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Identification of Land-Cover Changes Through Image Processing and Associated Impacts on Water Reservoir Conditions

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ABSTRACT / A temporal assessment of land-cover changes of the province Beykoz in Istanbul has been documented in this article. The study focuses on the acquisition and analysis of LANDSAT 5 TM images that reflect the drastic land-cover changes between the years 1984 and 2001 utilizing aerial photographs, orthophoto maps, standard topographic maps, and ground truth measurements. The status of the province, including its surrounding villages, were examined together with more specialized maps showing only the city center and part of the province that lies within the watershed of the Elmali Drinking Water Reservoir. The land distribution profiles were also calculated for each of the images to help authorities and decision-makers to better understand the main causes of such remarkable changes and to inform them of the changing quality conditions of the reservoir. Rapid, uncontrolled, and illegal urbanization accompanied by insufficient infrastructure has caused degradation of forests and barren lands in the province, especially within the past two decades. The proximity of the province to the reservoir's watershed, downtown Istanbul, and the transportation network has accelerated the land-cover changes whose adverse impacts on the reservoir water quality are sensed. It is intended that the data gathered and processed in this study will provide a basis for future sustainable urban planning and management activities.

Introduction

This article illustrates the utility of space-borne remote sensing to detect and assess land-cover changes and relate them to water reservoir conditions in a case study. It is an applied research without any developments of methodology emphasizing the importance of the analysis performed and informing the decision-makers of the changing conditions of a province in the megalopolis of Istanbul, which has already been confronted with the problems of heavy population.

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh 1989). Timely and accurate change detection of surface features provides the basis for better understanding the relationships and interactions between human and natural phenomena to properly manage and use resources. Remote sensing data are primary sources extensively used for change detection in recent decades (Lu and others 2003).

The temporal assessment, defined as the change detection analysis with time of a region regarding its land cover, is conducted in one of the important provinces of Istanbul, called Beykoz, to determine the land-cover changes that have occurred between the years 1984 and 2001 via the use of LANDSAT TM satellite data. Istanbul, which owes its importance to its historical background and cultural, industrial, and natural characteristics, has a current population over 12 million and is one of the most crowded cities in the world. The megalopolis has an annual domestic migration in-flow of about 400,000. Including migration from all areas of Turkey, its overall annual

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population growth for 1985–1997 was 4.4%, approximately double the country's average for the same period. Between 1975 and 2000, its population increased from 3,904,588 to 10,018,735, with an annual increase rate of 6.2%. About 45% of the industrial activity in Turkey takes place in Istanbul and its vicinity. The natural resources of the city are condensed into green zones that contain the surface water resources, forests, greenery, and cultivated land at the borders of the city, particularly to the northeast and northwest. After the 1950s, Istanbul suffered social and economic growing pains due to a national mass migration to city centers and rapid population growth due to improvements in public health services and living standards (Kocabas and Musaoglu 2003). These changes have become even more noticeable within the past two decades, resulting in many environmental problems difficult to remedy.

In order to control the rapid population growth and protect the natural environment and historic values, district municipalities and the Metropolitan Conservation Council have articulated and implemented planning strategies, adopted land-use zoning bylaws, subdivision regulations, and site plan reviews. Unfortunately, rather than hindering new industrial and residential development, these regulations have, in fact, encouraged such activities, further stretching and degrading local natural resources because these developments suffer from improper and insufficient infrastructure facilities. That being said, understanding the changes that have already occurred and forecasting those that will occur is critical to solving and minimizing the resultant environmental degradation. To facilitate and accelerate this process, utilizing readily available satellite and Geographic Information System (GIS) data is highly beneficial.

Satellite remote sensing has been widely applied and recognized as a powerful and effective tool for detecting land-use and land-cover changes (Ehlers and others 1990; Meaille and Wald 1990; Treitz and others 1992; Westmoreland and Stow 1992; Harris and Ventura 1995; Yeh and Li 1997). It is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand and Kieffer 2000). It provides cost-effective multispectral and multitemporal data and converts them to information valuable for understanding and monitoring land development patterns and processes and for building land-use and land-cover datasets. Satellite imagery has been used to monitor discrete land-cover types by spectral classification or to estimate biophysical characteristics of land surfaces via linear relationships with spectral reflectance or indices (Steininger 1996). Postclassification comparison and multidate composite image change detection are the two most commonly used methods in the change detection studies that predominantly focus on providing the knowledge of how much, where, and what type of land-cover change has occurred.

Spatially accurate and timely information on land-cover change patterns that supply required information on the previous and the current state of development and on the nature of changes that have occurred can be utilized by urban planners and decision-makers in the management and planning of urban space. Thus, through repetitive satellite coverage and the integration of satellite and spatial data, land-cover change analyses can be accelerated. The need for basic land-cover information is critical to both scientific analyses and decision-making activities (Haack and others 2000; Weber and Dunno 2001). In temporal scales of decades, human-induced activities are the basic factors in shaping landscape change, some due to specific management practices and others to social, political, and economic forces that control land cover (Mendoza and Etter 2002). Assessment of the long-term impacts of land-cover change is important for optimizing environmental management practices regarding both the land and water resources (Bhaduri and others 2000). Such applications that provide image illustrations impel the necessity to urge the related regional and/or national authorities to rethink and reassess appropriate management strategies.

This article intends to document the land-cover changes of Beykoz Province by means of digital land-cover classification between the years 1984 and 2001 with the purpose of linking the spectral characteristics of the images into a meaningful information class value, which can be displayed as maps. The maps will present the utility of remote-sensing technology to assess the land-cover changes and relate its associated impacts on the nearest drinking water reservoir conditions. This study will form an applicable example emphasizing and exhibiting dominant land-cover changes due to expansions in urban areas that have had significant detrimental effects on water resource quality.

Description of the Study Area

Beykoz Province is located on the Asian side of the Bosphorous and extends toward the hills near the Black Sea coast (Figure 1). It is bounded by 29°16′ and 29°15′ east and 41°10′ and 41°14′ north coordinates and is the second largest administrative district of Istanbul.

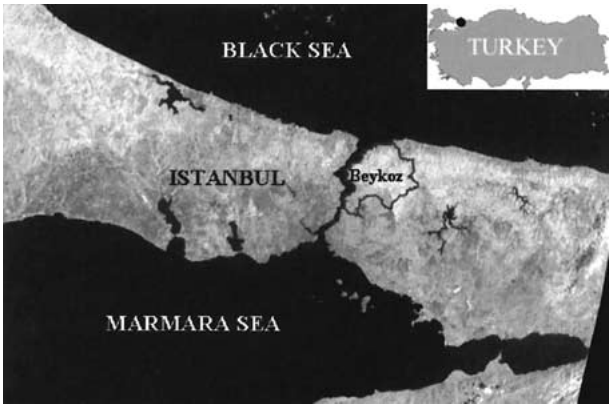

Figure 1. The location of the study area.

Land-use allocation denotes that almost 80% of its land is state-owned forest areas, 4.5% is privately owned forest areas, and 0.92% is municipality-owned land. Almost 534.42 ha of land belonging to Beykoz Province is within the boundaries of Elmali Reservoir watershed, of which 86.85 ha lie within the absolute protection zone. Beykoz is rich in rivers, forests, green areas, and cultivated land and has a wonderful sandy beach in the Riva region at the Black Sea coast. Besides, it also has spatial and geographic advantages, such as an ease of transportation, earthquake-resistant geology, natural amenities, and historic sites. The construction of the two bridges on the Bosphorous in 1973 and 1989, respectively, led to a better highway transportation network, but it also brought rapid urbanization problems around the recently constructed transportation areas within the boundaries of Beykoz Province.

The total area of the Beykoz Province together with its villages is 19.627 ha and occupied by a population of 210,832 according to the final census. Thus, the overall current population density is 10.74 cap/ha. Considering only the city center, which has an approximate area of 4370 ha, the population of 172,291 stated in the recent census recordings accounts for a population density of 39.42 cap/ha.

Between 1975 and 2000, the province was developed primarily via illegal residential settlements and partly by industrial districts (Kocabas 2003). Ancient settlements and natural areas were replaced by luxury apartment blocks to accommodate the amenity demands of high-income and middle-income groups, whereas tertiary areas were covered by squatter communities built by low-income groups. Therefore, because of these drastic changes, Beykoz has started to lose its historic and geographic purity. Moreover, forests and green areas, which are generally state-owned lands, become ever more attractive areas for urban development. In spite of the passage of the National Conservation Acts (Act numbers 2960 and 775) that declared these areas conservation zones, these developments initiated new gentrification processes in the urban areas. The resultant construction changed the hierarchy of the prestige areas in the urban zone, opened new areas to speculative activities, and created a new hierarchy of enlarged business centers. Beykoz is located adjacent to the second Bosphorous Bridge and the Trans European Motorway (TEM) at the western end of Elmali Reservoir, so the ease of transport for commuters and the natural surroundings make the province extremely attractive. The TEM especially has played an important role in encouraging the urban expansion and population increase in the Elmali Watershed (Goksel 1996; Goksel and others 2001). Similarly, a twofold increase in urban areas of Beykoz can be seen between 1984 and 2001. Most of these urbanized areas have been established illegally and without proper infrastructure. A majority of these residences only utilize individual septic tanks for domestic discharges. The effluent of domestic wastewater partially treated in septic tanks reaches the reservoir both through infiltration or surface runoff, resulting in direct and devastating water quality consequences.

Methodology Used

In the study, a variety of data, including satellite images, aerial photographs, orthophoto maps, standard 1:25000 scale topographic maps, and various thematic maps obtained from various sources, have been used as data sources together with ground truth studies that have also been conducted. Landsat TM images from June 1984, September 1992, and May 2001 were acquired and used in the analysis. The Landsat TM data have spatial resolutions of 30 m. The thermal band (6) was not used in the study because it represents emitted energy or radiant temperature and has a large spatial resolution (120 m). TM bands 1–3 represent visible electromagnetic radiation with wavelengths 0.45–0.52, 0.52–0.60, and 0.63–0.69 μm, respectively. Band 4 represents near infrared with wavelengths of 0.76–0.90 μm, and bands 5 and 7 represent mid-infrared with frequencies of 1.55–1.75 μm and 2.08–2.35 μm, respectively. The radiometric resolution of all the data was 8 bits with 256 levels of brightness.

Geometric Correction

Remote-sensing data are distorted by the Earth's curvature, relief displacement, and the acquisition geometry of the satellites (i.e., variations in altitude, aspect, velocity, and panoramic distortion). The intent of geometric correction is to compensate for the distortions introduced by these factors so that the corrected image will have the geometric integrity of a map (Lillesand and Kiefer 2000). Rectification is the process of projecting the data onto a plane and making it conform to a map projection system. Satellite images are rectified using image-to-image registration methods and are geometrically corrected to the coordinate system using the Universal Transversal Mercator (UTM) projection system with a 0.5-pixel root mean square (RMS) accuracy.

Classification

The overall objective of image classification procedures is to automatically categorize all pixels in an image into land-cover classes or themes. Normally, multispectral data are used to perform the classification, and, indeed, the spectral pattern present within the data for each pixel is used as the numerical basis for categorization. Thus, different feature types manifest different combinations of digital numbers based on their inherent spectral reflectance and emittance properties (Lillesand and Kiefer 2000). The purpose of digital land-cover classification is to link the spectral characteristics of the image to a meaningful information class value, which can be displayed as a map so that resource managers or scientists can evaluate the landscape in an accurate and cost-effective manner (Weber and Dunno 2001).

In this study, the Iterative Self Organizing Data Analysis Technique (ISODATA) unsupervised classification algorithm was used (Tou and Gonazales 1974). In the classification process, the classes were determined in accordance with Andersen Level 1 (Andersen and others 1976). To assess the accuracy of the classification, 100 random points were generated on the classified maps and compared to the correspondent at the same coordinates on the high-resolution images [SPOT PAN Indian Remote Sensing (IRS) IC] together with the utilization of ground truth measurements, orthophoto maps, and different scale thematic maps dated 1984, 1992, and 2001. The major land-cover changes and complex land-use distributions are mostly observed at locations near the city center and at the near-shore areas of Riva Creek, which forms the northeast and eastern boundaries of the province. Global Positioning System (GPS) measurements were performed mostly in the forest areas that have been converted to barren land over time so as to verify and confirm the information gathered through remote sensing. In places where no field surveys were conducted, aerial photographs and high-resolution satellite images and thematic maps were used. Figure 2 shows the ground truth locations and some selected photographs of the province.

Classification Analysis

Classification accuracy is typically taken to mean the degree to which the derived image classification agrees with reality or conforms to the ‘‘truth’’ (Campbell 1996). It covers the comparison of the results obtained from a digital classification of the known identity of land cover in test areas derived from a reference area. Accuracy assessments determine the quality of the information derived from remotely sensed data (Congalton and Green 1999).

Classification analysis in the study denotes that an accuracy of 84% for the images of years 1984 and 1992 and of 80% for year 2001 was reached. The higher accuracy attained in 1984 is due to the fact that the region had not been significantly urbanized and densely populated and most of the area has been devoted to forests. The image from 1984 is for June, representing a period that reflects the barren land covered with natural vegetation cover either as agricultural land or forest, which can be considered another reason for not obtaining a much higher accuracy level. The image of 1992 is for September, where even though the barren and agricultural land had no natural vegetation cover, it led to confusion with areas of newly developed residential sites, resulting in an accuracy of 84% in the classification. The image of 2001 is for May, where most of the barren land was covered by natural vegetation, which caused a mixing of barren land with agricultural land. In some locations, it is also understood that barren land without natural vegetation cover is mixed with urban land and resulted in lesser accuracy compared with the other image classifications. The results of the overall accuracy are tabulated in Table 1.

Land-Cover Changes

Land-cover changes experienced in Beykoz Province are clearly observed in the processed satellite images. A step-by-step evaluation of the images allows one to better understand the cause-and-effect relationship regarding the land-cover changes over time. Figures 3A–3C indicate the areas of interest in each of the three steps. Figure 3A considers the province together with its villages, which has a total surface area of 19,627 ha. Figure 3B takes into account only the city center of the province with an area of 4370 ha. Moreover, as mentioned previously, part of the province lies within the watershed boundary of Elmali Reservoir. Almost 540 ha of the province land are within the watershed of the reservoir, of which 157 ha lie within the absolute, short, and

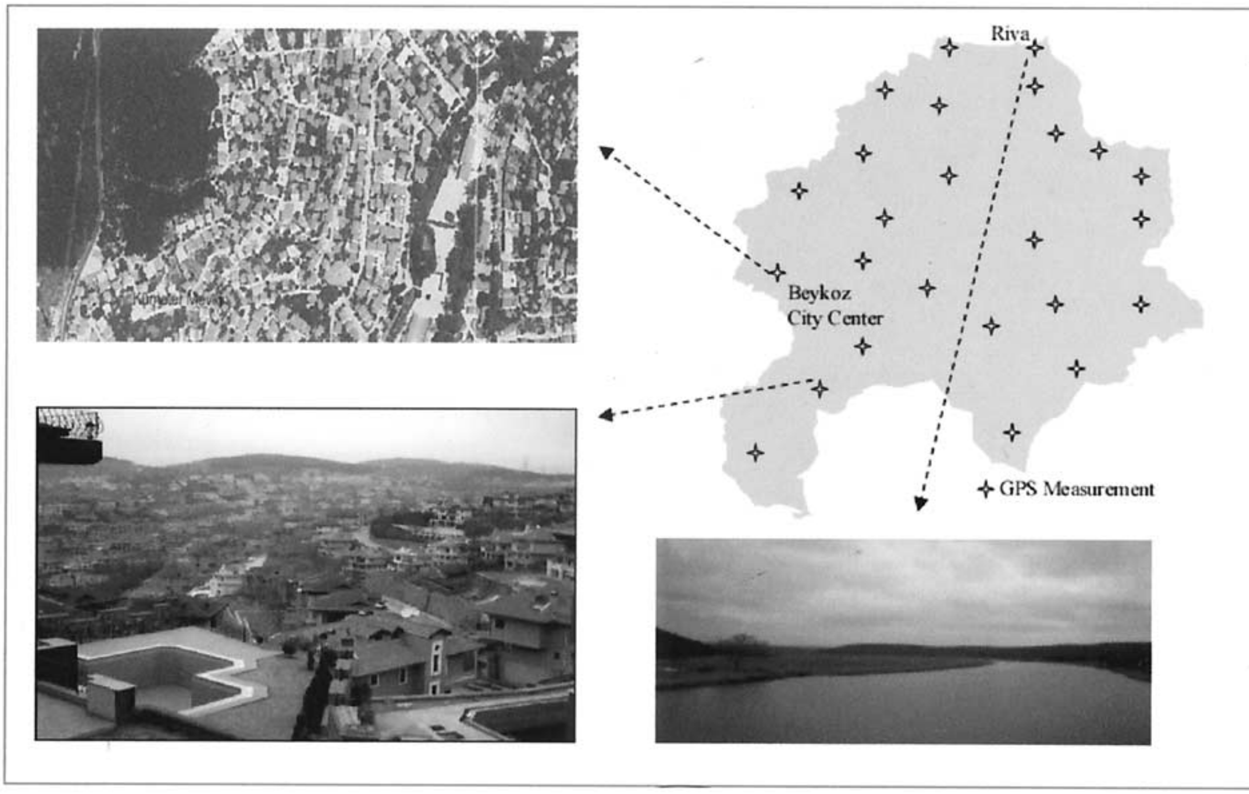

Figure 2. Ground truth locations and selected photographs of the province for year 2000.

Table 1. Classification accuracy results for (a) 1984, (b) 1992, and (c) 2001

Class name	Reference totals	Classified totals	Number correct	Producers accuracy (%)	Users accuracy (%)
(a)					
Forest land	45	51	44	97.78	86.27
Barren land	13	5	5	38.46	100.00
Agricultural land	26	25	20	76.92	80.00
Urban land	16	19	15	93.75	78.95
Totals	100	100	84		
(b)					
Forest land	60	58	53	88.33	91.38
Barren land	2	4	2	100.00	50.00
Agricultural land	9	6	5	55.56	83.33
Urban land	29	32	24	82.76	75.00
Totals	100	100	84		
(c)					
Forest land	24	29	24	100.00	82.76
Barren land	20	14	13	65.00	92.86
Agricultural land	24	14	12	50.00	85.71
Urban land	32	43	31	96.88	72.09
Totals	100	100	80		

Note. Overall classification accuracy 80.00% for 1984, 84.00%,for 1992, and 80.00% for 2001.

medium protection zones. The rest belongs to the long-range protection zone. Figure 3C refers to the part of the province that lies within the watershed boundaries.

The land-cover changes over time will be evaluated based on the parts of the region indicated in Figure 3, starting from the more general evaluation to the more

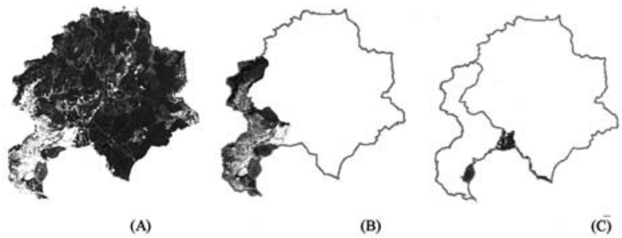

Figure 3. (A) Beykoz Province, (B) Beykoz city center, and (C) part of the province that lies within the Elmali Watershed boundary.

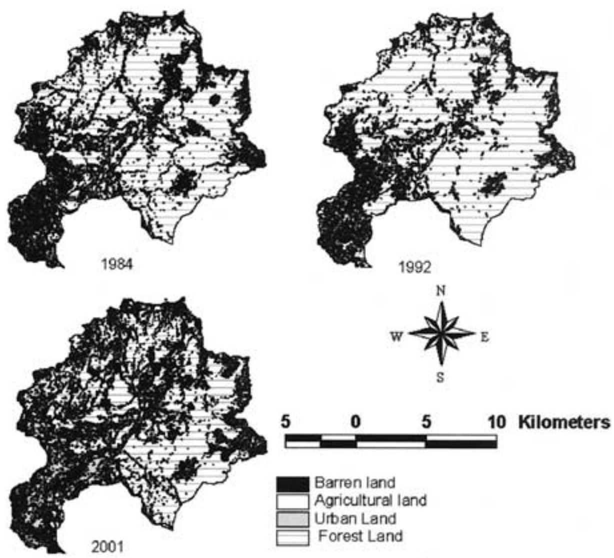

Figure 4. Classification results of Beykoz Province together with its villages.

specific areas of interest. In this manner, land-cover changes will be both reflected and tabulated in detail.

Figure 4 presents the image classification of the province for the selected years and Table 2 refers to the related land-cover distribution. It can be stated that a comparatively more significant variation in land cover has occurred between 1992 and 2001. Although there appears to be minor differences between 1984 and 1992, a 2% increase in forests has been monitored with a 3% decrease in unoccupied land and a 5% decrease in agricultural land and greenbelts, pointing out that such areas will be rapidly and illegally occupied by the inhabitants and the migrating population. The decline of forest areas resulted from establishment of new residential areas within forest areas. Figure 5 shows two aerial photographs of recently established residential sites within these forest areas and accurately typifies the forest destruction in Beykoz Province.

Table 2. Yearly land-use distribution in Beykoz Province

	Distribution		
Land-use	% in 1984	% in 1992	% in 2001
Forest land	76	78	60
Barren land	8.3	11.3	16
Agricultural land	15	10	10
Urban land	0.7	0.7	14

Evaluating only the city center of the province without taking into account the surrounding villages, a similar decline in forest areas and a huge increase in urbanized areas are observable, as reflected in Figure 6 and tabulated in Table 3. Urbanization activities date back to periods prior to 1992 and a total of a twofold increase is seen between years 1984 and 2001, urbanization efforts not withstanding. Forest areas decreased considerably after 1992, whereas agricultural land and greenbelts again gained interest.

As seen in Figure 6, the TEM, connecting the two continents via the second Bosphorous Bridge, passes through the province boundaries and is clearly seen (lower right) in the image for the year 2001, which is considered to be the main cause of the remarkable land-cover change in the district after its construction.

In the third step, the area of the province that lies within Elmali Watershed is considered. The corresponding land-cover patterns are illustrated in Figure 7 and are tabulated in percentages in Table 4. Watersheds have thus far been attractive especially for urbanization activities in the world where the transportation facilities are satisfactory and sufficient. This province, having the advantageous characteristics of transportation facilities, proximity to the metropolitan area, and nearness to a water resource, has already fulfilled all its positive impacts toward urbanization despite the legal acts against dense population. It is a typical example of how humans tend to settle near areas enriched with a freshwater body and transportation network.

The forest areas in part of the Elmali Reservoir Watershed have already diminished by one-half between 1984 and 2001, whereas the urbanized areas increased almost tenfold. The distribution of barren land in the city center and in the watershed presented significant 12-fold and 8-fold increases, respectively, reflecting the tendency toward urbanization. This utilization of conserved land like forests is a serious environmental problem and water quality threat that requires urgent consideration by decision-makers and municipal authorities. A general discussion of the

Figure 5. Aerial photographs for year 2000 showing the recent established residential sites within forest areas.

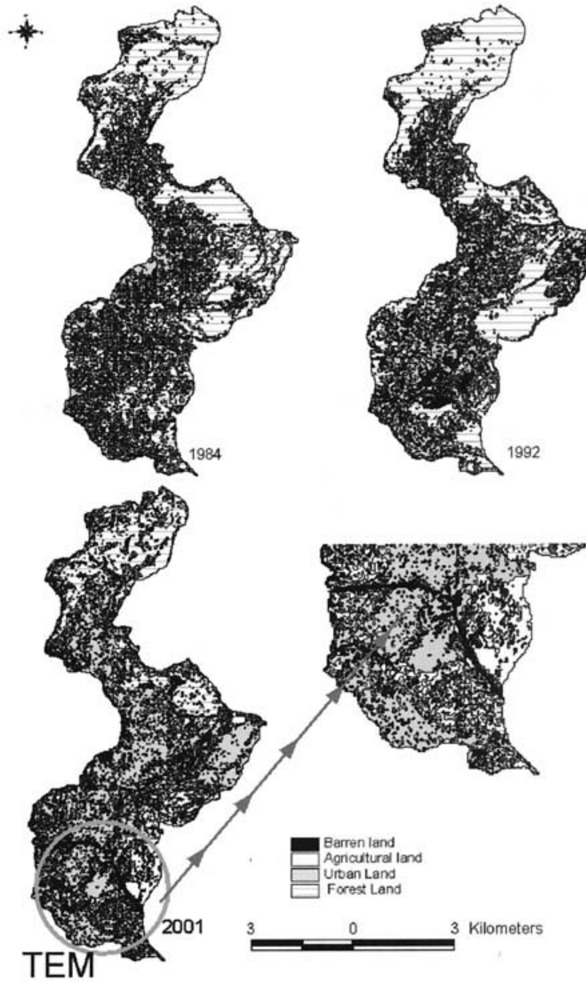

Figure 6. Classification results of Beykoz city center.

agricultural land available in all the three stages of evaluation shows that no significant changes have occurred in arable land. Unfortunately, humans typically and unknowingly spoil forest areas rather than relatively underproductive agricultural land to establish residential areas.

Land-cover classifications, especially in the absolute, short-range and medium-range protection zones of the Elmali Reservoir Watershed that lie within Beykoz Province, are given in Table 5. As presented in the table, the urban areas have doubled between 1984 and 2001 despite protective legislation. The rapid, unplanned urbanization has lacked proper infrastructure, so the negative impacts on the water quality of the Elmali Drinking Water Reservoir are so great that advanced water treatment facilities have been recently constructed adjacent to the reservoir as per requirements (Beler Baykal and others 2000).

Table 3. Yearly land-use distribution in the Beykoz city center

	Distribution		
Land use	% in 1984	% in 1992	% in 2001
Forest land	57.9	52.1	30
Barren land	0.1	7.9	12
Agricultural land	24	11	17
Urban land	18	29	41
Total	100	100	100

It is also interesting to note that the TEM passes through the absolute, short-range, and medium-range protection zones of Elmali Watershed, which is clearly shown in Figure 8 as an IRS image. Apart from the pollution of the reservoir by the partly treated domestic wastewater discharges, atmospheric deposition because of the vehicle traffic of the TEM also adds to the pollution load of the reservoir (Gonenc and others 1995). Establishment of both the TEM and adjacent development has greatly affected the pollution profile of the reservoir.

Impact of Land-Cover Change on the Water Reservoir Quality

The overall prevailing situation of Istanbul's drinking water reservoirs and their watersheds will be briefly detailed to give better insight into management activities prior to forming a link between land-cover change and associated impacts on the reservoir water quality of the piloted area.

Over 90% of the water demands of Istanbul are currently supplied by seven drinking water reservoirs, four

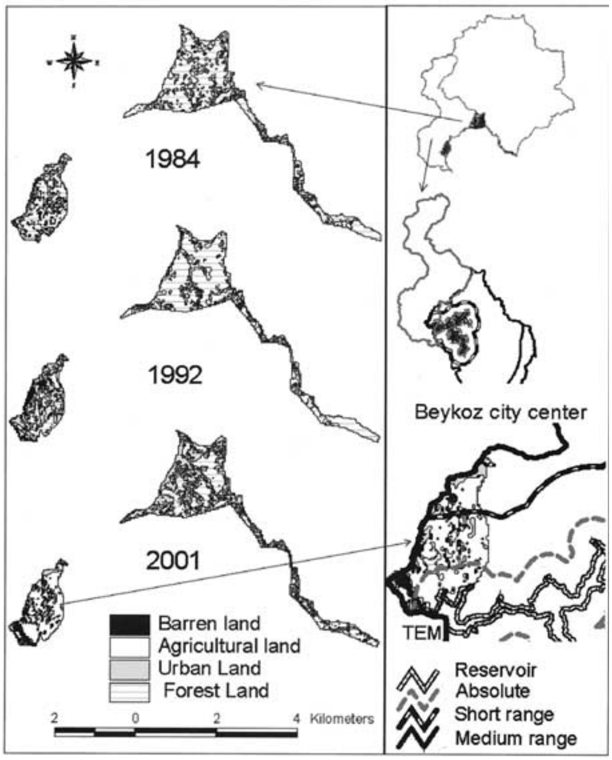

Figure 7. Land-cover change in part of the Elmali Reservoir watershed that lies within Beykoz Province.

Table 4. Yearly land-use distribution in part of the Elmali Reservoir Watershed that lies in Beykoz Province

	Distribution		
Land use	% in 1984	% in 1992	% in 2001
Forest land	74.2	60.5	33
Barren land	0.2	3.5	8
Agricultural land	22	20	32
Urban land	3.6	16	27
Total	100	100	100

Table 5. Yearly land-use distribution in the absolute protection and medium protection zones of the Elmali Reservoir Watershed that lies in Beykoz Province

	Distribution		
Land use	% in 1984	% in 1992	% in 2001
Forest land	54	40	38
Barren land	31	37	33
Agricultural land	15	23	29
Total	100	100	100

of which are located on the European side and three on the Asian side of Istanbul. Figure 9 shows the location of these reservoirs: Terkos, Buyukcekmece, Alibeykoy, and

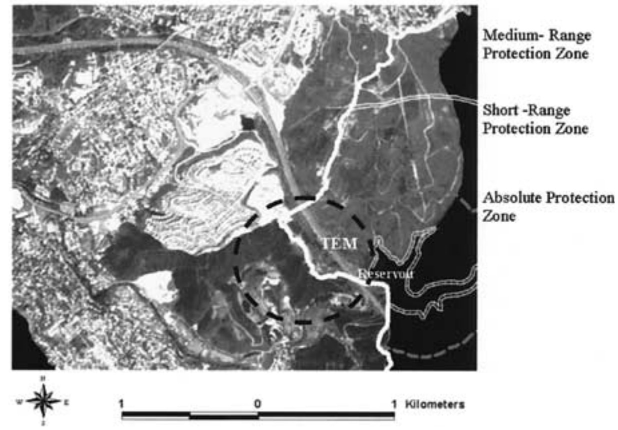

Figure 8. IRS image of the Elmali Reservoir watershed that lies in Beykoz Province.

Sazlidere reservoirs are on the European side, and Omerli, Darlik, and Elmali are on the Asian side.

Monitoring and management of the reservoirs and related watersheds are conducted by the General Directorate of Istanbul Water and Sewerage Administration (ISKI). According to the revised regulation of ISKI for watershed protection and management dated February 21, 2003, the maximum population densities of the residential sites within the boundary of each of the drinking water watersheds are stated. For Beykoz Province, the maximum population density is stated as 30 cap/ha (ISKI 2003), which is more than the referred value of 39.42 cap/ha.

Within the context of the National Water Pollution Control Regulation (WPCR) dated 1988 and of ISKI's revised watershed Protection and Management Regulation of 2003, protection zones are defined around the water reservoirs intended for water supply:

Absolute protection zone: the band from the water surface to 300 m

Short-range protection zone: the band from 300 to 700 m

Medium-range protection zone: the band from 700 to 1000 m

Long-range protection zones: the band from 1000 m to the ridge of the watershed

The WPCR also states the activities that are both permitted and prohibited in these bands, along with some protective measures toward pollution control. The regulations allow no permanent settlements or industrial activities in the absolute and short–range zones. Starting from the medium-range protection zone, very low densities of single houses under special measures and construction restrictions are permitted.

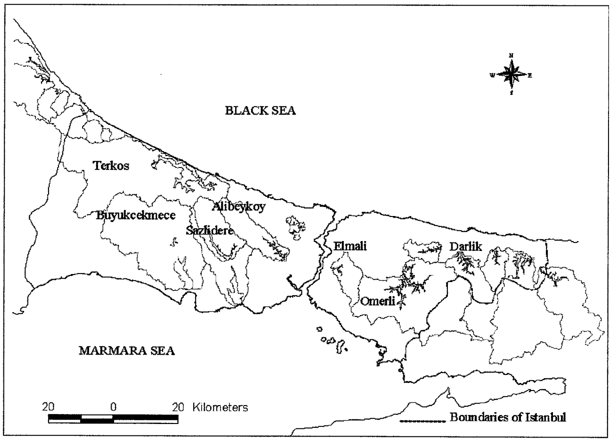

Figure 9. Location of the drinking water reservoirs of Istanbul.

However, as demonstrated by the current situation in the Elmali Watershed, the rules have already been broken. No new developments, either industrial or residential, are permitted and as many of the old ones as possible are to be removed from the watershed. However, if this is not possible, they might be permitted to remain in their current location by taking pollution control precautions so as to comply with the stringent standards.

Table 6 summarizes the characteristics of the Elmali Watershed and its settlements, population densities, and industries according to the stated protection zones.

The current situation of the Elmali Reservoir is comparable to the other reservoirs of Istanbul: already deteriorated both in terms of land and water resources. A ranking system is used from the highest/worst to the lowest/best in terms of numerical values with regard to population, population densities, percentage of the total settlement and industrial areas representing urban land use, number of industries, general quality, and trophic status of the reservoir water. Elmali Reservoir is found to be in the worst situation regarding the population density and distribution of total area devoted to settlements. Such an urbanization profile with insufficient infrastructure has, as anticipated, a direct negative effect on the overall water quality class and trophic status of the reservoir by being ranked in the first row. Only for the establishment of industries, Elmali is ranked in the fourth row (Beler Baykal and others 2000).

Similar to the European Community receiving water standards, in the Turkish Water Pollution Control Regulation (WPCR 1988), inland waters are divided into four groups with the following recommended beneficial uses (Beler Baykal and others 1996):

Class 1: High-quality water (drinking water supply after disinfection, recreational uses, trout breeding, animal breeding, and farm requirements)

Class 2: Slightly polluted water (drinking water supply after traditional treatment, recreational uses, fish breeding other than trout, irrigational uses after current irrigation water criteria are satisfied, all other uses apart from the ones listed in Class 1)

Class 3: Polluted water (industrial water supply except for those areas requiring high quality such as food and textile industries, after suitable treatment)

Class 4: Highly polluted water (surface waters of lower quality than the above-listed classes). The impact of land-based pollution arising from both point and nonpoint sources on the receiving water quality is observed and correlated by various works conducted on water quality monitoring and management. Implication of a change in land cover represents a method that can be utilized to enhance the availability of the receiving water for meeting the future projected needs. It is certain that nature and scale of hydrologic implications depend on the form of the land-cover change and the climatic context as referred by Benitez and others (2001). It has been stated that between 1984 and 1994, the overall water quality of Elmali Reservoir was maintained at Class 2; however, from 1994 onward, it has reached to Class 3 quality and even tended toward Class 4 characteristics, especially in terms of trophic criteria after 1997 (Burak and others 1997; Tanik and others 1999). Beler Baykal and others (2000) conducted a detailed study on the water quality classification of Istanbul's reservoirs based on both WPCR and German Technical Standards. The conclusion derived from the study was that the Elmali Reservoir had the worst quality conditions among the other reservoirs of the metropolis and that advanced treatment is required to use the Elmali Reservoir as a drinking water supply. Because of this, ISKI has started to upgrade the already existing water treatment system. Therefore, remarkable land-cover alterations reflected in the image illustrations, aerial photographs, and land-use distributions representing a dynamic and continuous structure of the study area directly resulted in water quality deterioration within years. The main reason for this direct association is the lack of sufficient infrastructure, which has not been realized with the same speed as urbanization. This is, in fact, a common problem in most developing countries with high population growth rates.

Table 6. Aerial and settlement characteristics of Elmali water reservoir

Total area (km^2)	Lake area (km^2)	Zone	Area (km^2)	% Distribution	Settlements (N)	Population	% Distribution	Density (person/km^2)	Industries (*N*)
81	4	Absolute	10	14	1	4,693	4	469	5
		Short	12	16	—	—	—	0	—
		Medium	29	37	1	13,523	13	466	1
		Long	26	33	2	87,457	83	3364	78
		Total	77	100	4	105,673	100	1372 overall	84

Source. Beler Baykal and others (2000)

Conclusions and Recommendations

The objective of this study was to examine the land-cover changes in the second largest administrative district of Istanbul, through the use of a variety of data sources, including satellite images, aerial photographs, orthophoto maps, standard scale 1:25000 topographic maps, and various thematic maps together with ground truth studies with the idea of numerically verifying rapid urbanization with lack of infrastructure and associating its adverse effects on the nearest receiving water quality. Landsat 5 TM images for the years 1984, 1992, and 2001 with high classification accuracies served quite well in detecting the remarkable land-cover changes within years. The investigation of the illustrations indicated the rapid conversion of forests and barren land to urban areas due to the attractiveness of the province, such as proximity to downtown Istanbul, well-established transportation networks, and nearness to a receiving water body. Despite the current regulations, land-cover patterns changed rapidly in response to social, economic, and political forces. It is clear that the current local regulations for the protection of watersheds have already been made redundant, as there exist residential areas in the absolute and short–range protection zones of the Elmali Watershed. Moreover, the TEM passes through all the protection zones. The significant decline of forest areas has occurred and deforestation has become a major problem as is clearly reflected in the illustrations. Such alterations in land cover have already resulted in water quality deterioration. The water quality of the Elmali Reservoir has exceeded drinking water maxima and can no longer be used as a drinking water supply without advanced treatment, as was not the case two decades ago. The water quality deterioration follows a similar trend with uncontrolled urbanization.

This study aims to help the managers, decision-makers, and city planners by informing them of the past and current land-cover changes, to influence the cessation of illegal urbanization through suitable decision-making and environmental policy that adhere to sustainable resource use. The research results indicate how remote-sensing technology can be utilized for detecting and defining the changes. However, continuous monitoring must be performed at regular time intervals of preferably 5 years to detect dynamic land-cover changes. In this manner, negative and/or positive effects on the environment can be observed and detected to identify current and future problem areas before such problems are irreversible. Such continual investigation is both simple to acquire and analyze, so it must become an integral part of sustainable resource management and environmental protection.

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