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Determination of shoreline change along the Black Sea coast of Istanbul using remote sensing and GIS technology

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ABSTRACT

This study aims to determine the shoreline changes along the Black Sea Coast of Istanbul, which has been occurred in 7 years from 2009 to 2016. For this purpose, remote sensing technology used to detect the shorelines in the study period and geographic information system was established for determining the general and specific changes along the shoreline. In this context, geometric and atmospheric corrections were applied to the data as the preprocessing of Landsat-7 Enhanced Thematic Mapper Plus and Landsat-8 Operational Land Imager images. Then after, the Black Sea Shoreline data of Istanbul was extracted by applying supervised classification using maximum likelihood classification algorithm and normalized difference water index to Landsat images. As the following stage of the study, the changes along Black Sea Shoreline were determined using the digital shoreline analysis system software based on the extracted shoreline data. As a result of the study maximum negative and positive distances were determined similarly for the outputs of both applied methodologies as approximately –438 and 466 m. The study concluded that the most significant change along the shoreline was observed at the European side of the city, at a location close to the construction area of Istanbul Airport.

Keywords: Shoreline change; Coastal erosion; Landsat-8; Spectral water index algorithms; Normalized difference water index; DSAS

1. Introduction

Coastal erosion is defined as the loss of coastal lands in to a sea or lake due to the natural processes such as waves, winds, and tides, however, even human activities such as the construction of coastal structures as wave breaker or seawalls can cause the transport of the coastal material away from the shoreline [1]. The location and geometry of the coastlines are the main indicators for understanding coastal dynamism, managing coastal areas and assessing changes in these sensitive areas [2–4]. Therefore, a systematic approach is required for the assessment and monitoring of the coastal environment. Seasonal, short-term or long-term mapping and monitoring of the coastline is necessary to understand the several coastal processes. However, monitoring the entire coastal system in a large area using traditional ground survey techniques is time-consuming and sometimes impossible [5,6].

Recent advances in remote sensing (RS) and geographic information system (GIS) technologies provide an effective platform for producing synaptic coverage and assessing shoreline change with several techniques [7,8]. Remotely sensed data is broadly used to analyze changes in shoreline since it can provide information over a large area in a short

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time. In addition, RS and GIS integration provides many advantages for coastal zone management [7,9] and also they are inevitable technologies in developing effective action plans for any coastal area. Several studies demonstrating the effectiveness of the use of GIS and RS integration for environmental change detection, specifically shoreline change, purposes have been conducted. Dewidar and Frihy [10] used ten scenes of Landsat sensors for quantifying erosion and accretion pattern along the coastline of the Nile Delta [10]. They calculated rates of shoreline changes using the digital shoreline analysis system (DSAS). Similarly, Mujabar and Chandrasekar [7] investigated the shoreline changes using multi-date Indian RS satellite images along the coast between Kanyakumari and Tuticorin of South India by using DSAS. DSAS has been used widely in analyzing the dynamics of shoreline movements at both shorter and longer time scales [4]. Recently, studies on the determination of shorelines have been conducted by using DSAS software which is an extension of ArcGIS software on different satellite images. Several image processing methods such as maximum likelihood classification (MLC), tasseled cap, spectral indices or MLC have been used for shoreline extraction [11–13]. Nassar et al. [14] also used DSAS for determining the shoreline change detection along the North Sinai coast in Egypt based on the shoreline data that was extracted shorelines using single-band thresholding method and tasseled cap transformation.

The main objective of this study is to determine the changes occurred at the Black Sea Shoreline in 7 years from 2009 to 2016. The usability of the different image processing methodologies in shoreline change detection was also examined for understanding their mapping potentials. For this purpose, the Black Sea Shoreline data was extracted from remotely sensed images by applying the MLC algorithm and normalized difference water index (NDWI) for the years 2009 and 2016. Changes in the geometric structure of the shorelines were determined using DSAS software in a GIS environment.

2. Materials and methods

2.1. Study area

With its strategic location, Istanbul as the only city in the world bridging Europe and Asia continents has been one of the most attractive cities at the center of life, art and culture for thousands of years. Istanbul located at the Marmara Region on the northwestern part in Turkey and is surrounded by the Black Sea in the north and the Marmara Sea in the south. The city has 524.5 km shoreline including the Bosphorus. Many changes have been observed at the shoreline of Istanbul for years due to human activities or natural processes. Black Sea Coast, which included long coastal dunes such as Kilyos and Agacli, constitutes the sea border of the 6 districts in Istanbul as presented in Fig. 1.

2.2. Data

In this study, Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Landsat-8 Operational Land Imager (OLI) satellite images, which are dated 29 June 2009 and 10 July 2016 respectively, were used as the main input to determine the change of the shoreline along the Black Sea Coast in Istanbul.

The Landsat-8 includes eleven bands and equipped with a thermal infrared sensor (TIRS). TIRS acquires data for the two thermal wavelength regions with a 100 m resolution while OLI obtains data for the visible, near-infrared

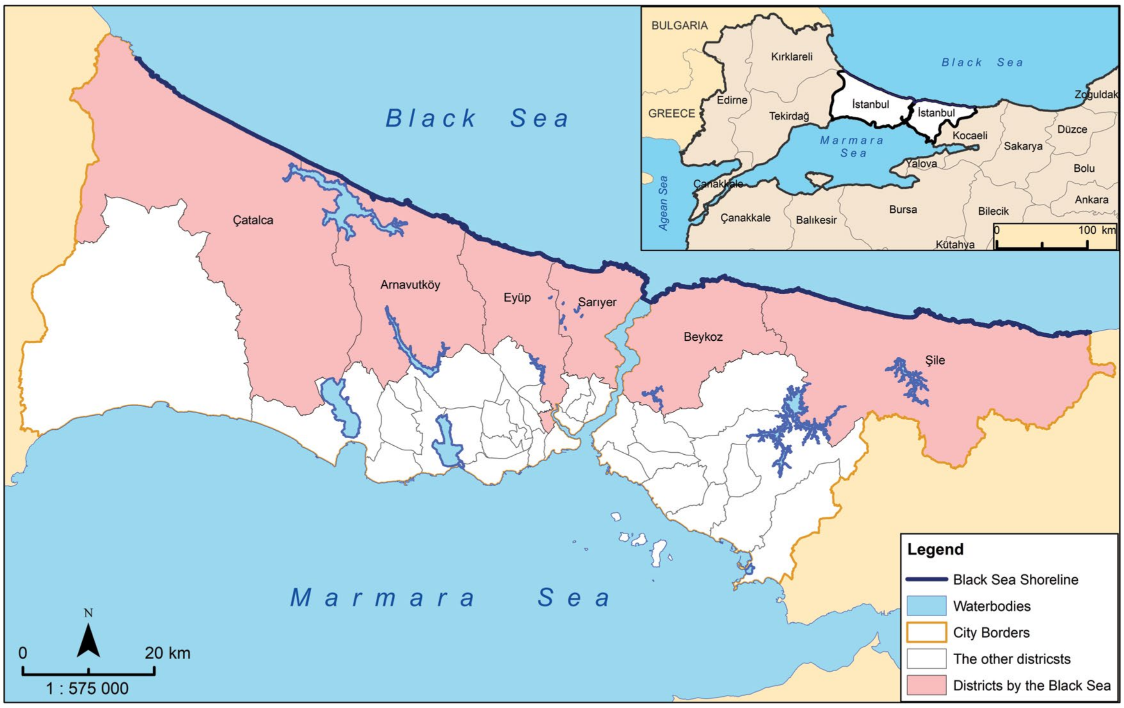

Fig. 1. Location of the study area.

(NIR) and shortwave infrared bands with 30 m resolution and panchromatic band with 15 m resolution. The spatial resolution of Landsat-7 is 30 m. RS images were both obtained from United States Geological Survey (USGS) Earth Resources Observation Systems data center.

In addition to remotely sensed images, ancillary data including 25 K standard topographic maps and 5 K orthophoto maps were used as reference data for the training site selection, classification process, and accuracy assessment of the classified images. Google Earth was also used as an additional source at these stages of the study.

2.3. Methodology

The methodology of the study composed of three main stages as image preprocessing, shoreline extraction and change detection (Fig. 2). As the preprocessing works performed in the first stage of the study, RS images were first geometrically corrected since accurate spatial registration of multi-temporal images is essential for change detection [15–17]. Geometric correction of both images was completed with less than ±0.5 pixel root mean squared error (RMSE) in accordance with existing literature on change detection techniques in RS [18,19]. Landsat images were then registered to Universal Transversal Mercator projection based on 25 K topographic maps of the region using the first-order polynomial method. During image rectification, the nearest neighbor resampling algorithm was used, and the process followed with approximately ±15 m RMSE for both images.

After completing preprocessing, shoreline data were extracted from RS images through supervised classification and NDWI techniques at the second stage of the study. MLC algorithm, which assumes that the statistics for each class in each band are normally distributed and calculates the probability of the specific class that pixel belongs to, was used in supervised classification. Unless a probability threshold is selected, all pixels are classified. Each pixel is assigned to the class that has the highest probability (i.e. the maximum likelihood). With the supervised approach, calibration pixels are selected and associated statistics are generated for the classes of interest [20]. This study used per-pixel supervised classifications which group satellite image pixels with the same or similar spectral reflectance features into the same information categories [21]. The main aim of NDWI is to determine open water features using the green (Band 2) and near-infrared NIR (Band 4) bands of Landsat imagery. This index minimizes the reflectance of non-water features by using the NIR band while maximizes the reflectance of water by using the green band [22]. The formulation of the NDWI is given in Eq. (1).

$$\mathrm{NDWI} = \frac{(\mathrm{GREEN} - \mathrm{NIR})}{(\mathrm{GREEN} + \mathrm{NIR})} \tag{1}$$

Accuracies of the applied RS techniques were also examined at this stage. In this context, conformity of the results obtained by MLC and NDWI with the real land cover type on the ground was assessed by generating an error matrix and determining overall accuracy (OA) and Cohen's Kappa statistics. Although there are several quality measures, OA and Cohen's Kappa statistics are considered as the common ones for the justification of the accurate processing results in RS [23,24]. Accuracy assessment of both RS images was performed by randomly selecting 200 control points for each method to determine the quality of thematic maps derived by processing the input data. When the required accuracy values were met for both methodology, shoreline data were extracted from processed images by applying raster to vector transformation through GIS established within the study.

As the final stage of the study, changes along the shoreline were detected using DSAS software, which congruously runs with the ArcGIS software. DSAS produced by USGS and it computes rate-of-change statistics for a time series of shoreline vector data. For this purpose, DSAS generates transects that are cast perpendicular to the baseline at a user-specified spacing alongshore. The transect shoreline intersections along this baseline are then used to calculate

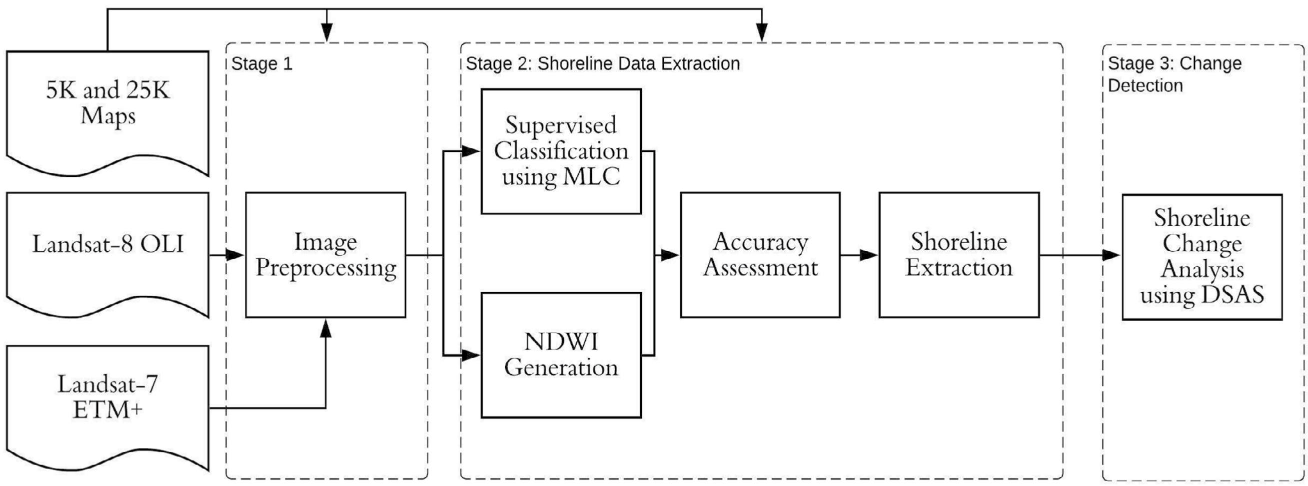

Fig. 2. Flowchart of the study.

the rate-of-change statistics [25]. Based on the DSAS methodology, the shoreline rate of change is calculated using two different statistical techniques:

- The net shoreline movement (NSM) is the distance between the oldest and the most recent shorelines for each transect. (unit: meter)
- The endpoint rate (EPR) is determined by dividing the distance between the oldest and most recent shoreline movement by the time elapsed between the oldest and the most recent shoreline. (unit: meter/year)

Negative values obtained using this methodology represent the erosion while positive values show accretion along the shoreline. In this study, a hypothetical baseline was created similar to the coastline geometry with a position of 150 m distance behind. 1,779 transects were generated perpendicular to the baseline with 100 m spacing along the Black Sea Coast of Istanbul.

3. Results

3.1. Shoreline data extraction

Black Sea Shoreline data was extracted from RS images through supervised classification and NDWI for the years of 2009 and 2016 within this study. Validation of the outputs was provided by the accuracy assessment process and the results are presented in Table 1 in terms of OA and Kappa values. As presented in the table, approximate values

Table 1
Statistical results of the mapping algorithms

	Kappa		OA (%)	
	Landsat-7 ETM+	Landsat-8 OLI	Landsat-7 ETM+	Landsat-8 OLI
NDWI	0.84	0.88	92.00	94.00
MLC	0.90	0.89	92.36	91.25

confirming the accuracy of the applied methodologies were obtained for both of the Landsat images. MLC methodology was applied to the Landsat-7 dataset with the highest kappa value (0.90), while NDWI resulted in the lowest value as 0.84 for the same data set. Additionally, OA values were all higher than Kappa values for all data and method combinations.

Shoreline geometries extracted from Landsat images are presented in Fig. 3. Potential of MLC and NDWI methodologies for mapping the shoreline along the Black Sea Coast in Istanbul was also confirmed based on the similarity of the extracted data in terms of their geometries and accuracies.

3.2. Results of the change analysis

In this study, changes that occurred along the Black Sea Shoreline in 7 years were determined for both of the extracted data set through DSAS. Statistical results were presented as NSM and EPR in Tables 2 and 3, respectively. According to

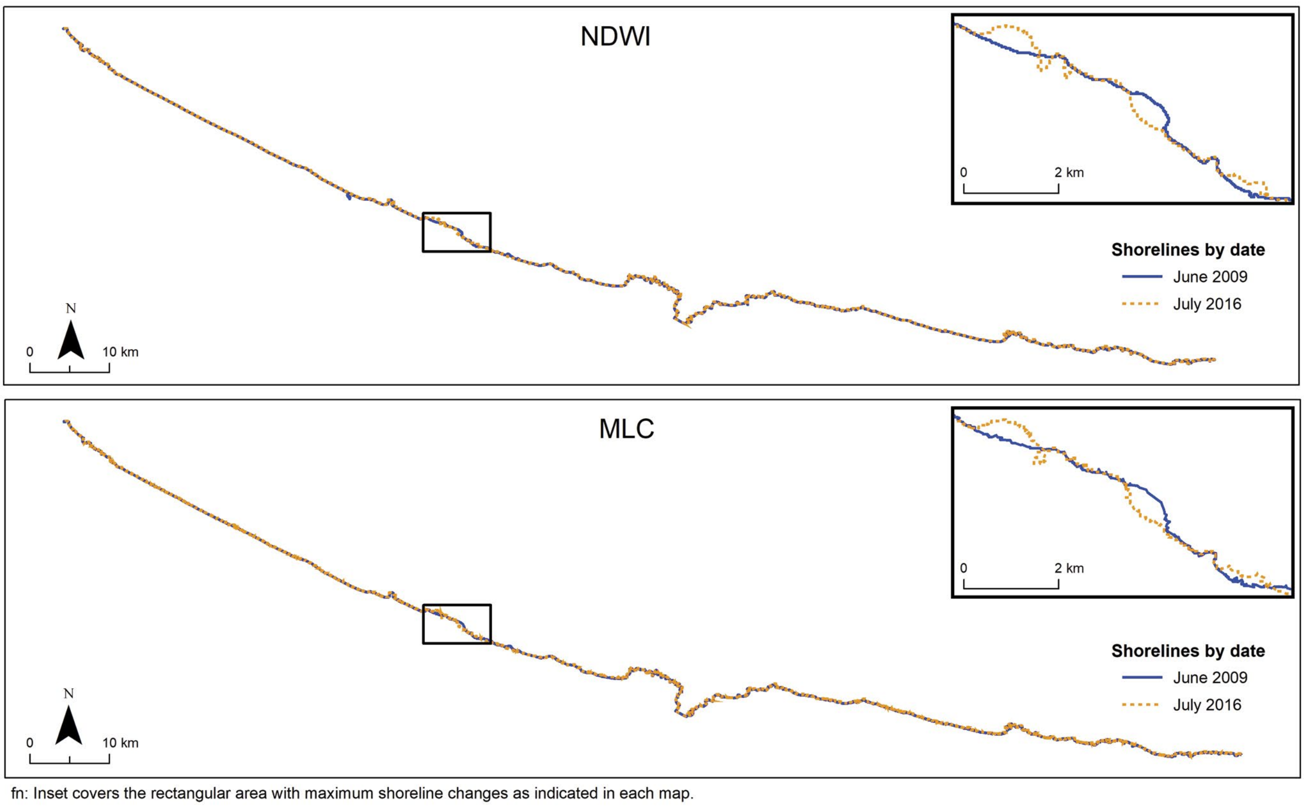

Fig. 3. Shorelines extracted in the study.

Table 2
Statistical NSM results of the DSAS analysis

NSM (m)	MLC	NDWI
Maximum negative distance	–438.51	–438.51
Average of all negative distances	–54.95	–53.3
Maximum positive distance	466.51	470.12
Average of all positive distances	32.32	34.18

Table 3
Statistical EPR results of the DSAS analysis

EPR (m/year)	MLC	NDWI
Maximum value erosion	–62.35	–62.35
Average of all erosional rates	–7.81	–7.58
Maximum value accretion	66.33	66.85
Average of all accretional rates	4.60	4.86

the NSM statistics, both of the data extraction methodology applied in the study concluded with similar results. In this context, maximum negative distance change appeared from 2009 to 2016 along the Black Sea Coast of Istanbul was observed as –438 m while the maximum positive distances were 466 and 470 m for data sets extracted using MLC and NDWI methodologies respectively. The average of all NSMs determined for 1,779 transects along the Black Sea Coast was approximately 54 m and 33 m in negative and positive directions respectively.

According to the EPR statistics presented in Table 3, the maximum value of the erosion was observed as 62 m/y, while the maximum accretion value was 66 m/y. The average of all erosional and accretional rates determined for all transects was around –7.7 m and 4.7 m respectively. When the results obtained from both datasets were examined in more detail, it is revealed that the locations of transects, where the highest values were assigned (in both directions), were identical as expected. Locations of the highest values were also close to each other and they appeared along a specific section of the Black Sea Coast where the Istanbul Airport was built as presented in Fig. 4.

4. Discussion and conclusion

This study examined the change along the Black Sea Shoreline in Istanbul based on two different Landsat images dated 2009 and 2016. Significant changes caused by erosion and accretion in 7 years were detected and the most potent factor of this change was addressed as a result of the study. As statistically confirmed, data extraction methodology applied in the study presented similarly high performances in shoreline data extraction.

Additionally, the results indicated that the changes in shoreline mainly occurred along the coastal part of the new airport construction area that is located between Karaburun and Kumköy towns with an average erosion rate of 7.81 m/y with MLC and 7.58 m/y with NDWI. The accretional changes

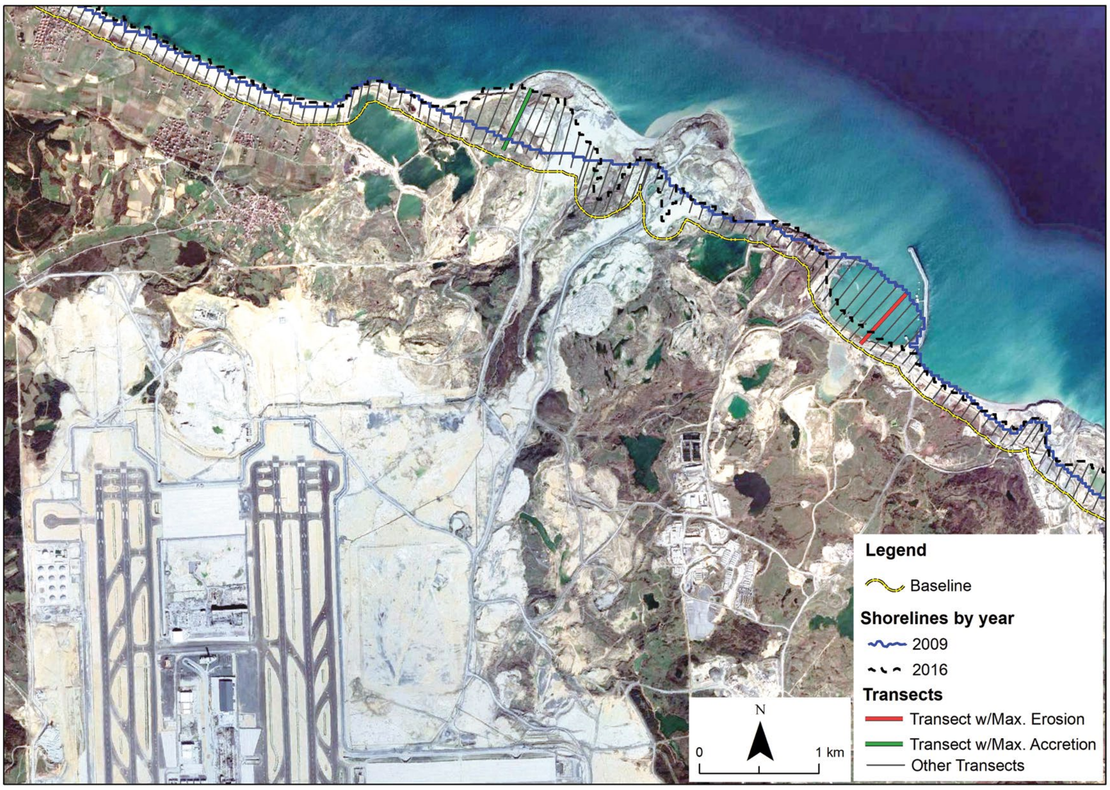

Fig. 4. Shoreline section with maximum NSM and EPR values along the Black Sea Coast.

also occurred in the same area with an average accretion rate of 4.60 m/y with MLC and 4.86 m/y with NDWI. Therefore this study can also be considered as the assessment of the artificial impacts on coastal systems. The misuse of coastal environmental resources due to poor management and lack of monitoring has been widely recognized in the study area. Therefore the result of this study is also valuable as a guide to the decision-makers who aim to preserve natural characteristics of the coastal ecosystem in Istanbul.

It is obvious that coastal erosion or accretion does not only change the coastal morphology together with its habitat but also causes financial losses. Moreover, they can turn into disasters if their impacts are not adopted by the society. Therefore, shoreline changes should be monitored regularly for mitigating the economic and environmental impacts. The efficient use of geo-information technologies as RS and GIS contributes to environmental monitoring operations by providing precise and accurate results as presented in this study.

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