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Full Length Research Paper

Coastline changes in Istanbul between 1987 and 2007

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The coastal region of Istanbul has experienced significant coastline changes over the last few decades owing to a rapid increase in industrialization and urbanization. This study was aimed at detecting coastline changes in the coastal region of Istanbul between 1987 and 2007 using remotely sensed data. Two Landsat images acquired in 1987 and 2007 with 30 m resolution were classified with the maximum likelihood supervised classification method. The study area was classified into six land cover classes comprising urban areas, agricultural areas, forest, bare soil, brush/grassland, and lakes/ponds. The study provided an in-depth analysis of the coastal changes in the study area and revealed that the coastlines of Istanbul had expanded by 32 km between 1987 and 2007. From the findings of the study, it can be concluded that the largest variations in the position of the coastline over time occurred on the Marmara Sea coast in the south of Istanbul. Consequently a sustainable coastal management plan should be prepared and put in action in order to preserve the coastal regions.

Key words: Coastline, coastline change, remote sensing, Istanbul.

INTRODUCTION

Coastlines are defined by the International Geographic Data Committee (IGDC) as one of the most important geographical features on the earth's surface. The coastline can be geographically defined as a linear intersection of coastal land and the surface of a water body. Coastline mapping and change detection are essential for safe navigation, resource management, environmental protection, and sustainable coastal development and planning (Di et al., 2004).

Coastal areas have constantly changed physically and ecologically depending on natural and human factors. Natural factors of coastal line changes have been evaluated in three different ways: short-term changes including effects from the rising and lowering of the tide, long-term changes including climate changes, periodical storms and waves, and episodic changes including sudden natural events (Tağıl and Cürebal, 2005; Krueger et al., 2008). Coastal recreation and construction of harbors and roads are considered important human factors for coastal change (Boak and Turner, 2005). These changes that occur on the coastline and in coastal regions continue to have a negative effect on human lives, agricultural activities and marine transportation (Bayram et al., 2004; Tai-Wen et al., 2007).

About a billion of the world's population (40 - 60%) lives within 100 kilometers of the coastline owing to coastal resources. Many coastal cities are confronted with intense coast utilization as a result of overpopulation (Mackenzie, 2003). In European countries, where the coasts are intensely used, the population density is 10% more than that upcountry. This reaches 50% in countries bordering the Mediterranean Sea, such as France, Spain and Italy. The coasts of Portugal, the Netherlands and Belgium are also regions where European population is dense. Sixty-one percent of the coasts in European countries are used for residents, service and entertainment sectors and artificial sites, which cause shoreline change (EEA, 2006).

There are 28 littoral cities with a total area of 221.414 km^2 or 28.76% of the country's total area (Sesli et al., 2002). Thirty-eight million people or about 54% of the country's total population live in these littoral cities (TUIK, 2002). The population of Istanbul is continuously increasing, as a result of its growth and industrial development. During the last decade Istanbul has shown a 33% rate of population growth. The coastal population of Istanbul grew from 5,299,647 in 1985 to 8,157,853 in 2007 (TUIK, 2008). Uncontrolled urbanization and concurrent population growth have resulted in unplanned

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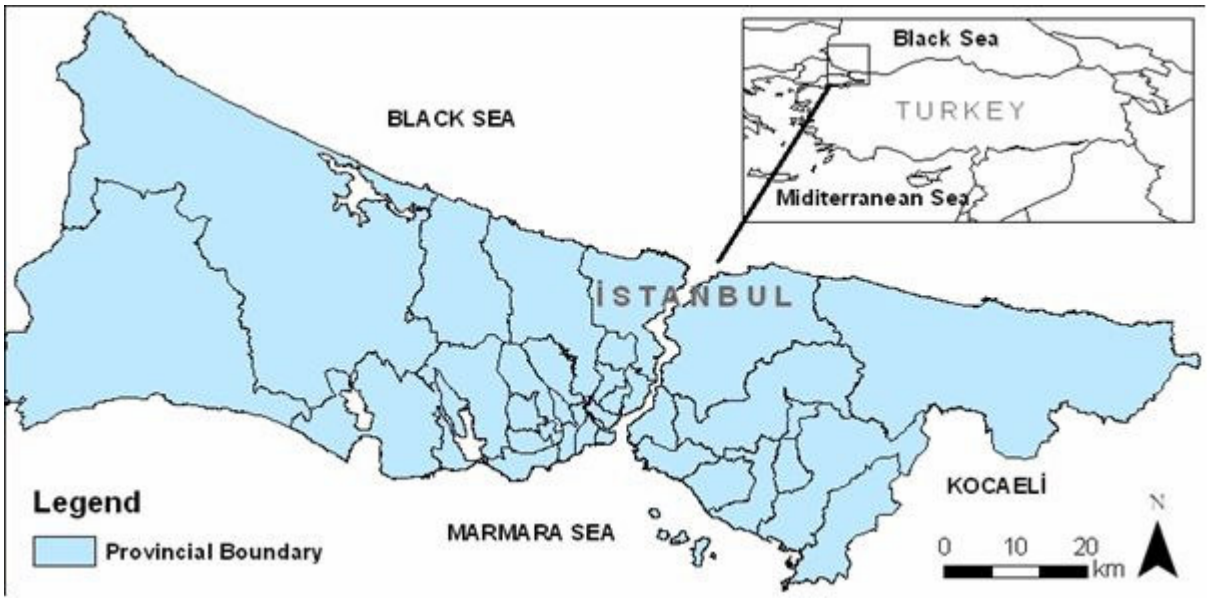

Figure 1. Location of study area.

and unregulated development in the coastal areas. The growth of economic activities and intense industrialization as well as urban sprawl have resulted in extensive human interventions in the coastal areas, filling an area of about two million square meters in different parts of the coast (Atakan, 2003).

Understanding spatial variation in coastlines through time is of importance to many investigations undertaken by coastal scientists, coastal engineers, and coastal managers (Douglas and Crowell, 2000). A plan designed to protect coastal areas requires information about where the coastline is, where it has been in the past, and where it is expected to be in the future. Potential data sources for shoreline investigation include historical photographs, coastal maps and charts, aerial photography, beach surveys, in situ geographic positioning system shorelines, and a range of digital elevation or image data derived from remote sensing platforms (Boak and Turner, 2003).

The aim of this study is to determine the coastline changes in Istanbul between 1987 and 2007 by using remote sensing. The main research questions of the study are as follows: 1. To what extent have the coastlines of Istanbul changed between the years 1987 and 2007? 2. What kind of arrangements/legislation should be made with respect to coastal land use in order to perform urbanization activities according to modern urban criteria?

Study area

Istanbul is located between 27° 58' – 29° 56' eastern longitudes and 40° 48' – 41° 36' northern latitudes. It is surrounded by the Black Sea in the north and the Marmara Sea in the south. The city, in the north-west of Turkey alongside the Marmara Sea and the Bosporus, acts as a bridge connecting Asia and Europe (Figure 1). Istanbul covers a surface area of 5.390 km^2 with 32 districts administered by the Istanbul Metropolitan Municipality (İBB, 2007). Istanbul is usually thought of as a peninsula since it is surrounded by the Golden Horn (Haliç), the Bosporus and the Marmara Sea.

MATERIALS AND METHODS

Remote sensing is one of the most preferred and reliable methods in monitoring and managing environment and resources (Doygun et al., 2003; Maktav and Erbek, 2005; Duran et al., 2006; Fan et al., 2007; Yuan, 2008; Deng et al., 2008; Karaburun and Demirci, 2009). The process of assigning pixels to particular spectral classes in remotely sensed data is called classification. The aim of image classification is to generate thematic maps where each pixel is assigned a value based on its spectral response to a particular class (Gupta, 2003). Supervised and unsupervised classifications are the main types of classification. Since supervised classification techniques provide an effective tool for generating land cover maps of regions (Richards, 1995), supervised classification was performed in order to classify each image in this study.

Seven land cover classes were identified in the study area, urban areas, lakes/ponds, clouds, forests, agricultural areas, bare soil, and bush/grassland, for the Landsat images acquired in May 1987 and May 2007 with 30 m resolution. Erdas Imagine 9.1 software was used to process images and Arcgis 9.3 was used to perform vector-editing tasks. In order to complete the land cover mapping the next step after classification of images is assessing accuracy (Congalton, 1996). Accuracy assessment is performed by comparing a pixel of a classified image with a pixel of a reference map. At the end of this process an error matrix is produced. The rows and columns in the error matrix represent land cover classes of classified images and reference maps. The correctly classified cells are represented by diagonal cells (Congalton, 1996). Accuracy of a classification is defined with kappa coefficient and

Table 1. Accuracy assessment.

Image	Overall accuracy (%)	Kappa statistics
1987 Landsat	79.00	0.76
2007 Landsat	83.50	0.81

Table 2. Total coastline lengths.

Year	Coastline length (km)
1987	459
2007	492

overall map accuracy. Overall map accuracy is calculated by dividing the total of correct cells by the total number of pixels in the error matrix. Kappa statistics are the measurement of difference between the classified map and the reference map. Kappa statistics show if the error matrix has obtained the correct value by chance or with real concordance (Congalton and Green, 1998; Lilles and Kiefer, 2000). The outputs of accuracy assessment for images are given in Table 1.

RESULTS AND DISCUSSION

The coastlines of Istanbul were extracted from classified Landsat images and the lengths of coastlines are given in Table 2. According to Table 2, the coastlines expanded by 32 km between 1987 and 2007. The total coastline length rose to 492 km in 2007 but was only 459 km in 1987.

Since Istanbul was surrounded by the Marmara Sea, Black Sea and Bosporus the coastline changes were analyzed as three sections. The filling and erosion area values of these coasts are given in Table 3.

The filling areas that appeared on the coasts are of two kinds in terms of their formation; artificial and natural. Just as people make artificially filled areas to meet their needs for leisure activities, the rivers also carry materials that accumulate on the river banks and lakesides to form natural filled areas like deltas. Artificially filled areas are built mainly for the construction of piers, docks, parks and for recreational purposes. Such areas are widespread in many countries that have coastlines. Filling activities for recreational areas are in progress even now in Istanbul. These filled areas, which are part of a project to redesign the coastlines, are situated in Fatih, Eminönü, Zeytinburnu, Bakırköy, Ataköy, Florya, Küçükçekmece, Avcılar and Büyükçekmece on the coast of Western Marmara, and in Üsküdar, Kadıköy, Maltepe, Kartal, Pendik and Tuzla in Anatolia (Figures 2, 3 and 4). On the Black Sea coast of Istanbul most fillings seem to be the result of natural forces, enlargement of the beaches and filling of seashores for ports and piers. There are no other forms of filling activity.

Coastal areas are the most essential recreational areas for people. On the other hand, the utilization of Istanbul's coastlines and rapid urbanization caused intensive construction of buildings very close to the coastline for 20 years from 1987 to 2007. Since most of the buildings on the Istanbul coastlines are private properties, there is no public access to the sea. That is why the Municipality of Istanbul has been filling areas in order to meet the public demand for recreational areas. Such works both relieved the coastlines and caused the coastline borders to change. The roads that were recently built on the Marmara Sea coast have particularly altered the coastlines. Removing sand from the coasts, building ports and piers, and creating beaches have also contributed to the changing coastlines. Major changes were made to the coastline of Istanbul from 1987 to 2007. By the end of these changes the coastline length of Istanbul had changed as well, mainly extending towards the sea. As shown in Table 3, an area of 1.678 ha was filled and transformed to land extending to the sea between 1987 and 2007 on the coast of Istanbul whereas an area of 58 ha was returned to the sea.

The changes that occurred in coastal areas between 1987 and 2007 resulted in changes in the length of coastlines (Table 2). The coastline in Istanbul changed substantially especially on the Black Sea coast and the Marmara Sea from 1987 to 2007. The coastline on the Asian side and on both sides of the Bosporus seems, however, to be stable.

Coastline changes on the Marmara Coasts of Istanbul

An area of approximately 906 ha on the Marmara coasts of Istanbul was filled between 1987 and 2007 (Table 2). These filled areas have been used mainly as places of recreational facilities, for roads and for the construction of ports. An area of around 464 ha was filled and changed to use as ports, recreational areas (Table 2). In the district of Üsküdar, the Üsküdar-Harem coastline was designed by filling an area of 2.5 ha (Atakan, 2003). There are parking lots, playgrounds for children and paths for pedestrians. The filled areas between Kadıköy and Maltepe contain Moda İnciburnu Park, Kurbağalıdere Park, Kalamış Marinası Park, Fenerbahçe-Cadde Bostan Park and Caddebostan Park. An area of about 5 km between Bostancı and Maltepe and one-sixth kilometre from Maltepe Kartal were filled for recreational purposes (Figure 2). About 5 km of the coast road to Tuzla, which is the eastern border of Istanbul after Pendik, was filled for road and recreational purposes. Most filling areas are in the frontiers of Pendik. If the Anatolian coastlines are observed in terms of the rate of filled areas, it is clear that Kartal is the district which has the highest rate of change and Üsküdar has the lowest (Figure 2). In areas where coastal lines changed, recreational parking lots, parks, and ports were generally constructed. Forest, bush/grassland and bare soil areas decreased in areas where constructions increased.

Filling of a coastal area of 442 ha from Eminönü to

Table 3. Filling and erosion area values.

Coasts	Filling area (ha)	Erosion area (ha)
Marmara Coasts	906	-
Black Sea Coasts	568	57
Bosporus Coasts	204	-
Total	1678	57

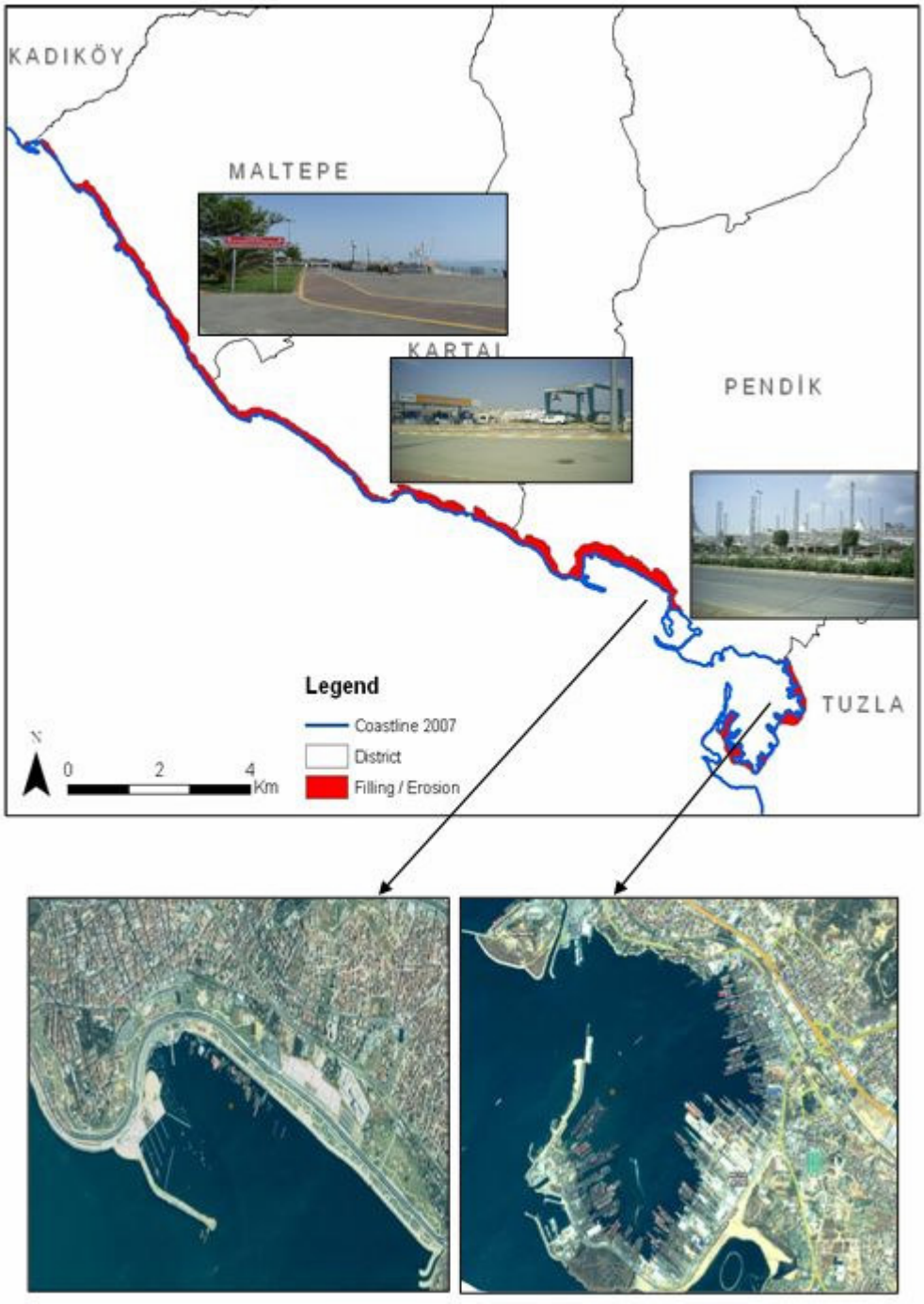

Figure 2. Filling areas and Coastline in Kartal and Pendik Districts along Marmara Coasts (2007).

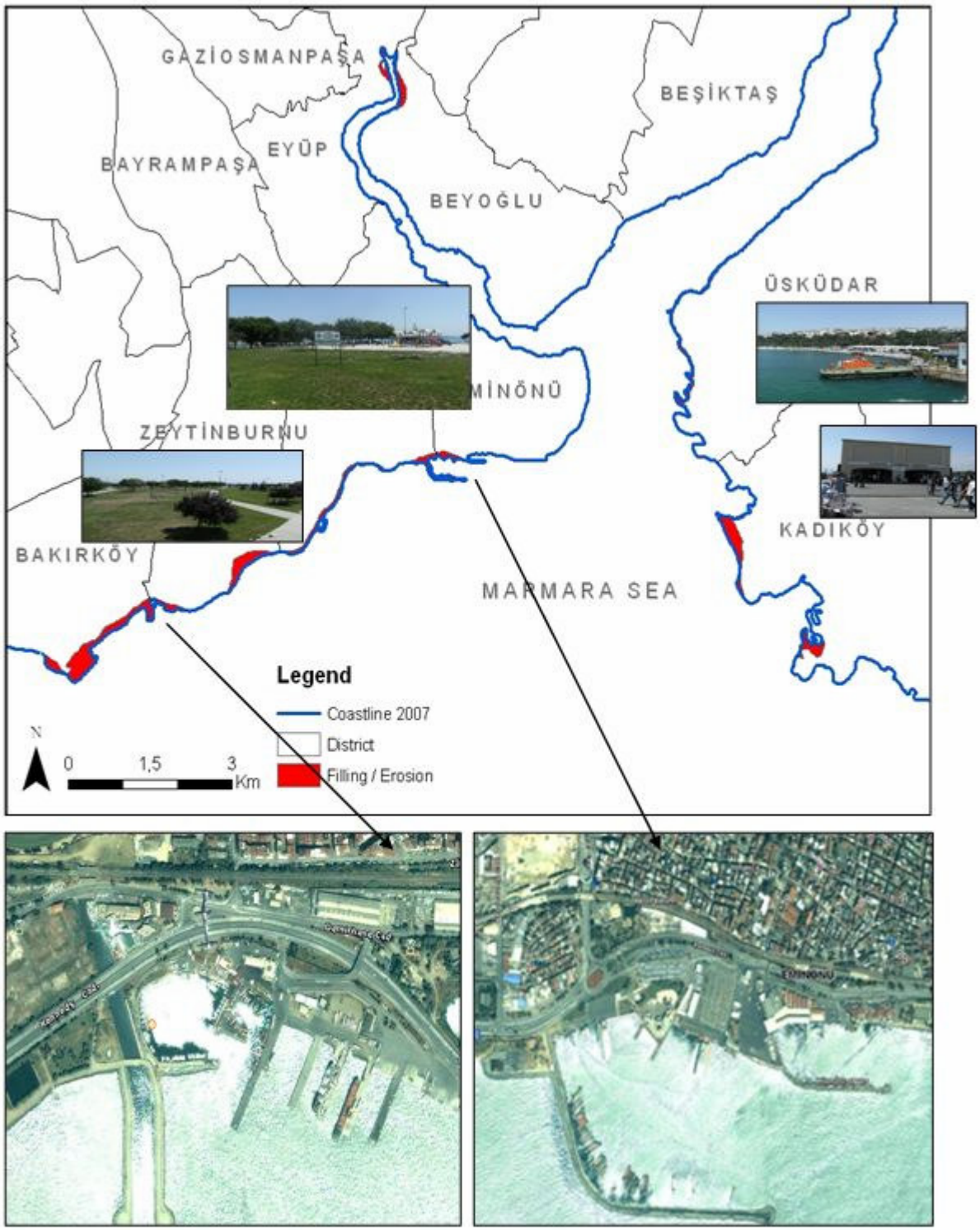

Figure 3. Filling areas and coastline Eminönü and Zeytinburnu Districts along Marmara Coasts (2007).

Büyükçekmece caused the coastline to advance seaward (Table 2 and Figure 3). Yenikapı and Türkmenistan Parks in the Fatih district are located on coastal fill areas. Kazlıçeşme and Mermerkule Parks are located on coastal fill areas of the Zeytinburnu district. Aytekin Kotil Park (spanning 1.5 km of coastal line), facilities for Bakırköy sea buses, and Yeşilköy coastal park (spanning 3.5 km. of coastal line) are located in Bakırköy coastal fill

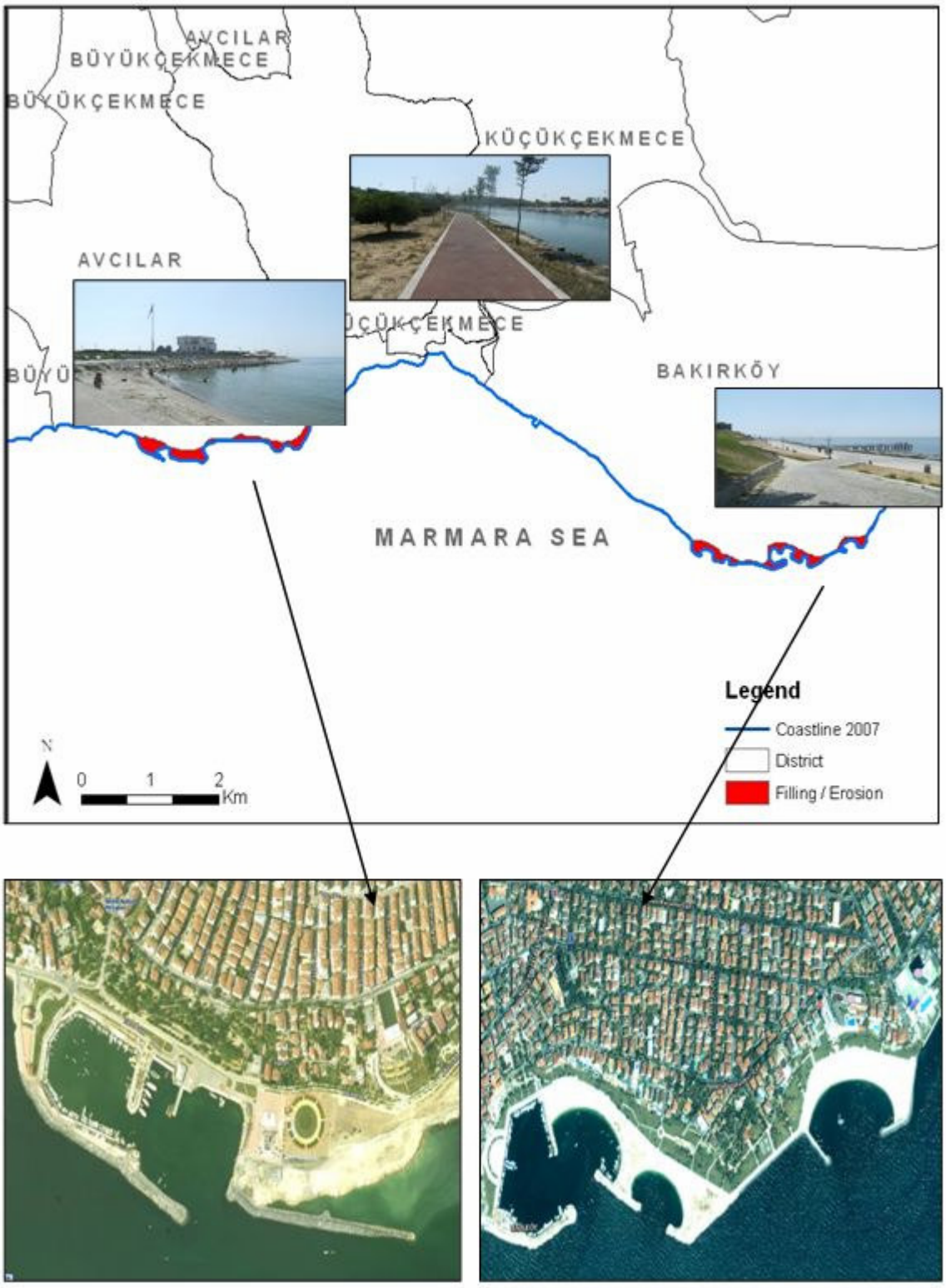

Figure 4. Filling areas and coastline in Avcılar and Bakırkoy Districts along Marmara Coasts (2007).

areas. In Avcılar district, it can be seen that most of the coastal area is filled (Figures 3 and 4). At Üsküdar and the Golden Horn, between 1987 and 2007, a total area of 65 ha was filled. On the filled areas in Üsküdar, the coastal road of Üsküdar-Harem and parks were constructed. At the Golden Horn, filled areas were used

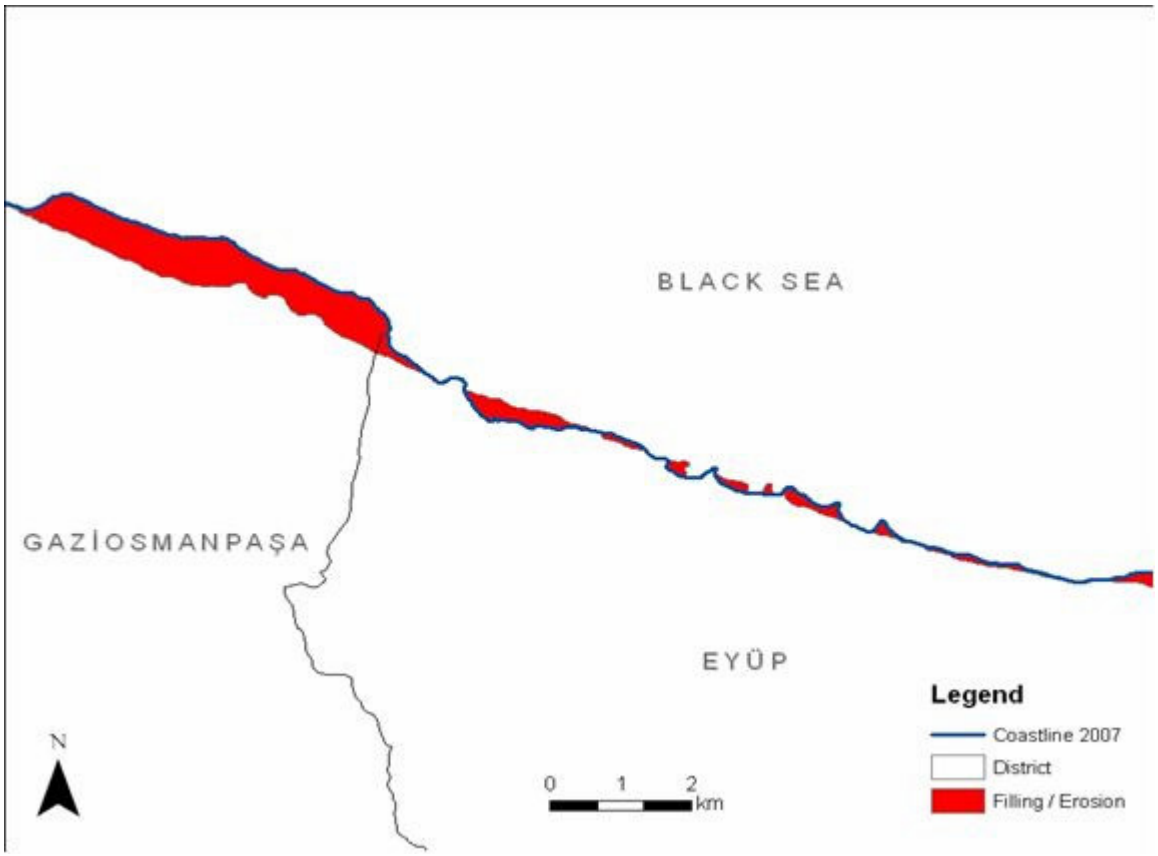

Figure 5. Filling areas and coastline in Eyüp and Gaziosmanpaşa along Black Sea Coasts (2007).

to construct recreational parks (Table 2 and Figure 3).

The coastline changes on the Black Sea coasts of Istanbul

In Istanbul, the Black Sea has one of the least structured coastal areas because of the narrow continental shelf and rocky terrain which is unsuitable for settlement. The Şile, Gaziosmanpaşa and Eyup coasts are the most populated and structured areas. In these districts, filling areas on shallow coasts are used as ports, docks, piers or beaches. The Black Sea coastal line on the northern coasts of Eyüp and Gaziosmanpasa advanced towards the sea as a result of the filling of an area of 568 ha (Table 2 and Figure 5). Some of the fillings in this region, however, are not only for docks or recreational use. For instance, accumulation of soil that is discarded from quarries and flows into the sea has generated an artificial foreland of 500 meters on the Karaburun coast (Arı et al., 2007). In the coastal region between Kilyos and Karaburun, between 1984 and 1994, 160 ha of sea was filled in with piles of coal, clay and sand. During this filling, 590 ha of forest were destroyed (Gazioğlu et al., 1997). In addition, as a result of both natural and human factors (such as wave abrasion and transfer of soil and sand from coasts by humans) the coastal line advanced towards the land to cover an area of 57 ha (Table 2 and Figure 6).

Conclusions

Having a very long human history, dating back almost six thousand years, Istanbul has experienced enormous changes in its natural environment, especially after the second half of the twentieth century. Rapid increase in population, most of which is owed to immigration, has caused unplanned urban growth in many parts of the city with accompanying problems such as environmental degradation, pollution, traffic congestion, etc. Because the city mainly expanded along the coasts surrounding three parts of each peninsula on the Asian and European sides of Istanbul, the coastal regions were the areas most affected by the rapid urbanization and population growth. In a study using the images from 30 meter resolution Landsat TM dated May 11, 1987 and May 11, 2007, coastal line changes for those 20 years were observed. In the area of study, that includes 24 districts of Istanbul, the population is 815.785 according to 2007 data. In the buffer area of 1.000 meters from the coastline to the land, there was a land area of 39.586 ha in 1987. This buffer

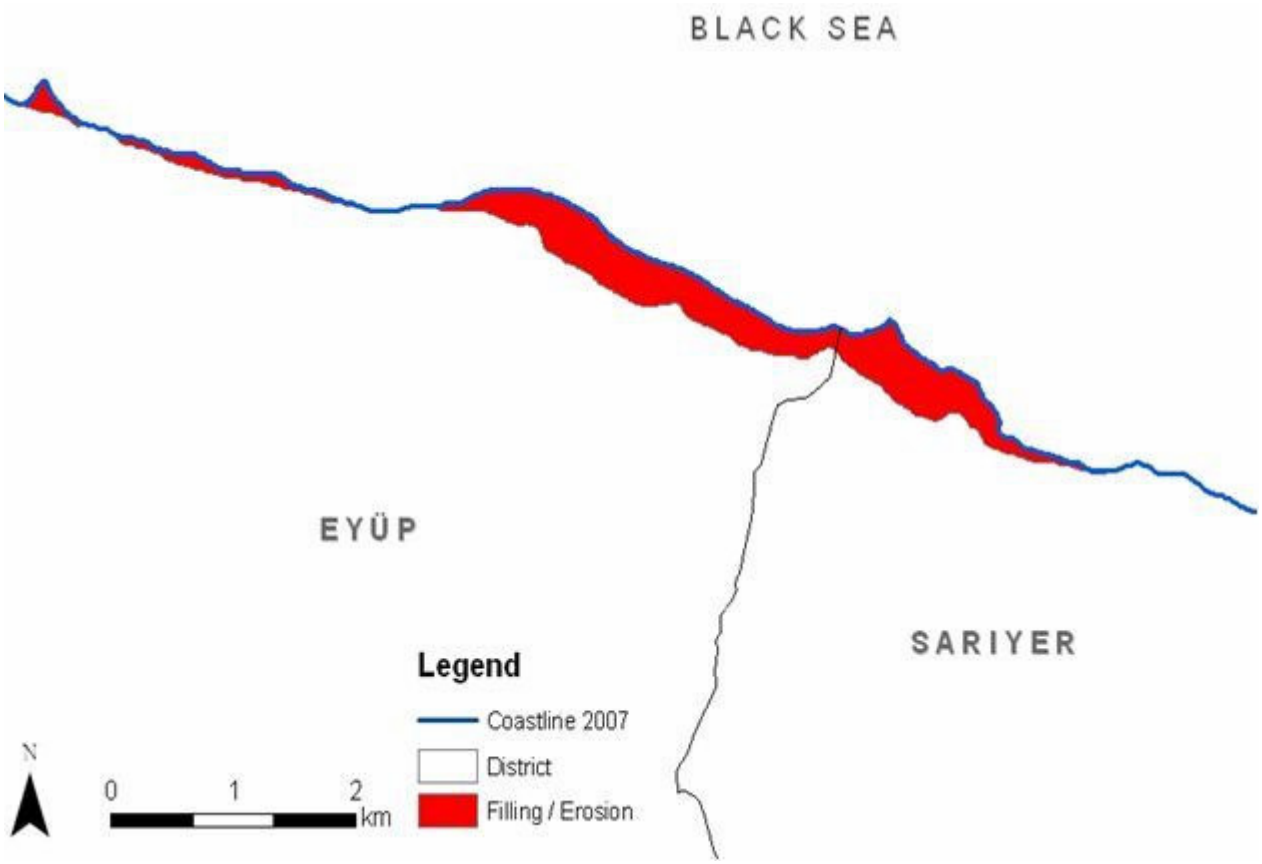

Figure 6. Filling areas and coastline in Eyüp and Gaziosmanpaşa along Black Sea Coasts (2007).

area expanded to 41.528 ha with filling additions in 2007. In the study area, it was observed that human factors, such as filling of coasts and transfer of sand, were more effective than natural factors in terms of general use of coasts and changes in the coastal lines. In addition, the change was observed most significantly on the Marmara and Black Sea coasts. On the other hand, because of the intensity of historic and private properties, no significant change in coastline and land use on Istanbul's Bosporus coasts has been observed. In the study area, beaches and recreation areas decreased and vanished completely in certain places: approximately 906 ha at Marmara, 568 ha at the Black Sea, and 65 ha at the Strait, Golden Horn and Üsküdar coasts have been filled to reconnect society and the sea (Table 2). It is apparent, however, that many beaches used by the public throughout history have ceased to exist. For example, there is no natural beach left in the Yeşilköy coastal area.

Although they helped people to connect to the sea and relax, filling operations have changed coastal lines in many places in the Istanbul area. It is clear that the coastal line has advanced 250 meters seaward at sites where coastal filling operations have been performed. After the reconstruction law came into force in 1984, the coastlines of Istanbul changed owing to filling operations in the districts of Eminönü and Fatih on the European side, as observed by Landsat satellite images in 1987. Changes in the coastline can be observed clearly at Zeytinburnu, Bakirkoy, Avcılar, and Büyükçekmece districts on the 2007 satellite images (Figures 3, 4). Coastal filling activities are still in progress at Avcılar. In Istanbul, operations at coastal areas were not only limited to filling. Especially in the Black Sea coastal area, soil and sand removal caused the coastal line to shrink landward. A total of 57 ha at the Black Sea coast was lost owing to human factors such as sand removal (Table 2). As a result of all these coastal filling activities total coastline length increased from 459 km in 1987 to 492 km in 2007 (Table 2). In this study, the temporal change of Istanbul's city coastline was determined and updated coastline information revealed. Some suggestions are listed below to solve all problems mentioned and to establish measures for proper use of coasts. In reorganizing Istanbul coastal areas, instead of filling the coasts, new approaches to reclaim coastal areas should be determined, and loss of natural coastlines should be prevented. Excavations and sand and gravel transfers that are likely to change the coastlines should be illegal.

Measures to prevent erosion, such as coastal spurs, should be taken at places where coastal erosion is very

effective such as Karaburun on the Black sea shores in Istanbul. In addition, coastal erosion dependent on human factors such as removal of sand should be prevented. Coastal areas should be easily accessible by the public, as required by Article 43 of the 1982 Constitution. In addition, according to Article 715 of law 4721 in 2001, coastal areas cannot be held as private property (Sesli et al., 2003). Legal measures should be taken to prevent construction of any building in areas decreed to be inside coastlines. According to the fifth article of coastal law, construction and planning should not be allowed at coasts where the coastline has not been determined. In this context, municipalities that govern coastal areas should protect them from pressure of private properties and public institutions by establishing regulations for the benefit of society. Measures of protection should be taken not only at the coastline but also inside the seaward and landward borders according to the morphological characteristics of the coast, to protect the topographic and silhouette of Istanbul's coasts. As the Bosporus coasts are attractive areas for tourism, problems related to organization and other uses such as transportation, infrastructure, industry, and recreation should be resolved by means of a holistic plan. Maritime and private properties built on the Bosporus coastline a long time ago cut the link between the people and the sea. Through the enforcement of new regulations, coastal areas in such places should be deprivatized. In addition, the city and the sea should be reconnected. Organization of the coastal areas should be aimed at protecting the natural and cultural values of the area and transferring them to future generations with the least amount of damage.

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