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Satellite Monitoring of Land Cover / Land Use Change Over 15 Years and its Impact on the Environment in Gebze / Kocaeli – Turkey

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Abstract: The rapid industrialisation of an area requires quick preparation of actual land-cover/land-use (LC/LU) maps in order to detect and avoid overuse and damaging of the landscape beyond sustainable development limits. Satellite Remote Sensing and Geographic Information System technologies fit very well for long-term monitoring and assessment of such effects. As a pilot area for the use of such technologies, Gebze district near metropolitan Istanbul is considered. The study is centred on the documentation of LC/LU changes resulting from fast and mostly unregulated industrialisation and urbanisation over the period 1986 – 1998 by satellite images of the area. A comparison is made among observed patterns of LC/LU of the study area and the land-use patterns projected by the regional planning administration prepared in 1986. Fast change in LC/LU patterns overshooting the planned borders over a short time is observable. Present results may also provide an inventory of the area prior to the 17 August, 1999 Marmara earthquake.

Key Words: Satellite Remote Sensing, Geographic Information Systems, Image Classification, Land-Cover/Land-Use, Temporal Changes

Gebze – Kocaeli'nde 15 Yıllık Dönemde Arazi Örtüsü / Arazi Kullanımındaki Değişikliklerin Uydularla İzlenmesi ve Çevre Üzerine Etkisi

Özet: Bir bölgenin hızlı sanayileşmesinin getirdiği, doğal yeryüzü yapısının sürdürülebilir kalkınma sınırlarının ötesinde aşırı kullanımının ve gördüğü zararların belirlenmesi için gerçek arazi örtüsü / arazi kulanımı haritalarının hızla hazırlanmasını gerektirir. Uydularla uzaktan algılama ve GIS teknolojileri bu tip etkilerin takip ve belirlenmesinde çok uygundur. Bu teknolojilerin pilot bir uygulaması için metropolitan İstanbul'a yakın Gebze ilçesi gözönüne alınmıştır. Çalışma 1986-1998 tarihleri arasında, çalışma alanına ait uydu verileriyle, hızlı ve kontrolsüz endüstrileşme ve şehirleşmenin neden olduğu arazi örtüsü/arazi kullanımı (AÖ/AK) değişikliklerine odaklanmıştır. Belirlenen dokuları arasında karşılaştırmalar yapılmıştır. Aynı karşılaştırmalar, İl Planlama Müdirlüğü'nün hazırladığı 1986 tarihli arazi kullanım proje haritası ile de yapılmıştır. AÖ / AK 'daki çok hızlı değişimin, planlanan sınırların çok kısa zaman içerisinde aşılmasına neden olduğu gözlenmiştir. Elde edilen sonuçlar, 17 Ağustos 1999 Marmara depremi sonrası çalışmalar için, bir arşiv de sağlıyabilir.

Anahtar Sözcükler: Uydularla Uzaktan Algılama, Coğrafi Bilgi Sistemleri, Görüntü Sınıflama, Arazi Örtüsü/ Arazi Kullanım, Zamansal Değişim

Introduction

This study presents the result of joint efforts by Space Technologies Group (STG) of the Marmara Research Center (MRC) of the Scientific and Technical Research Council of Turkey (TÜBİTAK), and the Institute of Forest Management and Yield Sciences (IFMYS), University of Göttingen (Germany), on the mapping of land-cover/land-use (LC/LU) with the aid of satellite remote sensing data and geographic information systems (GIS).

Recently, remote sensing with multi-temporal high-resolution satellite data has become a strong tool for monitoring aspects such as vegetation cover, soil degradation, urban expansion and more generally for most types of land-cover/land-use (LC/LU) changes (Akça 1989; Yıldırım et al., 1995). In contrast to ground-based terrestrial data acquisition, valuable knowledge can be gained in a relatively short time and very cost-effective way.

LC/LU classification on the basis of satellite images with appropriate specifications serves as an essential database for planning and making decisions at different administrative levels. The integration of such remote sensing data into a GIS offers a wide variety of new perspectives and possibilities for the analysis, evaluation and interpretation of such data, in combination with auxiliary digital information such as digitised maps (Özel et al., 1999).

A district area in the Kocaeli Peninsula (Turkey) situated on the immediate eastern border of Istanbul Province known as Gebze was chosen as the pilot study area. Up to now, uncontrolled and unregulated construction and urbanisation/industrialisation activities have presented an unsolvable problem as regards planned and presumably sustainable development efforts in Kocaeli Peninsula and other overcrowded regions of Turkey. In the present work our aim was to document LC/LU changes resulting from such activities. By use of multi-temporal satellite remote sensing data, a comparison will be drawn between land-use patterns in different years over the selected study area and the land-use originally projected by the regional administration for the same area.

Materials and Methods

Materials

The study area, which is a parallelogram of approximate sides 7 x 15 km^2 in size and located in Kocaeli Peninsula in north-western Turkey, is approximately centred at the coordinates of (41° N, 29° E), covering the city of Gebze, a district centre with a population well over 250,000 (in the year 2000), situated half-way between the cities of Istanbul (pop. 10 million) and İzmit (pop. 250,000) (Figure 1). The following data sources were used in the analysis:

(i)-Satellite Data: Images of the region from two different satellites on three different dates were evaluated for the present purposes. These were LANDSAT-TM (August 21, 1986); SPOT-XS (June 21, 1993) and LANDSAT-TM (October 9, 1998).

(ii)-Maps: In addition, a 1:15,000 scale topographical map of the study area and a map of the projected land-use of the same area (scale of 1:25,000) provided by the Provincial Planning Administration (PPA, İl Planlama Müdürlüğü) were at hand (Figure 2). The latter was completed in 1986 and was used for comparison and deduction in the present work.

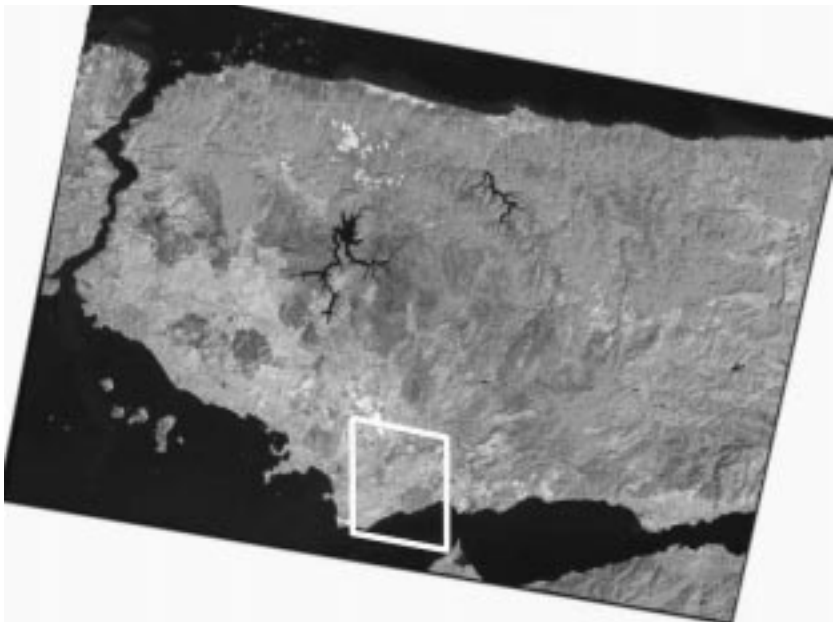


Figure 1. Location of Gebze Pilot Area in Marmara Region, on IRS Satellite Image.

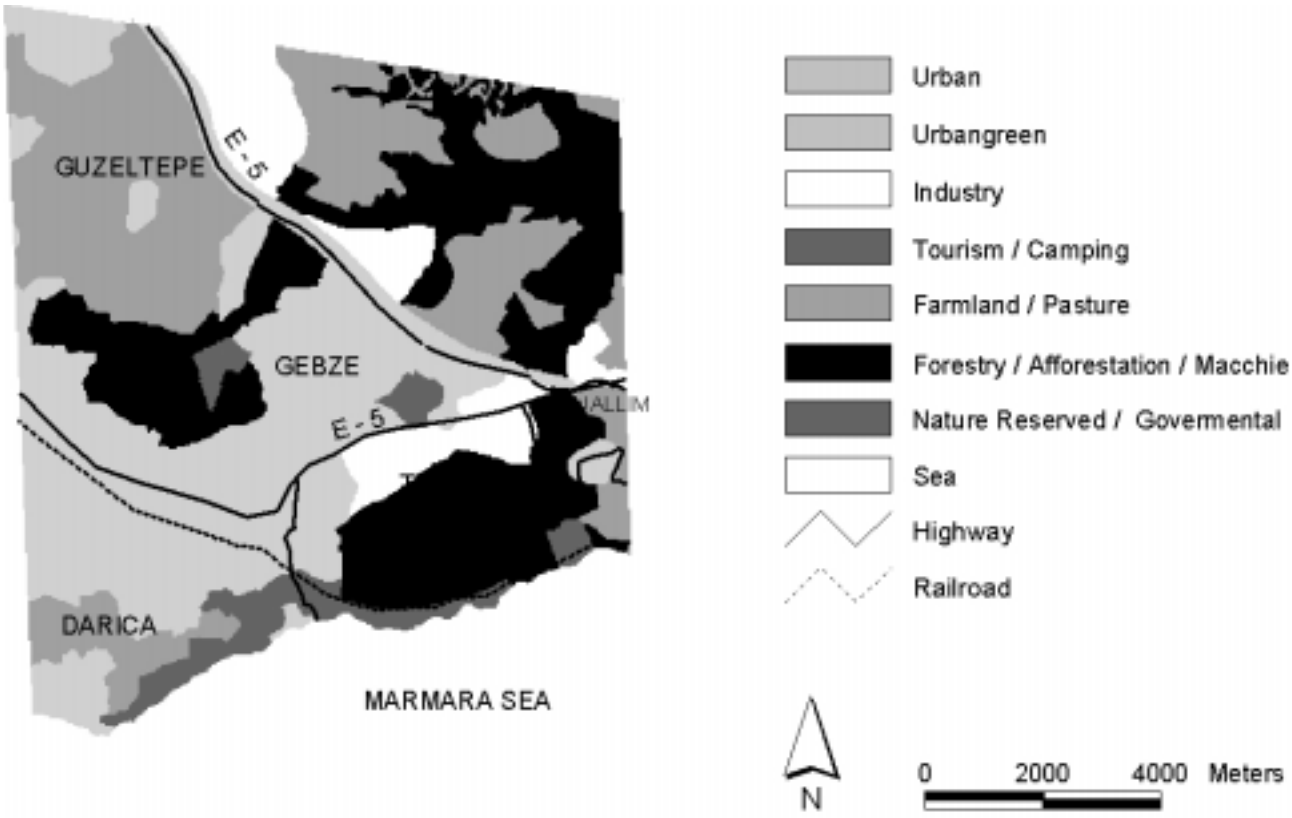


Figure 2. Land Use Planning for Gebze district prepared by local planning office in 1986.

Methods

(a) Image Processing

The image processing system 'ERDAS Imagine' was used in processing and classifying the acquired images. Geo-referencing of images was executed on the basis of ground control points, derived from 1:25,000 scale topographical maps. A sub-pixel accuracy of control-points was obtained for all satellite images by geo-referencing.

A supervised classification of images was carried out using the maximum likelihood method. This decision rule is based on the probability that a pixel belongs to a particular class with the highest probability among several possibilities. The algorithm is more computation intensive and therefore slower than most of the other classification algorithms; but the accuracy of classification is usually higher, especially in cultural, small-area heterogeneous landscapes (Huss, 1984). LANDSAT TM bands 5, 4, 3 are used in the image classification.

The actual LC/LU classification of the area was divided into the following classes:

1- Industry/Roads: The extensively sealed artificial areas covered by large buildings and asphalt roads are in this class. Assigning highways to this class was unavoidable, as their spectral signatures could not be reliably distinguished from those of the sealed industrial areas. These classes will simply be referred to as INDUSTRY.

2- Urban: This comprises purely housing areas (URBAN) or urban areas with a mixture of green vegetation cover (URBAN GREEN) and also the sectors with a mixture of both housing and commercial utilisation. These can be differentiated either visually or on the basis of the respective spectral signatures and are combined into a single class named URBAN.

3- Dense Forest: Areas covered by dense forest with relatively darker green colours.

4- Open Forest: Areas relatively sparsely covered by forest vegetation have a different signature and are

designated as OPEN FOREST. The disturbed sectors, including macchie, which is frequently found in the study area, are also in this class.

5- Pasture: This class includes pastures plus arable agricultural land. In Gebze district, pasture land-use is more dominant than the cultivation thereof. It was then decided to dispense with designating arable land as a separate class.

6- Water Surfaces: All bodies of water are in this class. This class comprises dominantly the İzmit Bay region in the south. This class of pixels are excluded from LC/LU change estimations.

The classified images were further smoothed with a 'majority filter' with a 3 x 3 kernel to eliminate 'fine' noise. Eventual class-based accuracy assessments for the analysis were performed by preparation of the contingency matrix for the classified images.

(b) Integration of Classification Results into GIS

The program package ARC/INFO was used as the geographic information system (GIS) software, for the analysis below. An overlay was subsequently executed with the classification results of all images. In the generated digital map, different land-use values were assigned to each individual pixel generated by the overlay. The continuity or the change of LC/LU could then be analysed by comparing these land-use values for different image pairs, i.e., 1986-1993, 1993-1998 and, to a limited extent, 1986-1998. A number of consistency checks of the overlays were executed prior to the analysis.

(c) Comparison with the LC/LU Planning Map of Gebze District

The map (scale of 1:25,000) prepared prior to 1986 depicting the planned LC/LU and main roads over Gebze, based on existing and projected land uses, was also digitised and integrated into the present GIS as an additional layer, permitting the evaluation of how far the actual LC/LU corresponds to the projected LC/LU of 1986.

Results and Discussion

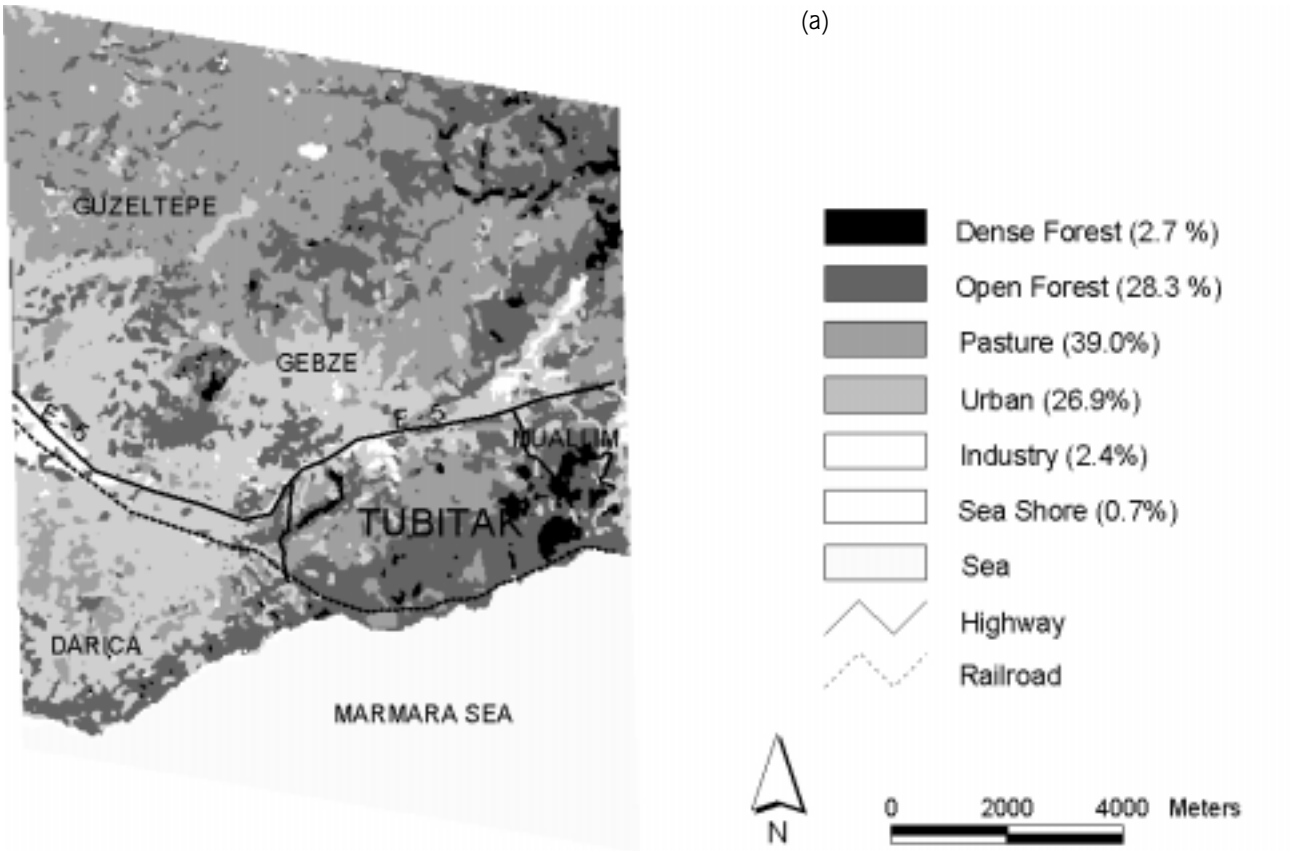
LC/ LU Statistics for 1986, 1993 and 1998

The entire project area of A = 105.5 km^2 has the size LC/LU classes for 1986, 1993 and 1998 as summarised in Table 1. The corresponding classifications can also be presented as maps, which are exemplified in Figure 3. It is clearly seen from Table 1 that in 1986 the scene is predominated by a combination of all NATURAL covers made-up of PASTURE (agricultural and pasture areas), DENSE FOREST and OPEN FOREST (the later two are also combined into 'FOREST ALL') making up a total of 70% of all land cover. LC/LU classes characterised by artificial covers and buildings (INDUSTRY plus URBAN) comprising the so-called 'MAN-MADE' coverage accounts only for 30%. Actually, the coverage INDUSTRYcomprises only a very small (≅ 3%) portion of the total area in this early phase. In the year 1993, however, we see that NATURAL coverage has decreased substantially, so that only 51% remains. In contrast, MAN-MADE classes have, in the meantime, increased and attained a percentage of 49% with more than a 50% expansion in area. Of this built-up area, the class

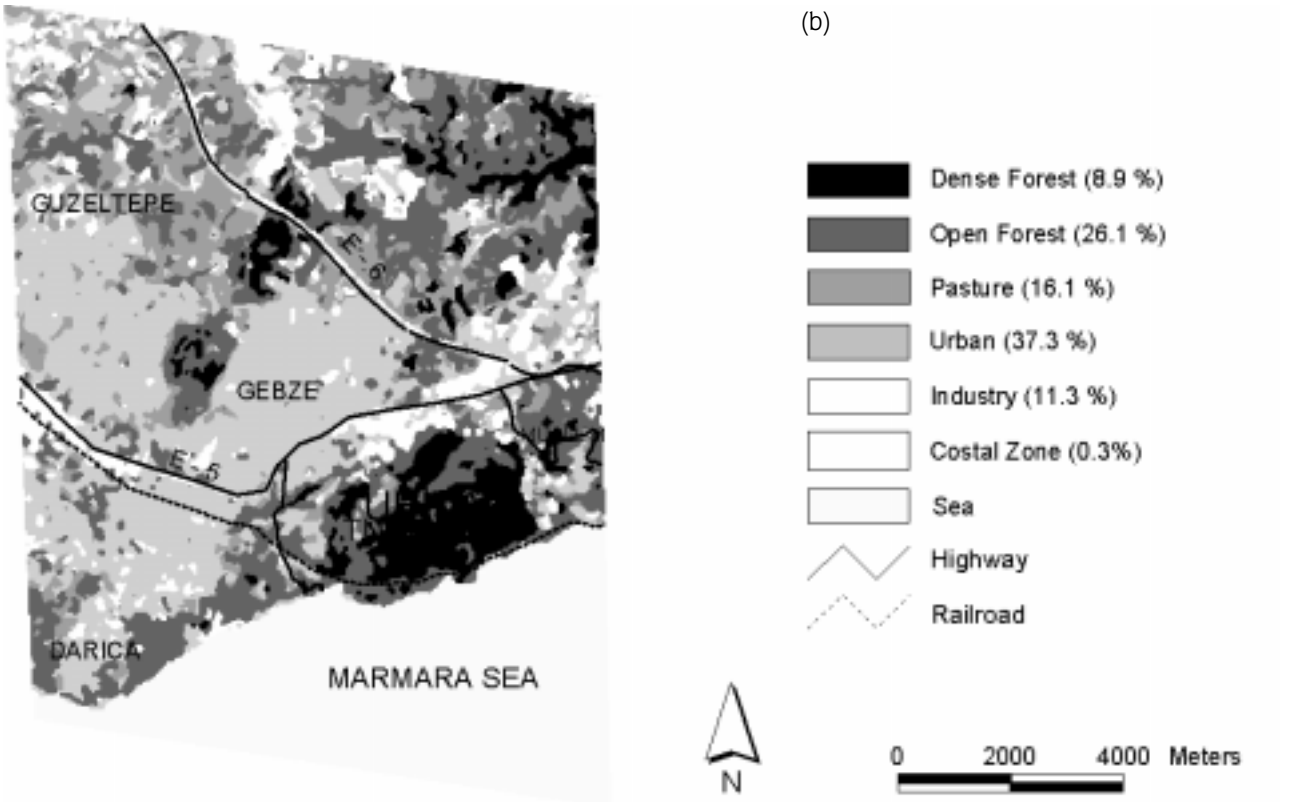
Years	1986		1993		1998	
LC/LU classes	Area (km^2)	%	Area (km^2)	%	Area(km^2)	%
URBAN	28.3	26.9	39.3	37.3	37.9	35.9
INDUSTRY	3.2	3.1	12.3	11.6	19.7	18.7
DENSE FOREST	2.8	2.7	9.4	8.9	20.8	19.7
OPEN FOREST	29.9	28.3	27.5	26.1	16.3	15.5
PASTURE	41.2	39.0	17.0	16.1	10.7	10.1
T O T A L	105.5	100.0	105.5	100.0	105.5	100.0
Combined classes						
'MAN-MADE' covers	31.6	30.0	51.6	48.9	57.6	54.6
'NATURAL' covers	73.9	70.0	53.9	51.1	47.9	45.4
'FOREST ALL'	32.7	31.1	105.5	35.0	37.1	35.2

Table 1. Sizes and percentages of LC/LU classes in the project region in 1986, 1993 and 1998 in comparison (percentages refer to the total size of the study area).

(a)


GUZELTEPE
GEBZE
E-5
E-5
MUALLIM
TUBITAR
DARICA
MARMARA SEA
Dense Forest (2.7 %)
Open Forest (28.3 %)
Pasture (39.0%)
Urban (26.9%)
Industry (2.4%)
Sea Shore (0.7%)
Sea
Highway
Railroad
N
0
2000
4000
Meters

(b)


GUZELTEPE
E-5
GEBZE
E-5
DARICA
MARMARA SEA
Dense Forest (8.9 %)
Open Forest (26.1 %)
Pasture (16.1 %)
Urban (37.3 %)
Industry (11.3 %)
Costal Zone (0.3%)
Sea
Highway
Railroad
N
0
2000
4000
Meters

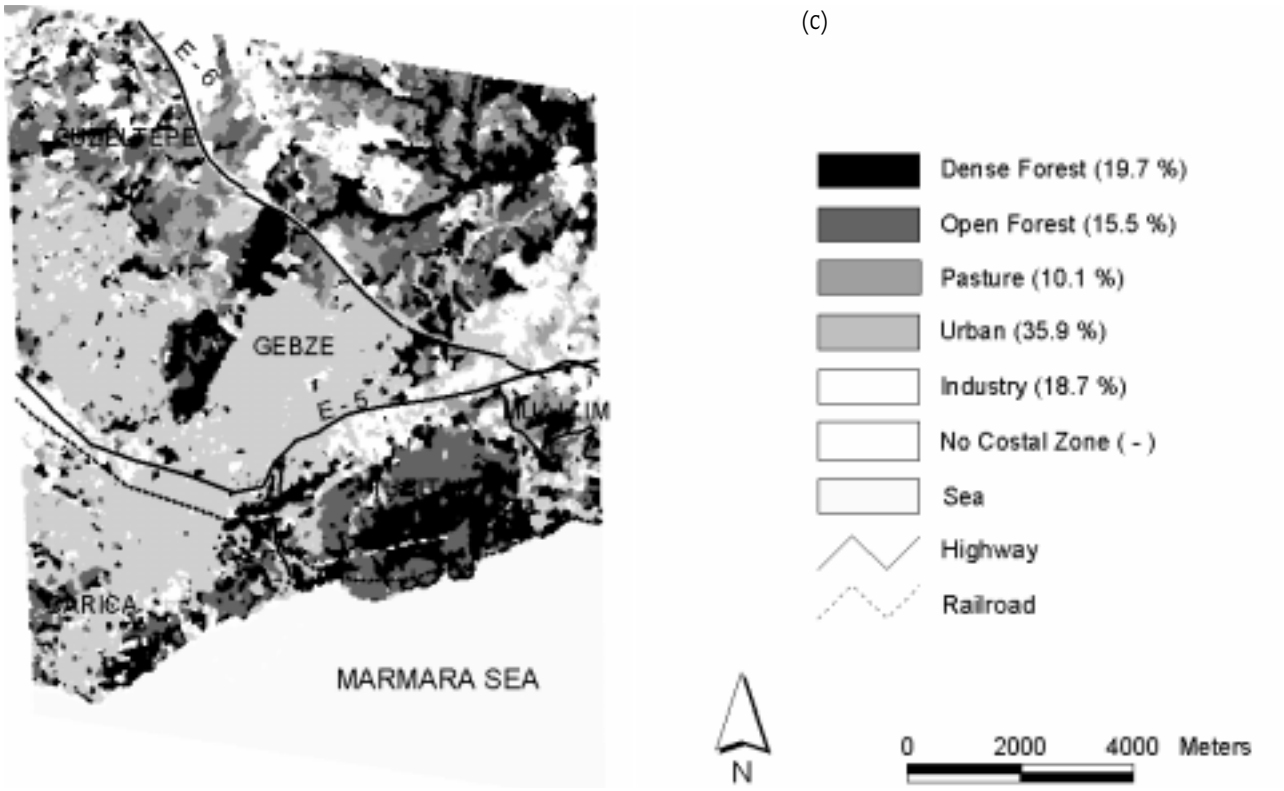


Figure 3. Classified images of Gebze pilot area by (a) in 1986, (b) in 1993 and (c) in 1998.

INDUSTRY has increased almost 4-fold (more than 12 km^2). These indicate that strong tendencies to decrease NATURAL cover and corresponding increases in MAN-MADE cover exist. The LC/LU conversions into the 3 main classes of FOREST, INDUSTRY and URBAN from 1986 to 1998 can also be followed in Figure 4 (graphically in Figure 5).

Comparison of Actual and Projected Land Uses in 1996, 1993 and 1998

The LC/LU planned prior to 1986 and then currently valid for the district was quite in line with 1986 image classification results. When it is compared with the LU/LC classifications observed in 1993 and in 1998, large deviations start emerging.

A comparison between actual LU/LC and that projected is specially executed (Table 2) for the two basic MAN-MADE classes (INDUSTRY and URBAN) whose increases, from an ecological point of view, can be considered problematic.

In detailed calculations (not repeated here) it is easily seen that of the areas actually used as INDUSTRY, only about one-fifth (21.8% in 1993, 20.5% in 1998) are to be found in regions which had been designated for industrial purposes in the LC/LU planning (which is depicted in Figure 2). For the URBAN class, the same ratios are above 50% (53.4% in 1993, 55.6% in 1998). On the other hand, 40% of INDUSTRY areas lie in regions designated for future URBAN use in 1986 planning. This ratio decreases to 22% in 1998, meaning that industry invaded other areas (such as PASTURE) during interval from 1993 to 1998.

In the class URBAN, actual land-use is somewhat more in alignment with that planned. In almost half the areas classified as such, utilisation and planning do overlap. However, here too more than 40% of the regions classified as URBAN are found to increase toward areas originally designated for either OPEN FOREST or PASTURE.

In summary, no single LC/LU class was correctly predicted even for the next 5-6 years, let alone above 10 years, except for FOREST areas, for which strong constitutional protection exists. DENSE FOREST area

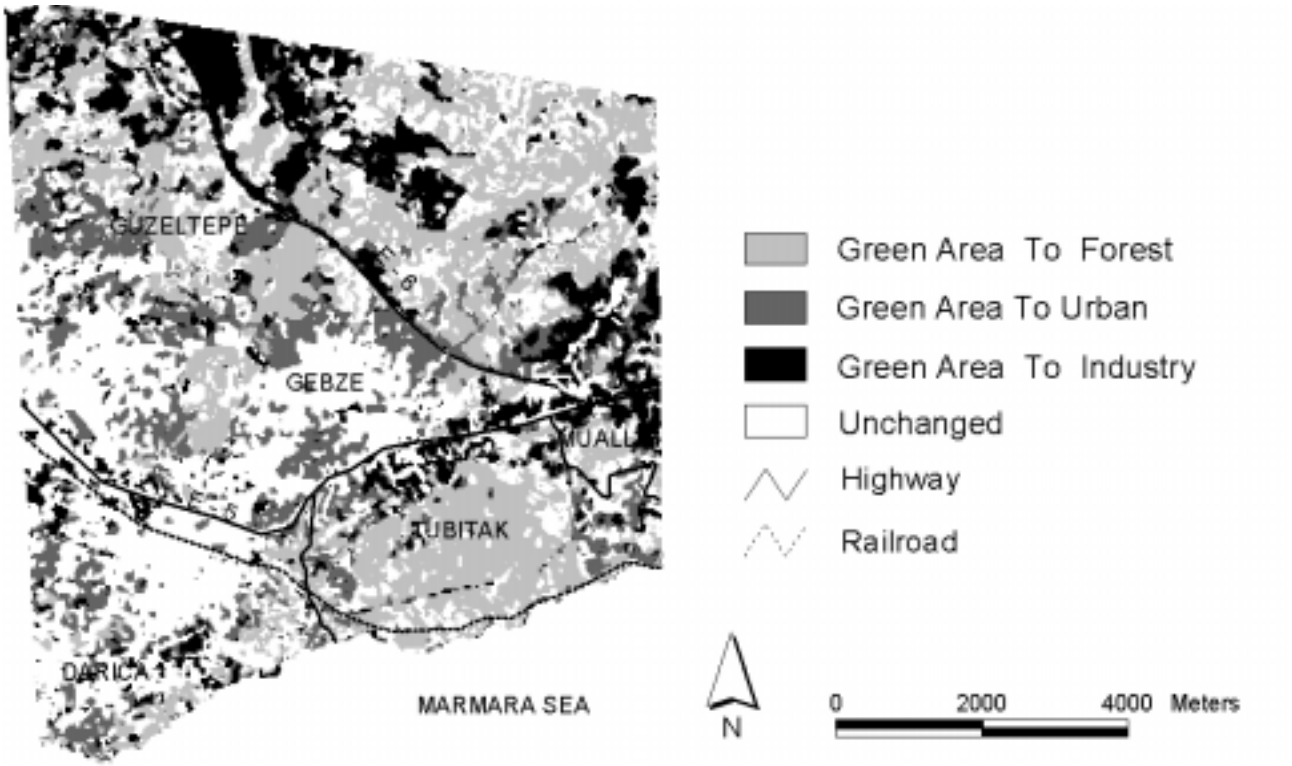


Figure 4. Conversion of LC/LU Classes into FOREST, URBAN and INDUSTRY from 1986 to 1998.

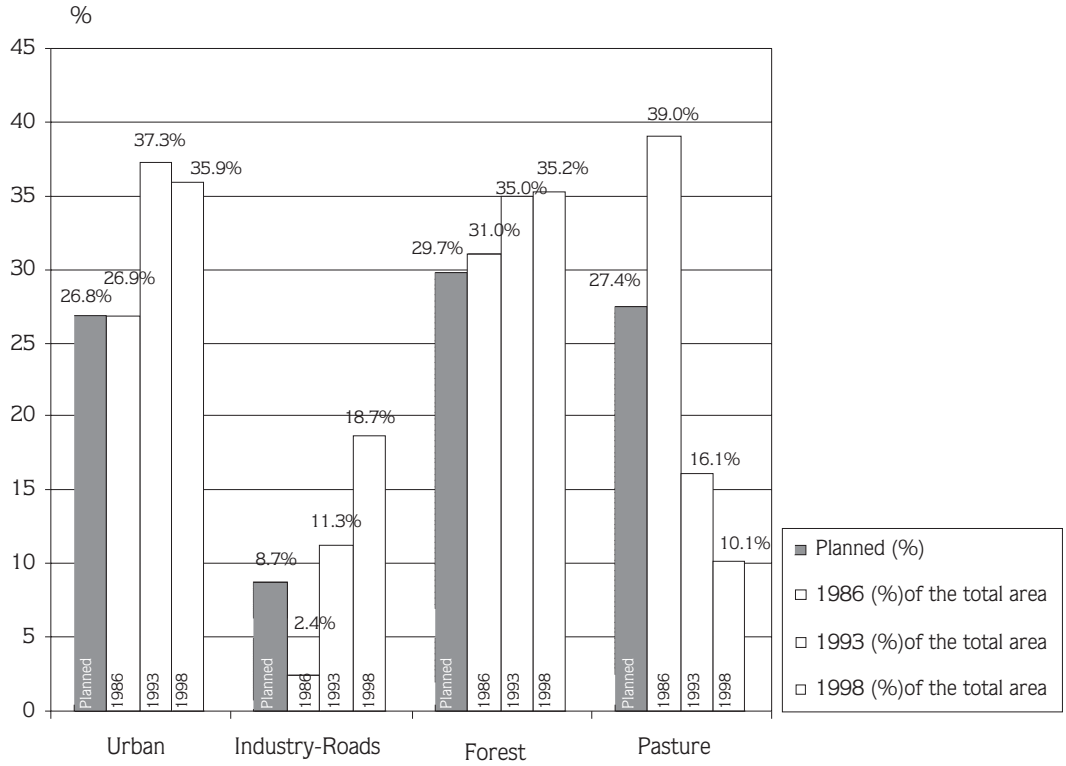


Figure 5. The LC/LU Changes in Graphical Form.

Table 2. Comparison of 1986 LC/LU planning to actual LC/LU in 1993 and 1998.

	(A): Comparison of 1986 planning to 2 main actual LC/LU classes in 1993.				(B):Comparison of 1986 planning to 2 main actual LC/LU classes in 998.			
Projected Land-Use	Actual Land Use: INDUSTRY		Actual Land Use: URBAN		Actual Land Use: INDUSTRY		Actual Land Use: URBAN	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Industry	2.6	21.8	1.7	4.8	4.0	20.5	1.5	1.5
Urban	4.9	40.6	18.5	53.4	4.7	22.0	21.1	21.1
Dense Forest	0.1	0.8	0.1	0.4	0.4	0.7	0.4	0.4
Open Forest	3.0	24.8	8.5	24.4	6.2	31.5	7.7	7.7
Pasture	1.4	12.0	5.9	17.0	4.6	23.3	7.2	7.2
Total	12.0	100.0	34.7	100.0	19.7	100.0	37.9	37.9

fluctuation in 1998 is even above the positive side and not far from the originally planned boundaries in 1986. This brings again the use and necessity of tools for timely monitoring, which may also help for correct revisions at timely intervals. Strong legal constraints also protect the natural habitat and help environmental, concerns which is the case for DENSE FOREST areas.

Contingency Table for 1998-Classification Results

Classification errors are usually assessed through a 'contingency table' (Lillesand and Kiefer, 1994). A representative case for the classification results obtained here will be given only for the year 1998 (Table 3) with one shortcoming. Here, higher resolution digitised data (5.8 m resolution IRS image taken, at about the same time as 30 m resolution TM image) were used as the 'ground truth' to estimate the 'incorrect class assignments' by the classification programs used, against the actual class values (i.e., the higher resolution IRS image). Since this is no true substitute for an extensive ground truth, results will only be indicative of general mixing trends among the LC/LU classes. However, due to the compensating nature of 'omission' and 'commission' errors involved in contingency table analysis, the estimation of 'overall accuracy' (80%) is considered rather reliable.

When the behaviour of each class in the resultant Table 3 is investigated, there were observed a number of noticeable differences in individual class behaviour: Overall accuracy of 80% is well above the producer's accuracy level for PASTURE and OPEN FOREST classes. Actually, these two are classes which can easily be incorrectly assigned to each other by the classification algorithm. For the class INDUSTRY, mixing with URBAN is also quite significant (up to 25%), while for URBAN,

Table 3. Contingency Table for 1998 LC/LU classification results.

	Urban	Industry	Dense forest	Open forest	Pasture	TOTAL	User's accuracy
Urban	41.8%	5.5%	0.9%	0.5%	0.2%	49.0%	85%
Industry	2.6%	15.8%	0.3%	0.3%	0.2%	19.2%	82%
Dense forest	1.5%	0.5%	15.4%	1.0%	0.0%	18.5%	83%
Open forest	0.4%	0.4%	3.0%	4.2%	0.4%	8.4%	51%
Pasture	1.1%	0.7%	0.2%	0.2%	2.6%	4.7%	54%
TOTAL	47.7%	22.9%	19.8%	6.2%	3.5%	100%	100%
Producer's accuracy	88%	69%	78%	68%	77%	100%	Overall accuracy: 80%

the confusion with INDUSTRY is relatively less significant (5% or so). We interpret this as being due to the fact that for a newly growing and uncontrolled industrial 'seed area', some housing near or within the same region also starts developing, thereby helping to increase confusion in the classification.

Conclusions

In summary, the following conclusions can be drawn from the above analysis:

1. Despite some uncertainties (e.g. mixing between NATURAL and MAN-MADE classes), the classification of images reveals that within a matter of years land-use developments have drastically changed from predominantly farming (pasture) and forest utilisation to that of urban-industrial use. LC/LU classes considered over the years are indicated as a bar chart for ease of visual inspection and interpretation in Figure 4. We clearly see that the pace of change (i.e., rate of industrialisation and urbanisation) has accelerated during the second interval.
2. The present extension of the MAN-MADE classes indicates that planning and timely monitoring of these classes are definitely 'problematic'. Both classes were 'out of control' in a short time interval (≤ 5 years) in the area coverage as well as in their geographical distributions. One reason for this quick and unchecked deviation is definitely the lack of the use of modern techniques (i.e., satellite images and GIS) to monitor and check the planning area. Presently, Gebze district has initiated a program for creating and using its own GIS system to control such unchecked developments (Yıldırım et al., 2000).
3. As the present exercise indicates, satellite remote sensing and digital image processing combined with information management systems form a strong and effective tool for monitoring and assessing of changes and deviations from actual plans in an economical and timely way.
4. The recent earthquake (about 1 year after the 1998 TM image used here) can be considered to have inspired new impetus for a more controlled urbanisation/industrialisation process in line with sustainable development and planning efforts. In this respect, the earthquake may have had its own unexpectedly 'positive' pressure on the use of more modern and effective techniques for LU/LC planning, management and monitoring of large areas for regional administrations.
5. Although the differences are rather minor, European Union LC/LU classification standards (Perdigo, 2002), known as CORINE, do not fully overlap with the present classification classes. The main reason for this difference is the fact that very rapid industrialisation and fast population growth in the area have dictated their own specific classes. If need arises, these classes can be converted into CORINE classes with some minor modifications.

Outlook

As the present exercise indicates, local development plans are quite hard to implement and monitor in fast-changing, developing areas without the help of modern space and information technologies. High resolution/multicolour/temporal dimensions of satellite imaging quickly help to establish the regions of fast deviations where more attention and control can be paid. Such monitoring and timely evaluation will definitely help provide more realistic, ecologically sustainable, sound implementations and timely revisions of economic development efforts.

Much more effective support to sustainable LU/LC planning is expected from the spectrally and geometrically higher resolutions of the newer generation of sensors, such as LANDSAT ETM (15 m resolution), IRS 1C (5 m resolution) and more recent IKONOS (1 m resolution) satellite imaging systems. The present study also provided the status and natural/municipal inventory of the region prior to the 17 August, 1999 Marmara earthquake and a tool to accomplish post-disaster relief and recovery efforts.

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