Shortly, landscape ecology is focused on the relationship between the natural environment and the human environment. In Turkey National Action Program, it has been planed that NDVI should be used to support and confirm early warning systems in desertification (Anonymous, 2005).

The main research goal of this study was to evaluate the usefulness of Landscape Metrics and NDVI in the context of land degradation studies. I analyzed multitemporal variations of landscape affected by land degradation processes by applying a set of LPMs obtained from classifications of three Landsat imageries. In this study, Gördes, Kavacık, Ilıcak, Kumçay ve Marmara Lake basins were examined. The most important reasons for my choosing to study in these basins are that they have a land degradation and desertification problem (Öner and Mutluer, 1993) and high environmental sensitivity. To achieve this goal, the following objectives were pursued:

- Determine NDVI change,
- Estimate the forest biomass change and distribution as a result of land degradation,
- Describe landscape pattern characteristics and their dynamics,
- Measure fragmentation degree,
- Identify interrelationship between land degradation and LULC change.

MATERIALS AND METHODS

Study area and general descriptions: The study covers Kumçay, Ilıcak, Kavacık, Gördes and Marmara Lake basins, which are situated in the frontier of the Manisa administrative province in the Egean part of the Egean Region (Fig. 1). A part of Gördes basin is situated in the frontier of Balıkesir province. The study area is divided into two; as Gördes and Kavacık basins where there are greater slope and altitude with regards to morphographic features and as Kumçay, Ilıcak and Marmara Lake basins where there are moderate slope and altitude.

Sarmaşık tributary which appears in the southern sides of the Demirci Mountains joins with Medar tributary and then it is named as the Gördes River. In the Akselendi plain, Gördes River is known as the Kumçay and then it ends in the Gediz River passing through the mountain pass which has the same name as Kumçay. The land that Gördes drains is generally the Gördes Neojen basin (Ercan, 1983). In the basin which is situated between Gördes and Kayacık, which is the most important branch, Neojen volcanics are visible (Ercan, 1983). Ilıcak creek is another river which partly extends along the Kumçay pass in to the Akselendi plain. The purpose of including the basin of this river in the study is to reveal the change in Akselendi plain more clearly. Ilıcak is fed by the source of Beşgöz and it extends along in the north of the former bed of Kumçay in the directions of W-SW (Öner and Mutluer, 1993). Ilıcak and Kumçay basins are divided into two with a hardly evident watershed threshold.

Marmara lake, a natural lake of which the outflow is dammed and regulated, has an average area of 3400 ha and depth of 3-4 m although its area and depth differ in some parts, as it is a seasonal lake which is fed by minor streams and underground water originating in Akselendi interior basin. A 10 km long barrier wall was built in 1953 by the lake, which rerouted the water of the Kumçay with the help of a channel by directing it towards the south, to nearby Çömlekçi village (Girgin, 2000). In addition, another channel was built between the lake and Adala regulator in 1955, in order to bring in more water from the Gediz River. These two channels were carried out for the purpose of making the water in the lake available for agricultural

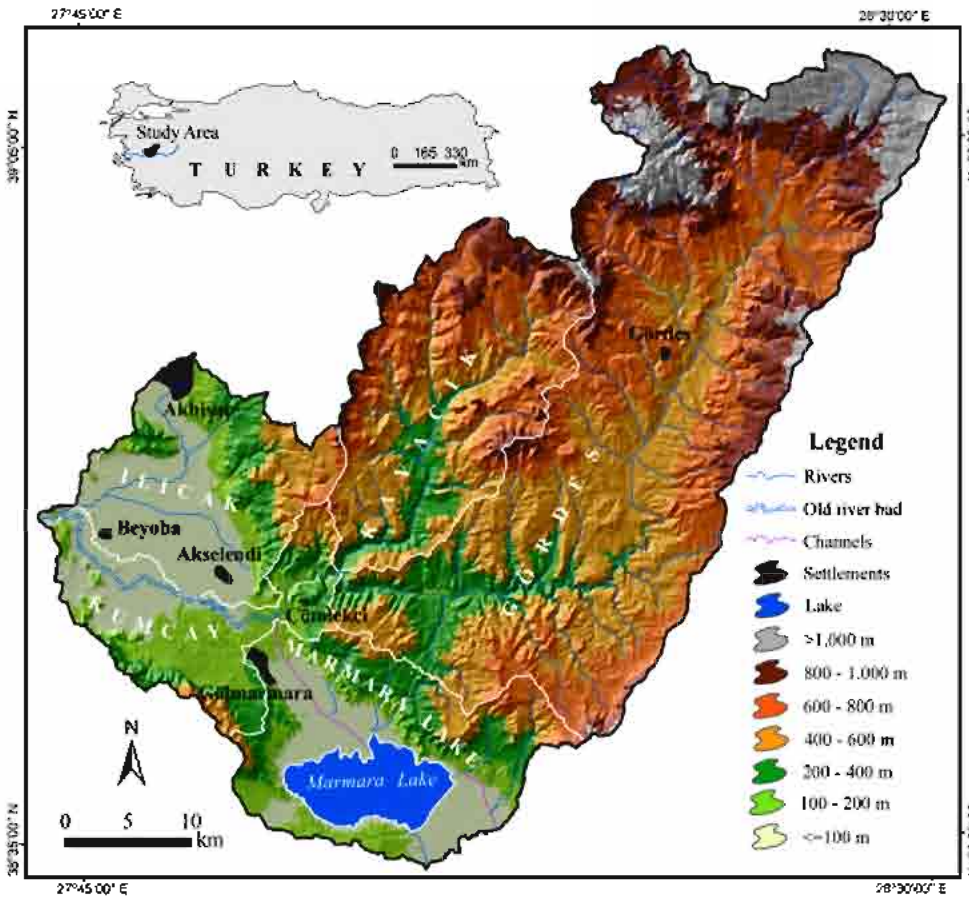

Fig. 1: Location of the study area

purposes. This lake has been used to water the great extent of the agricultural land in the irrigation area of Ahmetli and Menemen plains. However, in 1993, such a loss of water in the lake took place, that many animal species became extinct. As a consequence of the reactions to that, no water was left for the irrigation purposes from Marmara Lake between 1994 and 1995. The ecologically valuable mud fields and swamps, that appear when the water level in the lake is low, started to be used as agricultural lands by the local farmers. It was found by Öner and Mutluer (1993) that the rerouting of the water feeding Kumçay to Marmara Lake sped up the formation of sand of dunes in the Akselendi plain. Dunes in the Kumçay had been observed in the past too but they increase after diversion was built (Öner and Mutluer, 1993). The formation of sand of dunes resulting from the deflation in the bed of Kumçay, which had been dry for a long time, was the most significant environmental problem that has been revealed in the study area. The formation of sand of dunes threatened the agricultural lands. Although the active formation of the dunes was stopped partly, they still existed with their negative impact to the environment (Fig. 1 and 2).

In the study area, olive trees and grape have been grown at higher places around the plains. While in the plains which are in the terraces surrounding the lake, cotton has been the most common plant. At the higher basins (Gördes and Kavacık), sheep/goats and cattle have been put out to pasture. Fishing is the main means of earning a living around the lake. The land where this study was carried out is a low-moisture featured place. Summers are warm and dry, winters are rainy and chilly. According to the Akselendi meteorological data, the average temperature is nearly 16°C and the total amount of rainfall in a year is 566 mm. According to the data obtained from Gördes meteorological station, the annual average temperature is nearly 13°C and the total amount of rainfall is 641 mm.

Fig. 2: Sand of dunes in Kumçay basin (February, 2007)

Data used: For this study, Landsat Multispectral Scanner (MSS) image taken on May 31th 1975, Landsat Thematic Mapper (TM) taken on June 5th 1987 and Landsat Enhanced Thematic Mapper Plus (ETM+) taken on June 16th 2000 satellite images were employed. Remote sensing data which did not have clouds, haze, or extreme humidity were downloaded from the USGS Earth Resources Observation Systems data center.

Other materials used included a topographic map (1:25.000), a Digital Elevation Model (DEM), GPS (Global Positioning System) data collected from field in 2006-2007, field survey information, land cover maps provided by the General Directorate of Rural Services and Akselendi and Gördes climatic data.

Digital image processing: The image processing system ERDAS Imagine was used in processing and classifying the acquired images. All Landsat data were preferred near anniversary dates because sun angle, soil moisture, atmospheric condition and vegetation phenology are different one season to another. Preprocessing, such as geometric and radiometric correction were necessary before the analysis and were performed in order to reduce the radiometric distortion in the case of multi-date images. All images were georeferenced to 1:25000 digital topographic maps by nearest neighbor resampling algorithm and the RMS was less than one pixel. Spatial resolution of Landsat MSS (57 m) is different from Landsat TM and ETM (28.5 m). To allow pixel-by-pixel comparison for all years, all images we re-sampled pixels in the 1987 and 2000 images to a 57 m resolution. Six multi-spectral bands for Landsat TM and ETM and four multi-spectral bands for Landsat MSS were used.

Spatial data were collected with Global Positioning System-GPS during the field studies. And this data were used attributation process. Global Positioning System (GPS) points were also collected at the locations of sampled LULC classes. These points have been integrated with Landsat satellite imagery and other coverages into a Geographic Information System (GIS), which will provide additional information about LULC.

Methods:

Watershed delineation: Automated delineation of drainage network and watershed using a digital elevation model was used in this study. Sub-watersheds were created by using the Arc Hydro tools of ArcInfo. Raster analysis was performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation and watershed delineation. Five sub-watersheds are identified: Gördes Basin (~1090 km^2); Kavacık Basin (~353 km^2); Ilıcak Basin (~253 km^2); Kumçay Basin (~190 km^2) and Marmara Lake Basin (328 km^2). In these basins, Marmara Lake basin covers the outgoing river basin too.

Image processing:

NDVI classification: NDVI is a quasi-continuous field that is calculated as a normalized difference between the reflectance of two biologically meaningful bands of the electromagnetic spectrum. Actively, as a source of energy for photosynthesis, photosynthesizing leaves absorb the red wavelengths (Landsat TM band 3) and reflect the short-wave infrared (Landsat TM band 4). The difference between the two is proportional to the amount of photosynthesis. The reason NDVI is related to vegetation is that healthy vegetation reflects very well in the near infrared part of the spectrum (Parodi, 2002; Schreiber, 2006). Following NDVI index was used:

$$\text{NDVI} = \text{Band 4 (NIR - Band 3(RED)/}$$
$$\text{Band 4 (NIR)+ Band 3 (RED)}$$

The raw NDVI values are fractional real numbers that range between -1.0 to +1.0. An NDVI value of zero means no green vegetation and close to +1 (0.8-0.9) indicates the highest possible density of green leaves. Essentially, vegetation values have a range between 0.1 to 0.7. Higher values are associated with healthier vegetation and greater density and greenness of the plant canopy. Soil's and rock's NDVI values are close to zero and water bodies such as rivers and dams, the opposite trend to vegetation, have negative NDVI values. NDVI statistics were calculated for 1975, 1987 and 2000 (mean, maximum and standard deviation).

NDVI differencing for 1975, 1987 and 2000 was calculated in order to detect NDVI change and performed using Image Difference method. The percent change was calculated for increase or decrease in NDVI values normalized to the value of global maximum increase or decrease between the two images. 10, 25 and 35% threshold values were applied. An increase or decrease of less than 10, 25 and 35% was considered to be an area of no change. Interpretation of the NDVI difference image maps and the Highlight Changes image maps were drawn using ArcInfo. Generally, increases indicate the addition of vegetation and the regeneration of a forest after an earlier harvesting and decreases indicate the removal of vegetation and the removal of vegetative cover for land development.

Also, inter-annual increase or decrease relative to this baseline can serve as an indicator for drought intensity. Among climatic factors, precipitation and temperature strongly influence both temporal and spatial patterns of NDVI (Wang *et al*., 2001; Holm *et al*., 2003). It is a well-known fact that the temperature and rainfall which are the two important issues of climate have an undeniable effect on the variation in vegetation, the period at which plants are grown and the reproduction of the plants (Wang *et al*., 2001). In a study which was carried out by Davenport and Nicholson (1989), NDVI is very sensitive, especially in the lands where the annual rainfall is less than 1000-1200 mm. According to Hess *et al*. (1996), the use of NDVI with rainfall is only feasible in the lands which get rainfall less than 650 mm in a year. Pearson's correlation coefficient (Pearson's r) between the mean annual NDVI and the mean annual temperature and rainfall were calculated for the study area. NDVI is directly related to past rainfall and seasonal primary production (Schreiber, 2006). Because of this, the last 6 months (January-June) rainfalls have been analyzed too.

Image classification: A hybrid supervised-unsupervised classification approach called guided clustering outlined in Messina *et al*. (2000) was used (Lillesand *et al*., 1998). Then, a 3×3 median filter applied in order to remove speckled pixels, random pixels in the middle of a main class and to refine the classified maps. During the attribution process, GPS data, NDVI, field knowledge, air photos and different band combinations were taken into account. Detailed land-use and land-cover classification scheme was illustrated in Table 1 for the study area. The overall accuracy carried out using 1: 25.000 scale topographic maps and land cover maps provided by the General Directorate of Rural Services and field knowledge was 79% for the 1975 data, 85% for the year 1987 and 83% for the year 2000.

Landscape Pattern Metrics (LPMs): Quantifying fragmentation is important to identify land degradation (Schlesinger, 1990). Habitat fragmentation is recognized as one of the major threats to species survival in human-disturbed environments by contributing to the isolation of inhabiting populations and by decreasing their size

Table 1: Classification scheme of the land-use and land-cover types

LULC classes	Abbreviation	Description
Forest	F	Includes deciduous forest lands, evergreen forest lands and mixed forest lands.
Mixed land	ML	Includes degradated forests mixed with agricultural areas, transitional woodlands and shrub-bmsh rangelands. Young forests also are in this class. Mostly this class cover *Quercus* which has less than 6 m height
Rangeland	R	Includes natural grasses. Mostly these areas are used for grazing.
Agricultural areas	AG	Includes crop agriculture, pasture, orchids and vineyards.
Bare exposed rock and soil	BR and S	Includes areas of bedrock exposure, volcanic material, rock glaciers, extractive mining and other accumulations of rock without vegetative cover. Because settlements have high spectral signature like barren soil surface, this class include settlements.
Sandy areas	SA	Sand accumulations most commonly are found in deserts but they also occur on river flood plains and deltas. In study area SA descript river and delta sands.
Water	W	Includes lakes, reservoirs and streams.

Table 2: Set of landscape metrics selected for the study (McGarigal and Marks, 1995)

Metrics	Indices	Purpose
Area metrics	Percentage of landscape (%) 0< % LAND≤100	Measure of landscape composition
	Largest patch index (%) 0<LPI≤100	Measure of the area of the largest patch in each class (in hectares)
Patch density, patch size and variability metrics	Number of patches NP≥1	Measure of the extent of subdivision or fragmentation of a class
Edge metrics	Edge density (m ha^{-1}) ED≥0	Measure of sum of length of all edge segments, divided by total area for each class
Shape metrics	Landscape shape index LSI≥1	Measure of the habitat diversity
	Fractal dimension 1≤FRAC≤2	Measure of shape complexity at patch level
Nearest neighbor metrics	Mean nearest neighbor distance (m) MNN>0	Measure of patch isolation
Contagion and interspersion metrics	Interspersion and juxtaposition index (%) 0<IJI≤100	Measure of relative interspersion of each class
Diversity metrics	Shannon's evenness index 0≤SHEI≤1	Measure of patch distribution and abundance
	Shannon's diversity index SHDI≥0	Measure of relative patch diversity

(Lienert, 2004). Fragmentation processes, the subdivision of continuous cover into smaller patches, can be linked to three components: direct removal, reduction in patch size and increasing isolation of the remaining patches (Nagendra *et al*., 2004). The set of indices selected for this study to identify land degradation was reported in Table 2 (McGarigal and Marks, 1995). The computation of indices was performed by using FRAGSTATS (ver. 3.3), the widest diffused program developed by Oregon State University for calculating landscape metrics and for quantifying landscape structure (McGarigal and Marks, 1995). FRAGSTATS provides a very comprehensive set of spatial statistics and descriptive metrics of pattern at the patch, class and landscape-levels. LPMs were executed using 16-bit binary image files and 8 neighborhood rule.

RESULTS

NDVI classification: When the mean and standard deviation of NDVI values to be found to be positive (NDVI>0 = productive lands) is considered, it was found that there was a fluctuation in NDVI value. Likewise, whereas the mean NDVI in 1975 was 0.30, it was found to have relatively increased in 1987 with 0.35. Later it went down to 0.31 in 2000. A regular decrease in maximum NDVI values was observed, in sequence, 0.83, 0.72 and 0.65. When all of the NDVI values in the intervals of -1 and +1 were examined, the mean NDVI in 1975, 1987 and 2000 were found to be, in sequence, 0.15, 0.18 and -0.07 (Table 3). When the maximum NDVI values, which represent the maximum green biomass, were examined, a decrease was revealed. With regards to general mean, it was found that there had been a decrease to a great degree in 2000.

The NDVI values of each basin were examined separately so as to see at which basin the change had been found to be higher. According to (Table 3), the NDVI values in 1987 were found to be higher than in 1975. On the other hand, far too much of a decrease was experienced in 2000. When maximum values were examined, the NDVI values in Kavacık and Gördes basins were found to constantly decrease. As the variety of the agricultural crops becomes more limited in the basin, the decrease in the amount of maximum NDVI values is considered to result from the decrease in the quality of the vegetation. On the other hand, at Ilıcak, Kumçay and Marmara Lake basins which have plain and almost plain characteristics, relatively higher maximum NDVI values were recorded in 1987. The reason for that is that the consciousness related to environmental problems has increased as a consequence of the dune problem in Kumçay basin and new policies related to deforestation started to be employed in the region.

The NDVI changes related to the periods between 1975-1987, 1987-2000 and 1975-2000 were examined to see if there were any increase or decrease (Fig. 3; Table 4). When we took the change into consideration, the decrease in the NDVI values related to the period of 1987-2000 was found to be more than that of the period between 1975 and 2000. Just opposite to that, the increase in NDVI between 1987 and 2000 was found to be less than that of the former period. When 1987 is in question, rather than 1975, the lands where the decrease was observed were the lands which were covered with *Quercus cerris* L. and *Quercus ithaburensis* sp., which are very common in the eastern part of Gördes basin. This shows us that deforestation was started there before 1987. The following times, destruction in the vegetation started to increase and the quality of the vegetation started to decrease more than before. In 2000, the lands where the NDVI increase was observed were the delta areas surrounding Marmara Lake and the dune areas in Kumçay basin. That resulted from the forestation practices in the region or attempts to reclaim land from the lake and the new vegetation species appearing in the region. On the other hand, in 2000, sharp decreases in NDVI values were generally observed in all basins.

In different studies, it has been seen that there was a relatively high correlation between NDVI and rainfall-temperature (Wang *et al*., 2001; Holm *et al*., 2003). In such

Table 3 The NDVI statistics of each basin (maximum mean and standard deviation)

	1975		1987		2000	
Basins	Max	Mean±SD	Max	Mean±SD	Max	Mean±SD
Gördes	0 83	0 22±0 08	0 71	0 21±0 11	0 65	-0 03±0 14
Kavacık	0 83	0 24±0 08	0 66	0 21±0 12	0 62	0 05±0 14
Ilıcak	0 45	0 08±0 10	0 67	0 12±0 14	0 54	-0 14±0 12
Kumçay	0 44	0 10±0 10	0 57	0 12±0 12	0 56	-0 12±0 12
Marmara lake	0 54	-0 01±0 25	0 72	0 06±0 22	0 61	-0 18±0 18
All study area	0 83	0 15±0 15	0 72	0 18±0 15	0 65	-0 07±0 16

Table 4 The NDVI changes related to the periods (1975-1987, 1987-2000 and 1975-2000)

	1975-1987			1987-2000			1975-2000		
	10	25	35	10	25	35	10	25	35
Threshold values	(%)								
Decrease	13 8	2 0	0 4	93 2	49 8	18 3	85 4	50 6	23 4
Increase	22 3	3 2	1 3	0 8	0 3	0 2	1 2	0 4	0 2
Others	63 8	94 8	98 2	5 9	49 9	81 6	13 4	49 0	76 4

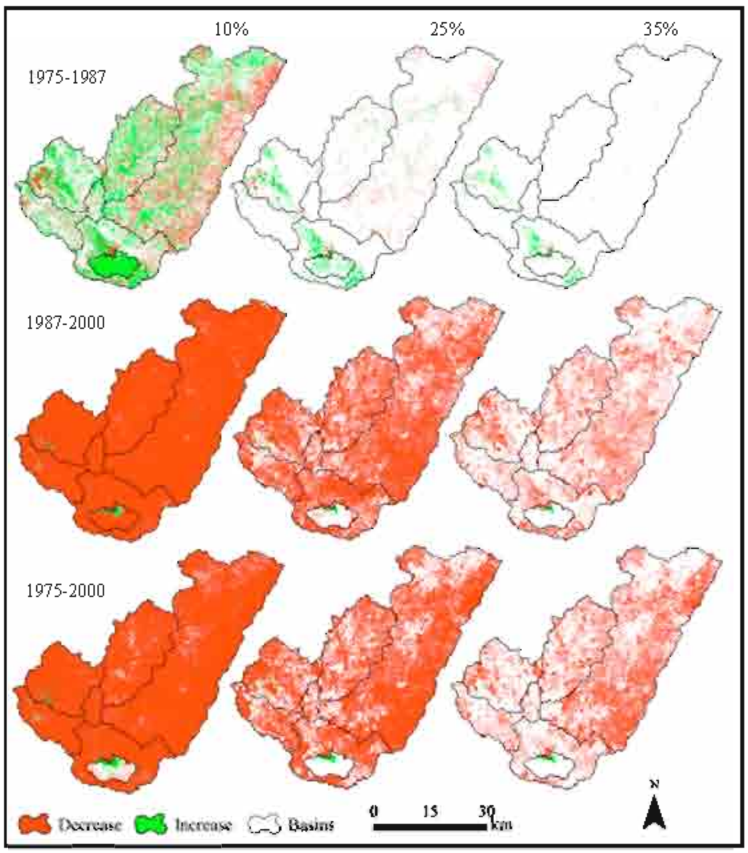

Fig. 3: NDVI difference image maps and the highlight changes image

a case, the decrease of the NDVI values in the study area also depended on the increase in the rainfall. In other words, the alteration in the vegetation between 1975 and 2000 was influenced by the changes in the amount of rainfall in the same period. NDVI values in 2000, in which a serious drought was experienced, were also found to have decreased. This shows that vegetation was seriously affected by the decrease in the rainfall in the study area. As, in 1975 and 1987, the amount of average annual rainfall was, in sequence, 556 and 570 mm, the amount of annual rainfall in 2000 was found to be just 400 mm. At the same time, in May and June in 1975-2000

Table 5: Landscape-level pattern metrics (largest patch index-LPI, number of patches-NP, landscape shape index-LSI, fractal dimension-FRAC, mean nearest neighbor distance- MNN, interspersion and juxtaposition index-IJI, Shannon's diversity index-SHDI, Shannon's evenness index-SHEI)

Basins	LPI	NP	LSI	FRAC	MNN	IJI	SHDI	SHEI
1975								
Gördes	11.5	1274	13.0	1.0	507.1	73.8	1.4	0.8
Kavacık	26.9	435	9.6	1.0	520.9	65.8	1.3	0.7
Kumçay	6.2	231	6.5	1.1	528.6	77.2	1.7	0.9
Ilıcak	7.8	347	9.5	1.0	459.9	61.9	1.5	0.8
Marmara Lake	11.6	360	9.3	1.1	508.8	68.6	1.7	0.9
1975	7.5	2484	20.3	1.0	502.7	70.2	1.6	0.8
1987								
Gördes	8.8	1445	14.2	1.0	496.2	71.2	1.4	0.7
Kavacık	22.2	542	11.1	1.0	493.5	69.4	1.4	0.7
Kumçay	10.9	261	6.4	1.0	560.3	73.9	1.7	0.9
Ilıcak	20.9	311	8.4	1.0	557.3	69.7	1.5	0.8
Marmara Lake	12.3	339	7.9	1.0	610.8	76.4	1.6	0.8
1987	6.6	2702	20.9	1.0	522.6	76.2	1.7	0.9
2000								
Gördes	10.5	1441	14.1	1.0	494.9	81.8	1.4	0.8
Kavaik	24.9	574	10.6	1.0	522.5	81.7	1.3	0.8
Kumçay	10.1	331	7.1	1.0	515.3	85.3	1.6	0.9
Ilıcak	23.1	387	9.0	1.0	496.9	81.4	1.4	0.8
Marmara Lake	11.3	391	8.5	1.0	602.9	77.7	1.7	1.6
2000	6.2	2910	21.2	1.0	504.9	77.6	1.6	0.8

period, the total amount of rainfall was above 10 mm. However, in May and June in 2000, no rainfall was reported. In 1975-2000 period, a systematic increase in the average temperature rate was found, whereas there was a systematic decrease in the rainfall. Single-tailed Pearson's correlation coefficient suggests that there was a strong significant positive association between rainfall and NDVI ($r = 1$, $p<0.01$) and a negative significant association between temperature and NDVI ($r = -995$, $p<0.05$).

Landscape pattern metrics: Although NDVI values suggest the alteration related to the characteristics of vegetation, it is quite difficult to attribute the obtained results to land degradation as a consequence of anthropological effects. Therefore, this study attempted to reveal if there was any degradation dependent on anthropogenic influences, using different landscape pattern indicators.

At landscape-level, that there was a decrease in LPI and increase in NP shows us that the area of the land in the study was found to consist of smaller parts, thus increasing the local heterogeneity (Table 5). Depending on this fragmentation, the shape of the largest patch dominating the land had either spoiled or become disorganized. At landscape-level, whereas no significant change in LPI was observed from 1975 to 2000, when we took the basin into consideration, it was observed that there was a decrease in Gördes and Kavacık basins and there was an increase in Kumçay and Ilıcak basins. The largest patches which were becoming smaller in Gördes and Kavacık basins were the ones which belonged to forest and forest-like vegetation, while the largest patches expanding at Kumçay and Ilıcak basins belonged to agricultural lands.

That FRAC is equal to 1 or bigger than 1 shows the complexity of shape of classes. The fact that no change was observed in FRAC in landscape-level demonstrates that LULC classes formally had the same environmental characteristics. The IJI scores suggest that there was not only fragmentation but increasing interdigitation of classes (Table 5). The IJI, which was found to be above 50% every year is an evidence for that LULC classes have been scattered in the landscape randomly. At landscape-level, the heterogeneity of the studied area does not show any change to a great extent because no significant change was detected in SHDI and SHEI under any type of whether conditions.

The class-level metrics are presented in Fig. 4. When the class-level metrics were examined, the dominant LULC class in the study area between the 1975-2000 periods is mixed lands. Forests follow that. However, during the study period, mixed lands, rangelands and bare exposed rocks and soils were found to decrease. It was also found that there was an increase in agricultural areas and sandy areas. No significant change related to water level was detected. However, there was a decrease in forests in 1987 and an increase in 2000 after forest policies started to change. When the largest patches of LULC classes were examined, it was observed that LPI of agricultural areas experienced a significant development, but mixed land and bare exposed rocks and soils performed a significant decrease. NP in almost all LULC was found to have increased except for water levels. It is hypothesized that NP increases in spite of the decrease in the land size demonstrates that there has been a significant increase with regards to fragmentation. Another significant change

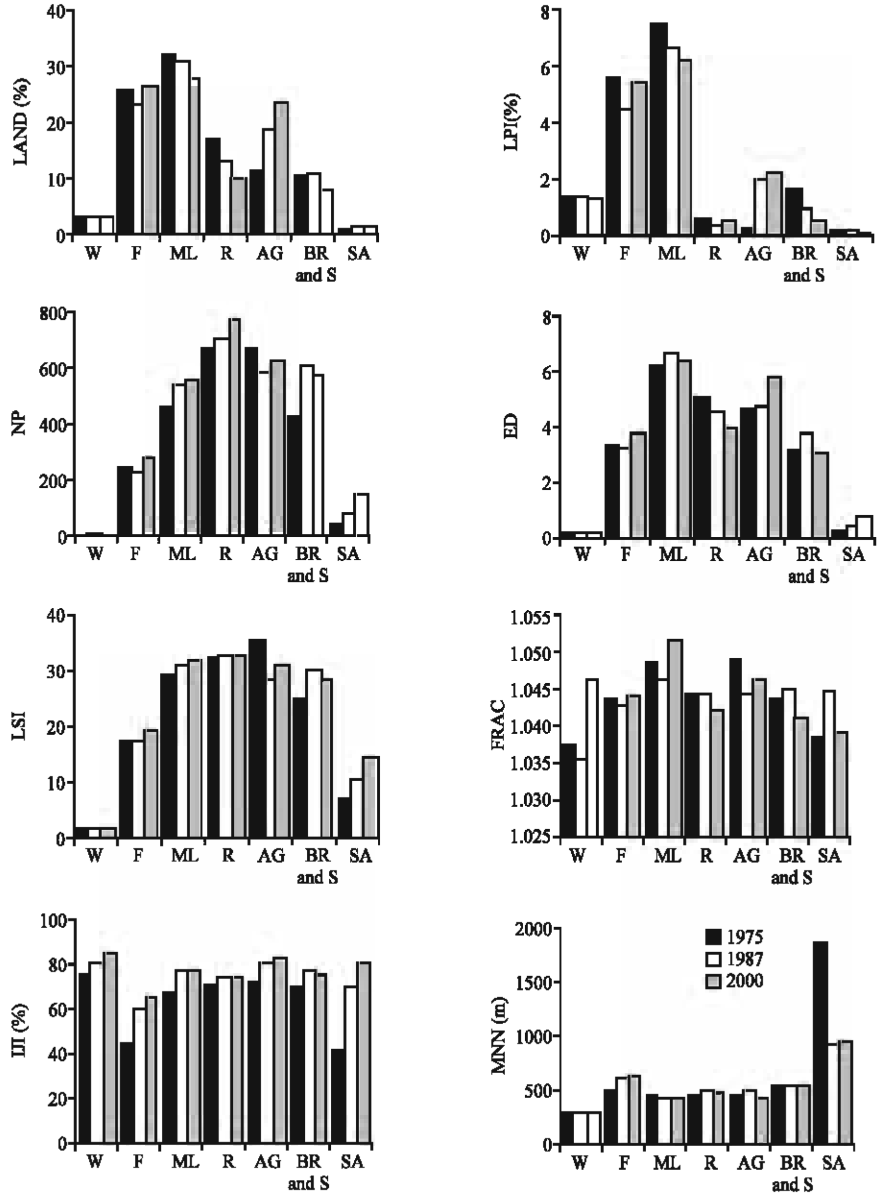

Fig. 4: Class level landscape pattern metrics (percentage of landscape-%LAND, largest patch index-LPI, number of patches-NP, edge density-ED, landscape shape index-LSI, fractal dimension-FRAC, interspersion and juxtaposition index-IJI, mean nearest neighbor distance-MNN, forest-F, mixed land-ML rangeland-R, agricultural areas-AG, bare exposed rock and soil-BR and S, sandy areas-SA, water-W)

is in bare exposed rocks and soils and sandy areas. It was also determined that there was a significant increase in the number of patches at which fragmentation also increases at these two LULC classes. The increase in LSI is an indicator of the fact that landscape patches have formally become irregular. According to this, all patches except for agricultural areas' and water's have formally become irregular. The most eye-catching one is the increase in the LSI of bare exposed rocks and soils and sandy areas. IJI experienced a significant increase, as in the landscape- level. That showed that LULC had scattered in a more controlled way to the landscape in 1975; later it was found to have scattered to the whole landscape in an uncontrolled way. Together with this increase in scattering, shape complexity was also found to have increased. MNN of the LULC classes did not change except sandy areas. It can be hypothesized that decrease in the sandy areas' MNN values was result of the increase in the areas and patches of sandy areas.

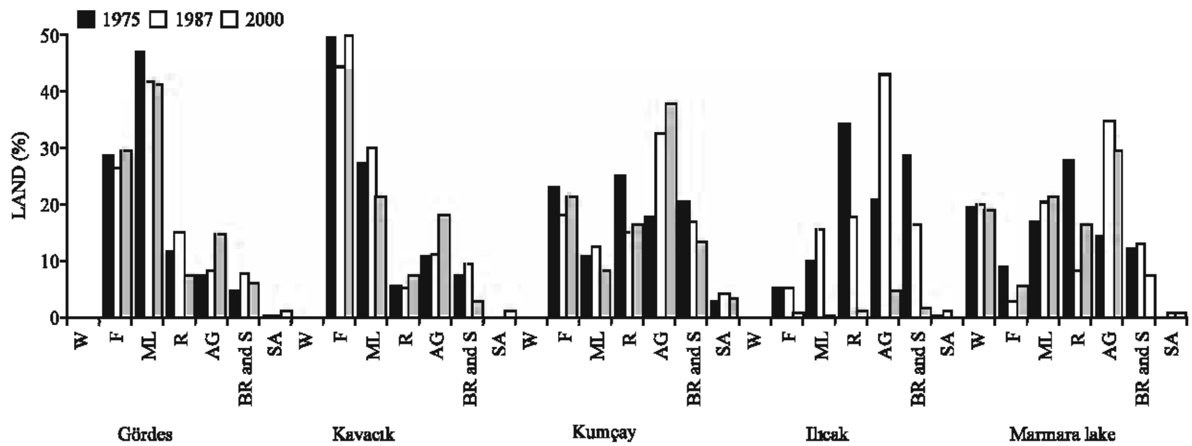

Fig. 5: Percentage of landscape (%LAND) of LULC classes of the basins

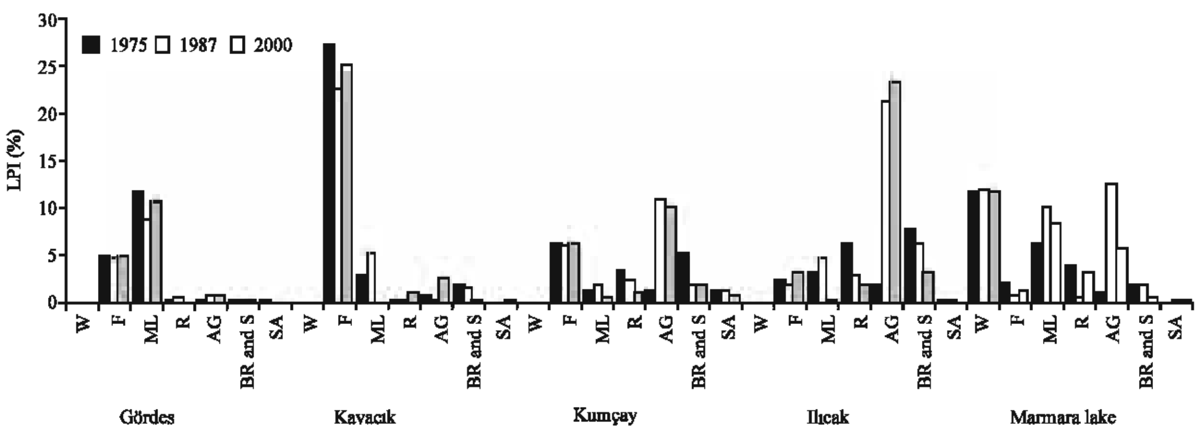

Fig. 6: Largest Patch Index (LPI) of LULC classes of the basins

When the landscape pattern characteristics depending on basins were examined to put forwards sub-basins differences, agricultural areas were found to have increased in all sub-basins (Fig. 5). This rate of increase in Ilıcak, Marmara Lake and Kumçay basins was very high. Rangelands were found to have decreased in all basins. With regards to mixed lands, all basins were found to have decreased except for Marmara Lake basin. It was also found that there was a different change in forests. Whereas there was a decrease in 1987, a partial increase was detected in 2000. Bare exposed rocks and soils and sandy areas achieved a significant increase in Gördes basin. It was found that bare exposed rocks and soils experienced a decrease in all other basins. However, an interesting development was that sandy areas, which were generally expected to decrease, always increased, although a clear decrease is expected where environmental consciousness is quite high.

When the patches (LPI) dominating the landscape were examined, it was observed that mixed lands in Gördes and forests in Kavacık have become smaller (Fig. 6). On the contrary to that, agricultural areas tend to get bigger in Kumçay and Ilıcak basins. Although the patches dominating the landscape undergo no change in Gördes and Kavacık basins, they were observed to have changed in Kumçay, Ilıcak and Marmara Lake basins. That shows that no consistency in the use of the lands existed during the study period. The only consistency observed in the study was in Marmara Lake, which is an artificial lake no more.

In general, NP tends to increase at all basins (Fig. 7). At Gördes and Kavacık basins which have high altitude, NP was observed to have increased as a consequence of fragmentation, caused by greater development of agricultural land. The fact that NP decreases in agricultural lands at other basins demonstrates that they

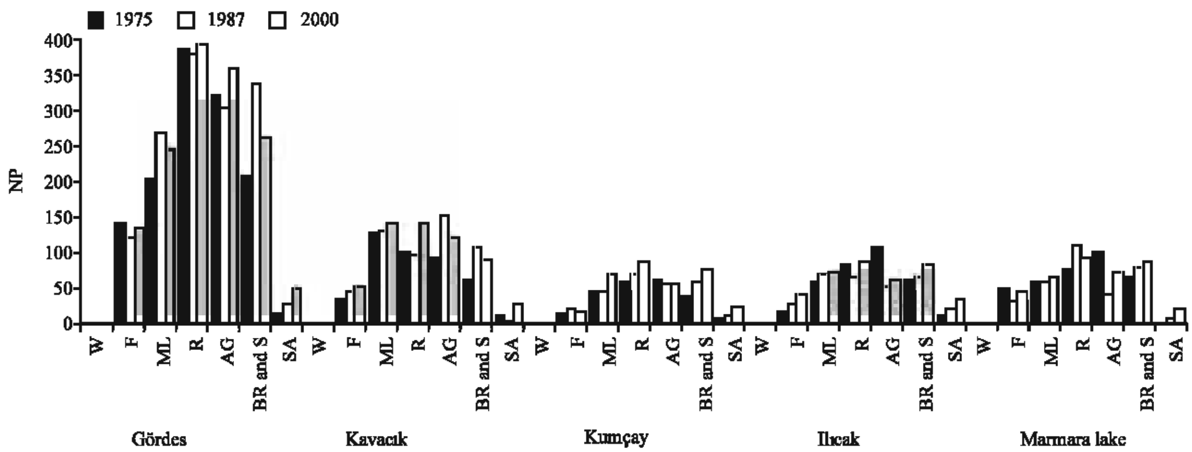

Fig. 7: Number of Patches (NP) of LULC classes of the basins

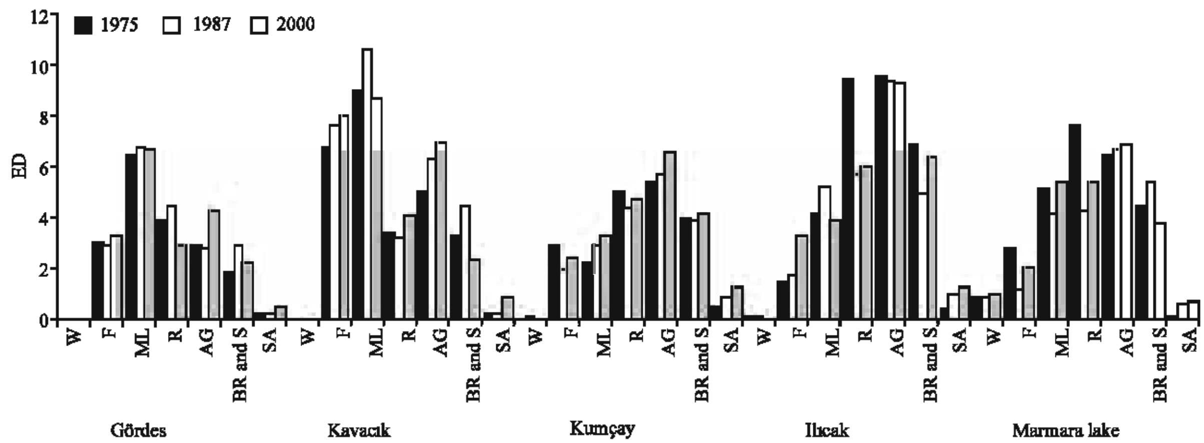

Fig. 8: Edge Density (ED) of LULC classes of the basins

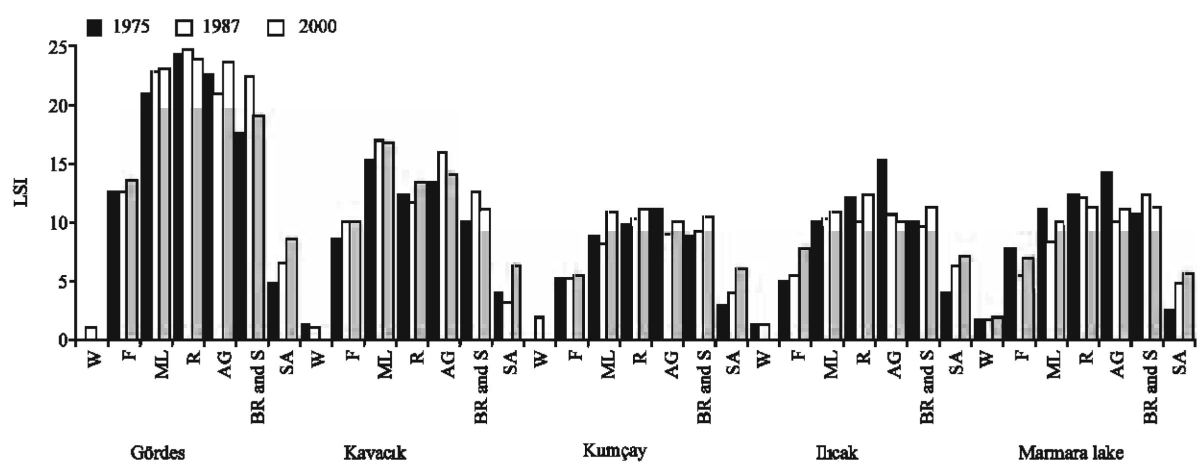

Fig. 9: Landscape Shape Index (LSI) of LULC classes of the basins

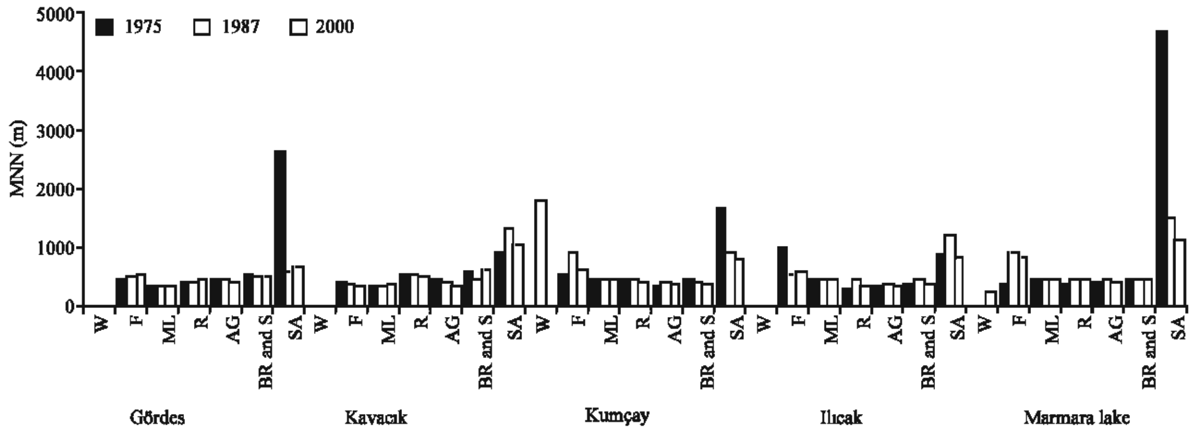

Fig. 10: Mean Nearest Neighbor distance (MNN) of LULC classes of the basins

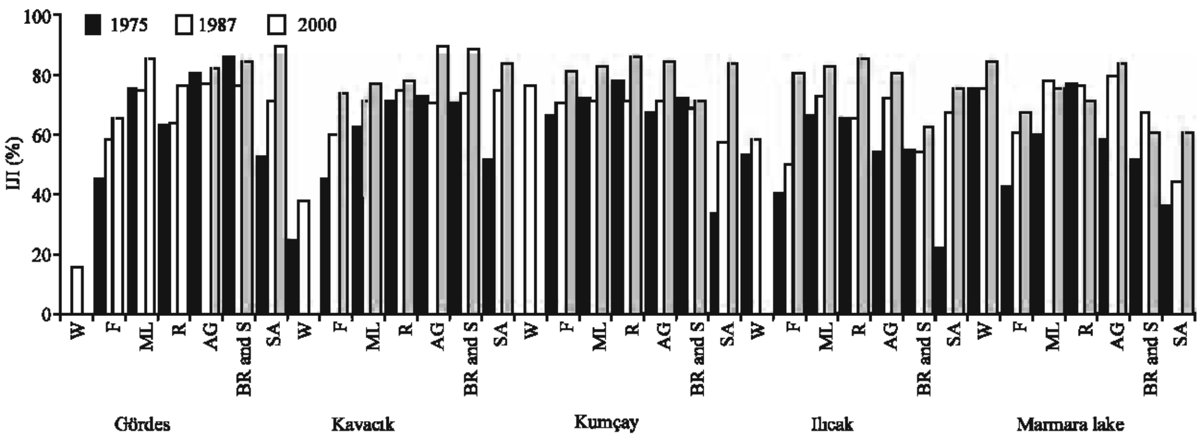

Fig. 11: Interspersion and Juxtaposition Index (IJI) of LULC classes of the basins

get bigger in size. Change in NP of forests progresses in a more complex way because it decreased in general in 1987, except for Ilıcak basins, but later started to increase, which must be as a consequence of greater environmental consciousness.

When we examined the ED (Fig. 8), it was observed that there was a constant increase in forests, agricultural areas and sandy areas, a continuous decrease in rangelands and an increase in bare exposed rocks and soils and mixed lands in 1987. The increase in forest, agricultural areas and sandy areas is as a consequence of the increase in fragmentation in LULC classes. The constant decrease in rangelands results from the too much loss in size. Healing was observed in bare exposed rocks and soils and mixed lands till 1987, then fragmentation increased as environmental damage increased.

Most important increase in LSI was in the sandy areas (Fig. 9). This shows that the patches in sandy areas in the all basins were most irregular. Also LSI values show that in the Gördes and Kavacık basins agricultural areas stared to be irregular, however in another basins shape of agricultural areas stared to be regular. This was result of deforestation and unstable agricultural areas in the Gördes and Kavacık.

MNN values, which showed the distance among the LULC classes having the same characteristics at basins level, performed almost no change (Fig. 10). The biggest change was observed in MNN of sandy areas at Gördes, Kumçay and Marmara Lake basins. The patches in sandy areas at these basins seem to have come closer. However the patches in sandy areas at Kavacık and Ilıcak basins moved away from one another as a consequence of the severe change till 1987 and then they seem to have come closer to one another. IJI increased between 1975 and 2000, indicating more uniform landscape configuration (Fig. 11).

DISCUSSION

The Mediterranean countries have been affected by the land degradation, which is a wide-spread problem in Turkey, as a consequence of the increase in population (Kapur *et al*., 2003; Atalay, 2002). The RS and GIS techniques should be used in determining this problem, expressing it quantitatively and determining the progress of the problem. In this study, it was attempted to determine the land degradation at the neighboring Gördes, Kavacık, Ilıcak, Kumçay and Marmara Lake basins, with the use of RS and GIS techniques.

In the NDVI values in which vegetation was analysed in the study area, both increases and decreases were found in 1975, 1987 and 2000. The NDVI pattern of the 1975-image was found to be greatly different from the 2000-image, which indicated that the environment in the study area had changed not only on the LULC types in some areas, but also on the quality of the same LULC. If land use remains stable, changes in NDVI reflect the trend of green biomass production that may be attributed to land quality and the success of management in dealing with variables such as climate, pets and disease. However, LPMs in the study have shown that landuse was not stable. The decrease demonstrated high land degradation, while the increase demonstrated the increase in vegetation and soil moisture. The fact that NDVI values had a negative correlation with temperature, but had positive correlation with rainfall demonstrated that drought had a significant role in the degradation in the region. However, drought did not act as the sole cause of the land degradation. It was found, with the use of landscape pattern metrics, that human factors had increased the land fragmentation at Kavacık and Gördes basins, where intentional deforestation for grazing purposes was commonplace. Between the two factors, drought on one side and anthropogenic on the other, it was believed that human activities had a greater role in the increased degradation of the basins.

The analysis, carried out in a land where environmental consciousness is very high, revealed that this consciousness was only applied to the Kumçay basin, with the sole aim of rehabilitating agricultural land in the Akselendi plain. Agricultural lands in all these basins were found to have increased. On the other hand, an increase in the NDVI values was found in dune lands at Kumçay basin and in new delta area of Marmara Lake. However, some of the most significant materials carried by the Kumçay River to the Akselendi plain, come from Kavacık and Gördes basins and consist of Neogen sedimentary formations and volcanites. This can be understood as a result of the lack of adequate precautions in the rerouting of the river and in light of the dune problem and subsequent delta growth at the edge of Marmara Lake. The analysis at Marmara Lake demonstrated that there was a corresponding decrease in lake depth. No analysis related to the degree of the degradation in the lake was performed in this study. However, it is hypothesized that there was degradation in the lake considering the results from the basins in general. The building of the Gördes dam near Çömlekçi village is another reason of the degradation of the lake, which naturally resulted in changes in material suspension, channel morphology, water temperature and water chemicals. This, in turn, affected populations of fish, water organisms and other wildlife. To this effect, the change appearing depended on the land use in the basins, the building of a reservoir and the change in the flow of the water into the lake, lead to degradation of the lake ecosystem.

In short, the most important human interference happened in 1953 when the Kumçay River was rerouted to Marmara Lake. This interference, which aimed to help the life in the region of Marmara Lake, actually increased the dune problem in the Kumçay basin. In addition, the rerouted river failed to raise the water levels and simply dumped more sediment along the shores and in the lake's growing delta. As a consequence of the above mentioned changes, this lake which had been used since pre-historic ages became an artificial lake. This demonstrates that human interference with nature can lead to very serious outcomes in the study area.

While there were attempts to stop the dune formation at Kumçay basin, which still exist, the same could not be said of the Kavacık and Gördes basins, which have a greater degree of slope. That helps solve the problems experienced at Akselendi basin temporarily. Mostly, when the environmental problems break out, rehabilitation is understood as the reclamation and extension of forest-like land. Therefore, in the study area, an increase was observed in forests, but it was observed that an equal amount of precaution was not taken in pastures and lands covered with shrub and heath lands. The field studies at Kavacık and Gördes basins helped to see that there were attempts to agricultural activities in the lands which were gained from the forest on the high slopes (Fig. 12). The fact that grazing still continued in the areas close to the woodlands, as well as in nearby, already damaged, poor grazing areas, was evidence that people were still unaware of the existence and severity of land degradation and its resulting problem of erosion (Fig. 13). It is clear here that no matter what precautions are taken at Kumçay basin,

Fig. 12: Agricultural activities in the lands which were gained from the forest

Fig. 13: Grazing and extreme land degradation

unless measures are taken for the whole of the river sub-basins, problems will not be solved, or solutions will be short-term.

LPMs indicate that fragmentation had increased especially in the lands which were full of vegetation, like bush and heath. Only in the agricultural lands, fragmentation had decreased. Sandy areas still sustained its increase, in spite of being in lands where environmental consciousness was very high. Grasslands, mostly pasturages, have been lost in the study area. It is certain that all of this increase in fragmentation and corruption in the shape of the patches, will negatively affect the fauna, flora and farms in these patches. As no former record is available to the researcher, the change could not be examined as wished. However, the related literature suggests that habitat fragmentation affects animal lives (Ims and Andreassen, 1999; Riley *et al*., 2003). In the study area, much of the landscape was fragmented by land clearing for timber and agriculture instead of by urban sprawl.

CONCLUSIONS

Two methods successfully detected the landscape changes in this study. During the period of 15 years from 1975 to 2000, the landscape (including LULC types and also quality through NDVI values) did have a great deal of change. Most of changes were detected from the areas along the Gördes and the Kavacık basins. They indicate that human activities were the main driving force of landscape change in the study area. The results obtained in this study suggest that LPMs come up with positive outcomes in land degradation studies. Besides, the indices chosen in this study were found to determine the degradation process in many LULC classes in landscape and class-level significantly, as well as in woodlands. In other words, the indices used here can be used as an input in early warning systems of land degradation or land improvement- once they are validated by field study. The results indicated that all NDVI indicators have biological meaning. The major changes are in the vegetation quality, reflected by the reduced NDVI. Comparison of the NDVI trend from 1975 to 2000 and NDVI-climate relationships show that the temperature rise and precipitation decrease is the mechanism of NDVI decrease. On the other hand, the positive correlation of precipitation and NDVI in the region indicates that the vegetation growth is limited by precipitation. It is hypothesized that the reason of NDVI decrease was still unknown, but the mixed effects of deforestation, woodland clearing can be considered. This study demonstrates to what extent GIS and RS studies are useful in the analysis of land degradation, in guiding further decisions and in revealing the sensitivity of the environment.

RECOMMENDATION FOR FURTHER STUDY

In order to obtain more accurate results, it would be necessary to have more satellite images collected during different seasons during one year. This would aid greatly in comparing NDVI values with climate data. Also it would be necessary to measure erosion risk, in order to show the effect of land degradation. Because of this, in this study area soil erosion should be calculated and compared with situ data.

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