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Automatic detection of shoreline change on coastal Ramsar wetlands of Turkey

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ABSTRACT

This research focuses on the shoreline change rate analysis by automatic image analysis techniques using multi-temporal Landsat images and Digital Shoreline Analysis System (DSAS) along the coastal Ramsar wetlands of Turkey. Five wetlands were selected for analysis: Yumurtalik Ramsar, the Goksu Ramsar, Kizilirmak and Yesilirmak wetlands and Gediz wetlands. Accretion or erosion processes were observed on multi-temporal satellite images along the areas of interest. Landsat images were geometrically and radiometrically corrected for the quantitative coastline delineation analysis. DSAS (Digital Shoreline Analysis System) was used as a reliable statistical approach for the rate of coastline change. For the detection of coastal change in Aegean part (Gediz wetland) of the study, zonal change detection method was used. As a result of the analysis, in some parts of research area remarkable shoreline changes (more than 765 m withdrawal and −20.68 m/yr erosion in Yumurtalik, 650 m withdrawal and −25.99 m/yr erosion in Goksu, 660 m withdrawal and −16.10 m/yr erosion in Kizilirmak and 640 m withdrawal and −4.91 m/yr erosion in Yesilirmak) were observed for three periods (1989, 1999 and 2009). Wetland in Gediz delta which is 35.57 km^2 was converted to sea or salt pan for the period 1975 and 2009.

1. Introduction

Coastal zone monitoring is an important task in national development and environmental protection, in which, extraction of shorelines should be regarded as fundamental research of necessity (Rasuly et al., 2010). The shoreline is one of the 27 features recognized by IGDC (International Geographic Data Committee). A shoreline is defined as the line of contact between land and a body of water (Li et al., 2001). Information about coastline position, orientation and geometric shape is also essential for autonomous navigation, geographical exploration, coastal erosion monitoring and modeling, and coastal resource inventory and management (Liu and Jezek, 2004). Shoreline change is considered as one of the most dynamic processes in coastal area (Bagli and Soille, 2003; Mills et al., 2005). In many coastal areas in the developing countries, dense population being placed next to the shoreline creates the more vulnerable areas. It has become important to map the shoreline change as an input data for coastal hazard assessment (Marfai et al., 2008). With no exception coastal wetlands have been adversely affected by natural or anthropogenic activities. Coastal wetlands are important geographic areas because of their unique floral and faunal characteristics and they are also a component of world coastal ecology.

According to the Ramsar Convention on Wetlands, Article 1.1; "Wetlands are areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 m" (Ramsar, 2004). Wetland components provide many goods of great value and function including; fish, timber, fuel wood and tree products, wildlife, fertile land for agriculture, water supply, water transport, peat, flood control, storm protection, groundwater recharge, sediment–pollutant–nutrient retention, evaporation and preservation (Barbier et al., 1997; Ramsar, 2004; Daily et al., 1997; Mitsch and Gosselink, 2000). Besides, this importance coastal wetlands are under various natural and human caused threats including coastal erosion. Coastal erosion is the permanent loss of land along the shoreline and is usually the result of a combination of both natural and human induced factors. Most important natural factors are winds and storms, near shore currents, relative sea level rise and slope processes on the other hand, human induced factors of coastal erosion include coastal engineering, land claim, construction of dams or reservoir, dredging, mining and water extraction (Coastal Engineering Manual, 2002). As a result of coastal erosion shoreline position can change over the time.

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Knowledge of shoreline position is the basis for overcoming coastal problems, measuring and characterizing land and water resources, such as the area of the land, and the perimeter of coastline. The extraction of shoreline and water bodies is an important task useful for various application fields such as coastline change detection, coastal zone management, watershed definition and flood prediction. This task is difficult, time consuming and sometimes impossible for a large region, when using traditional ground survey techniques (Cracknell, 1999). Remotely sensed data can provide valuable preliminary estimates of change and is a unique tool for research and monitoring wetlands and deltaic environments (Ciavola et al., 1999; Yang et al., 1999). Moreover, maps generated from satellite data have a great potential to project recent changes of shorelines (Kevin and El Asmar, 1999; Shaghude et al., 2003).

Remotely sensed data were utilized for the analysis of shoreline change in coastal and deltaic environments in many researches. For example, Rebelo et al. (2009) used remote sensing and geographical information system (GIS) for wetland inventory, mapping and change analysis, Maiti and Bhattacharya (2009) analyzed shoreline change by using remote sensing and statistical approach, Genz et al. (2007) researched beach variation on Hawaii, Wal et al. (2002) researched long-term morphological change in the Ribble Estuary, northwest England, Ghanavati et al. (2008) used Landsat TM and ETM+ data in order to monitor geomorphologic changes of Hendijan River Delta, southwestern Iran. Wu (2007) monitored coastline evolution of Nouakchott region (Mauritania) using remote sensing methods, Vanderstraete et al. (2006) used different Landsat images to detect changes of the coastal zone near Hurghada in Egypt.

Remotely sensed data has also been used in Turkey as a powerful tool especially in coastal zone and city management. For example, Kuleli (2009) analyzed shoreline changes at the Mediterranean Coast in Turkey, Sesli et al. (2008) monitored the changing position of coastline using aerial photography and satellite images at the eastern coast of Trabzon. Bayram et al. (2008) monitored temporal coast line changes from Black Sea coast of European part of Istanbul, using Corona panoramic satellite photo, SPOT-4, PAN and IRS-1D PAN satellite images. Ekercin (2007) used multi-temporal Landsat images to monitor change detection at the Aegean Sea. Kuleli (2005) used multi-temporal satellite image for assessment and change detection of North-East Mediterranean Coast.

In this research, Yumurtalik Ramsar wetland including the coastal zone located in the Cukurova Delta, the Goksu Ramsar wetland located on Goksu River delta as a part of southeast Mediterranean Sea, Kizilirmak and Yesilirmak Ramsar wetlands in the Black Sea coastal zone and Gediz Ramsar wetland on Aegean coastal zone were investigated in point of coastline changes. Sedimentation, deposition, erosion and human uses for instance coastal agriculture, coastal engineering, land claim, dredging, mining and construction dams or reservoir have caused the morphological changes (accretion or erosion) of coastline along some parts of these important Ramsar wetlands. Natural and human induced processes and coastline changes were analyzed with the use of image processing methods, DSAS (Digital Shoreline Analysis Software) software, multi-temporal Landsat data and zonal change detection method.

2. Study area

Turkey presently has 13 sites designated as Wetlands of International importance, with a surface area of 179,898 ha and 5 of 13 wetlands are located in the coastal zone. These are Kizilirmak Delta (21,700 ha) in Black Sea coast, Gediz Delta (14,900 ha) in Aegean Sea coast, Akyatan Lagoon (14,700 ha), Goksu Delta (15,000 ha) and Yumurtalik Lagoons (19,853 ha) in Mediterranean Sea coast (URL-1).

Goksu Delta was designated as Ramsar Area in 13.07.1994 (Fig. 1). The site has approximately 15,000 ha surface in between 0 and 5 m elevations. Goksu Delta has been under protection as Specially Protected Area and Wildlife Reserve by national act. An important wetland delta located on a bird migration route. Sands and saline steppe cover large areas. The site supports reed beds, marshes, swamps, meadows and, in the surrounding area, agricultural fields. It is a refuge for internationally important numbers of wintering ducks. Up to 327 bird species occur, including the globally endangered *Phalacrocorax pygmeus* and *Pelecanus crispus*. Two species of endangered marine turtles nest in the area. Reptiles and amphibians (34 species) form a primary link in the food chain of waterbirds. Human activities include fishing, tourism, and conservation education. Remains of cities from Neolithic times through many subsequent civilizations are found there, including nearby Silifke Castle and ancient Seleucia. Non-point agricultural pollution and proposed dams present potential threats.

Yumurtalik Lagoons was designated as Ramsar Area in 13.07.1994 (Fig. 1). The site has approximately 19,853 ha surface in between 0 and 3 m elevations. Yumurtalik Lagoons have been under protection as Nature Conservation Site by national act. Lagoons comprise the whole of the alluvial delta formed by several rivers in the eastern Mediterranean Sea, with a broad array of freshwater and coastal habitat types which support sand dune vegetation, salt marsh vegetation, stream bank vegetation and ruderal vegetation of roadsides and field margins. The threatened sea turtles *Caretta caretta* and *Chelonia mydas* are supported, and the site is one of the key points where migratory birds on the Palearctic-Africa route meet, using the site as both a stopover and a wintering site. It is also a key area for fish reproduction. The main uses of the area are irrigation agriculture, commercial and artisanal fishing, and recreation.

Kizilirmak wetland site include dunes, beaches, shallow lakes, seasonal marshes, and wooded areas (Fig. 1). Dominant vegetation includes vast reed beds and seasonally flooded forest. Numerous species of waterbirds breed at the site, several of which are globally threatened. Over 92,000 waterbirds of various species winter at the site. Human activities include cattle grazing, reed cutting, fishing, and agriculture. In recent years, eutrophication, deforestation, illegal constructions, and coastal erosion have become increasingly problematic in Kizilirmak coastal wetland (URL-2).

Yesilirmak wetland is a candidate wetland that it is to be registered by Ramsar and it is also under national protection law of wetlands in Turkey (Fig. 1). Yesilirmak site is important for breeding waterbirds and congregations of wintering wildfowl. The majority of the latter are forced to spend the day at sea as a result of human disturbance, returning to feed in the delta at night. Yesilirmak is one of the largest delta on the Turkish Black Sea coast, the majority of which is now under agriculture. Ongoing drainage and irrigation projects threaten the areas of natural wetland. Pinus forests designed to stabilize the dunes and *Salix/Alnus* plantations threaten to native vegetation (URL-3).

Gediz delta has extensive coastal wetland with bays, salt and freshwater marshes, large saltpans, and four highly saline lagoons located at the mouth of the Gediz River near Izmir (Fig. 1). The site supports dry grasslands, arable land, and some woodland. The globally threatened pelican *P. crispus* breeds at the site. Delta is an important area for breeding, feeding, wintering, and sheltering internationally important numbers of numerous species of waterbirds. Human activities include fishing, agriculture, cattle grazing, and the largest salt production center in the country. A number of ancient cities, such as Leukai and Larissa, are found there. The Gediz River is of vital importance for agriculture in the region, but is becoming significantly polluted.

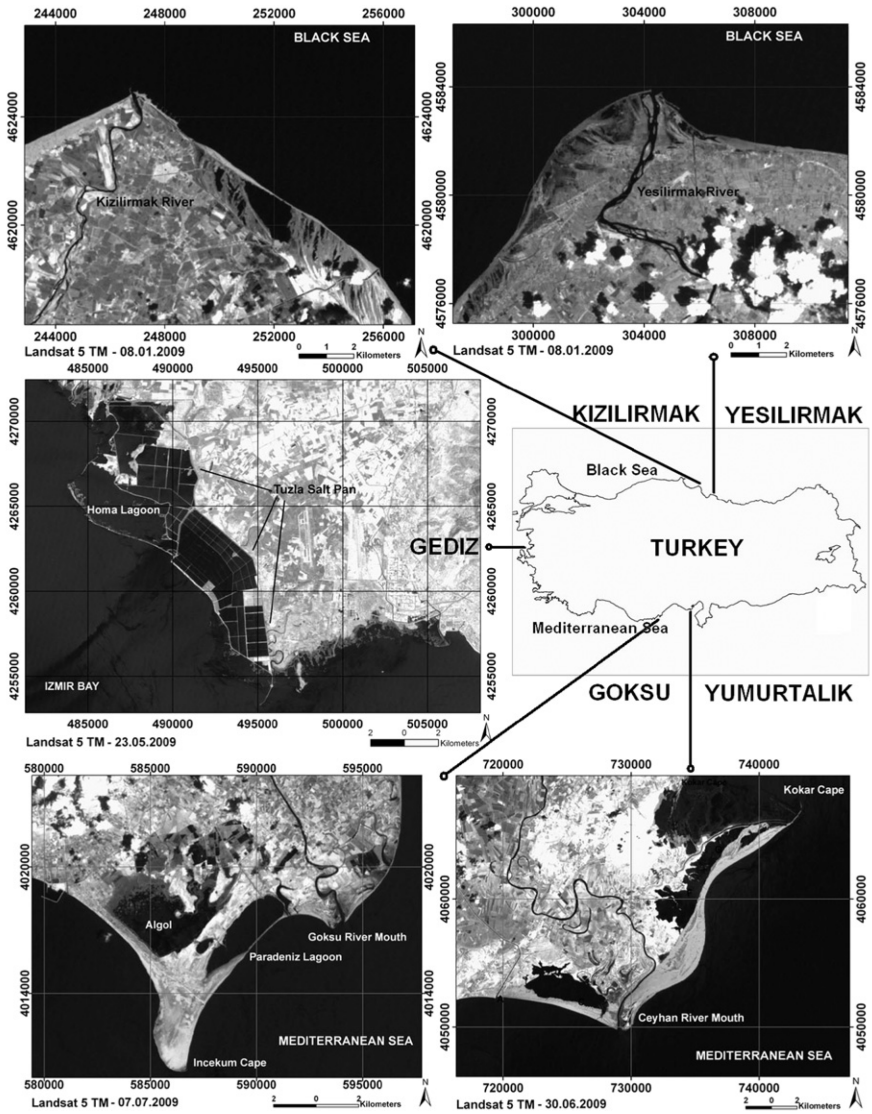

Fig. 1. Location of the study area.

3. Data and methods

Orthorectified and geodetically accurate global land data set of Landsat Multi-spectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) data have been widely used in coastal research and environmental studies for many years. Because of becoming the only record of global land-sea conditions at a spatial scale of tens of meter spanning over 37 yr, multi-spectral features and easy availability make Landsat suitable for monitoring water quality, glacier recession, sea ice movement, invasive species encroachment, coral reef health, land use change, deforestation rates and coastline change (Tucker et al., 2004).

To determine coastline change on Ramsar wetlands of Turkish coastal zone, multi-spectral and multi-temporal satellite images were used in the present study. Each image was acquired in different dates: Landsat MSS image acquired in 1972, Landsat TM in 1987, ETM+ image from 2002, TM image from 2009 and Landsat ETM+ between 1999 and 2001. Landsat MSS image has 60 m pixel resolution and TM image has pixel resolution of band 2 and 4 in 30 m, ETM+ band 2 and 4 particularly in 30 m which were archived on the Global Land Cover Facility (GLCF) server (URL-4).

All images were in the world reference system (WGS84) datum with GeoTiff format, and were projected using the Universal Transverse Mercator system (zone UTM 35–36 and 37 North) by Earth Science Data Interface (ESDI) (Luna and Robles, 2003; Yagoub and Kolan, 2006). Further information about the specifications of satellite data used in the study is given in Table 1.

Various techniques for coastline extraction and change detection from satellite imagery have been developed. Manual, write function memory insertion, image enhancement, multi-date data classification and comparison of two independent land cover classifications, density slice using single or multiple bands and multi-spectral classification, both supervised and unsupervised (e.g. ISODATA, PCA, Tasseled Cap) are the most common change detection techniques (Mas, 1999; Braud and Feng, 1998; Frazier and Page, 2000; Ryu et al., 2002). In addition, several image processing algorithms such as pre-segmentation, segmentation and post-segmentation have been used for automatic extraction of the coastlines from remotely sensed images (Liu and Jezek, 2004).

The methodology developed here consists of automatically delineating the land/sea boundary using segmentation algorithms that evaluate TOA (Top of the Atmosphere) reflectance of Landsat satellite images. The proposed methodology has four major components. The first component is the pre-processing and converting DNs to spectral radiance and reflectance for radiometric calibration. The second involves enhancing the TOA reflectance with NDWI index,

Table 1
Image data specifications.

No	Wrs	Path/row	Acq. date	Sensor	File type	Data source
Yumurtalik wetland						
1	1	188/035	1972/12/15	MSS	GeoTiff	ESDI
2	2	175/035	1987/08/10	TM	GeoTiff	ESDI
3	2	175/035	2002/12/12	ETM+	GeoTiff	USGS-EROS
4	2	175/035	2009/06/30	TM	GeoTiff	USGS-EROS
Goksu wetland						
5	2	176/035	1984/07/02	TM	GeoTiff	USGS-EROS
6	2	176/035	1998/08/26	TM	GeoTiff	USGS-EROS
7	2	176/035	2009/07/07	TM	GeoTiff	USGS-EROS
Gediz wetland						
8	1	194/033	1975/05/31	MSS	GeoTiff	USGS-EROS
9	2	181/033	1984/07/05	TM	GeoTiff	USGS-EROS
10	2	181/033	1987/05/11	TM	GeoTiff	USGS-EROS
11	2	181/033	2000/06/07	ETM+	GeoTiff	USGS-EROS
12	2	181/033	2009/05/23	TM	GeoTiff	USGS-EROS
Kizilirmak—Yesilirmak wetlands						
13	2	175/031	1989/08/02	TM	GeoTiff	ESDI
14	2	175/031	1999/08/22	TM	GeoTiff	ESDI
15	2	175/031	2009/08/01	TM	GeoTiff	ESDI

and the third is the histogram based segmentation of land and water based on automatic thresholding algorithm (Otsu, 1979). The final step is designed to differentiate the coastline edges from other object edges, and trace the coastline edge pixels into a vector representation. A flowchart of the proposed scheme is shown in Fig. 2 (Karsli et al., 2010).

In the first stage of this study, the digital numbers recorded by the Landsat TM and ETM+ were transformed to TOA reflectance using the method developed by Chander et al. (2009). The TOA reflectance of the Earth is computed according to Eq. (1):

$$Rr_{TOA} = \frac{\pi L_\lambda d^2}{ESUN_\lambda \cos\theta_s} \tag{1}$$

where Rr_{TOA} is planetary TOA reflectance, π is mathematical constant equal to ~3.14159, L_λ is spectral radiance at the sensor's aperture (W m^{-2} sr^{-1} μm^{-1}), D is Earth–Sun distance (astronomical units), $ESUN_\lambda$ is mean exo-atmospheric solar irradiance (W m^{-2} sr^{-1} μm^{-1}]) and θ_s is solar zenith angle.

According to Chander et al. (2009), when comparing images from different sensors, there are three advantages of using TOA reflectance instead of at-sensor spectral radiance. First, it removes the cosine effect of different solar zenith angles due to the time difference between data acquisitions. Second, TOA reflectance compensates for different values of the exo-atmospheric solar irradiance arising from spectral band differences. Third, the TOA reflectance corrects for the variation in the Earth–Sun distance between different data acquisition dates. These variations can be significant geographically and temporally. This is the reason that TOA reflectance of the Landsat images is used for present study.

NDWI index (bands 2 and 4 for Landsat) and automatic thresholding technique by Otsu (1979) and Sezgin and Sankur (2004) for TM Bands (4 and 2) and ETM+ with the same bands were used for the coastline delineation for coastal wetlands. Because it is more rapid and more robust than the other techniques, these methods were used to extract coastline from TM and ETM+ satellite images. Experimental results show that these methods give the best results. The NDWI is expressed as follows in Eq. (2) (Mcfeeters, 1996):

$$\mathrm{NDWI} = (\mathrm{Green} - \mathrm{NIR})/(\mathrm{Green} + \mathrm{NIR}) \tag{2}$$

where Green is a green band such as TM or ETM+ band 2, and NIR is a near infrared band such as TM or ETM+ band 4. This index is designed to (1) maximize reflectance of water using green wavelengths, (2) minimize the low reflectance of NIR by water features and (3) take advantage of the high reflectance of NIR by vegetation and soil features. As a result, water features have positive values and enhanced, while vegetation and soil usually have zero or negative values and therefore are suppressed (Mcfeeters, 1996; Xu, 2006). A clustering technique by Otsu (1979) is used for thresholding. To obtain an optimum threshold, minimized weighted sum of within-class variances of the foreground and background pixels are used. This method gives satisfactory results when the numbers of pixels in each class are close to each other. The Otsu method still

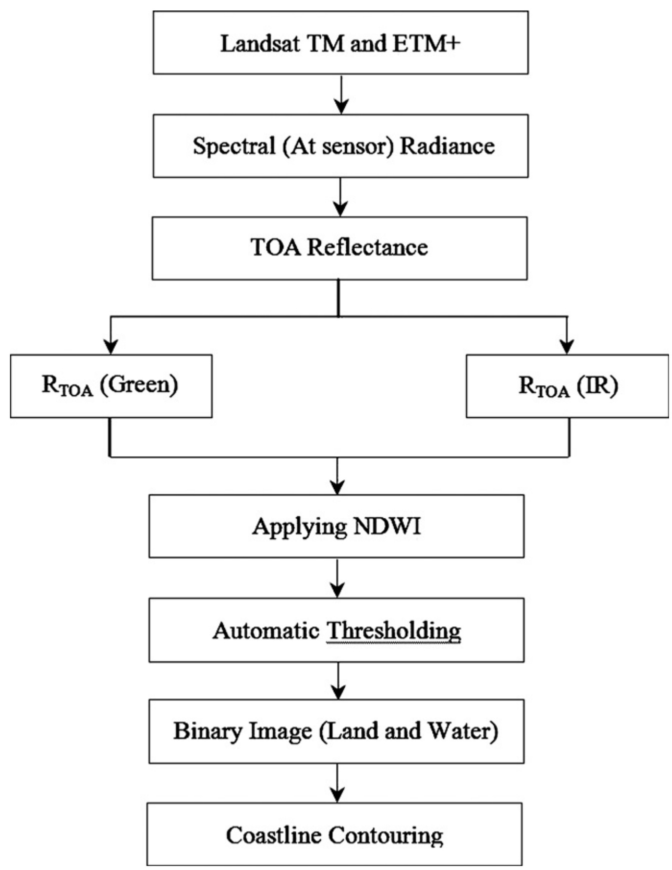

Fig. 2. Flowchart of the automatic coastline extraction methodology.

remains one of the most referenced thresholding methods (Sezgin and Sankur, 2004).

The purpose of image segmentation is to separate the image into its constituent homogeneous regions. The border pixels between segmented land/water regions can then be delineated as the coastlines. In order to reliably separate land objects from the ocean background, an automatic thresholding algorithm by Otsu (1979) is used for image segmentation. The thresholding method used in this study sets the threshold value automatically according to the local characteristics to achieve a good separation between the land and sea water. Also, a few pixels showing specification and intensity levels of the land can be eliminated using automatic thresholding. This result has improved the accuracy of the shoreline extraction. Coastline is delineated using binarized images which are produced from thresholding based segmentation algorithm. For this process, the threshold value calculated by Otsu was used to divide the result image to two main segments as water and land. After this stage, the detected coastline is transferred to GIS environment as a shape file for further processing and mapping.

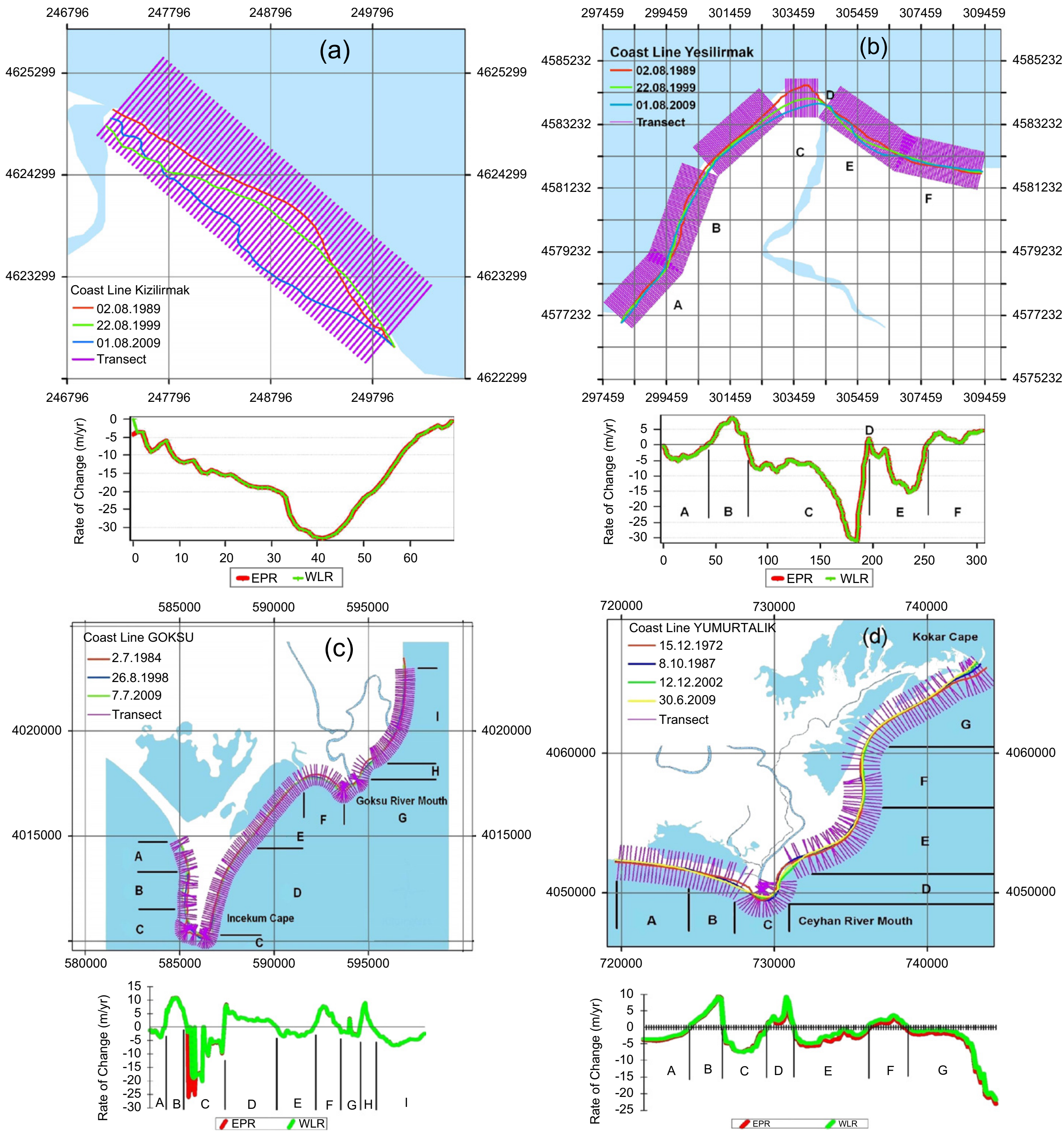

Fig. 3. The resulted rates of coastline changes (erosion or accretion) estimated at each transect are plotted alongshore of the study area (a: Kizilirmak; b: Yesilirmak; c: Goksu; d: Yumurtalik).

After the extraction of coastline from Landsat MSS, TM and ETM+ images the Digital Shoreline Analysis System (DSAS) was used to calculate the rate of coastline movement and changes. The DSAS is computer software that computes rate-of-change statistics from multiple historic shoreline positions residing in a GIS (Thieler et al., 2005). 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 the rate-of-change statistics. Based on the setting, DSAS program generates 353 transects that are oriented perpendicular to the baseline at a 100 m spacing and 35 km length along the Yumurtalik wetland shore (Fig. 3d). For the Goksu wetland shore DSAS program generates 264 transects that are oriented perpendicular to the baseline at a 100 m spacing and 26.4 km length (Fig. 3c). For the Kizilirmak (4 km alongshore) and Yesilirmak (16 km alongshore) wetlands 70 and 301 transects with 100 m spacing intervals were generated respectively (Fig. 3a and b). Gediz wetland is evaluated in terms of areal changes because the alongshore perpendicular changes are much lower than vertical zonal changes (Fig. 4). To assess the spatial and temporal movement trend of shoreline positions a hypothetical baseline was created similar to the actual coastline geometry with a position of 1250 m distance behind.

In this study, shoreline changes were estimated using two different statistical approaches. The End Point Rate (EPR) is calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and latest measurements at each transect. The Weighted Linear Regression (WLR) emphasis on data points where the shoreline position accuracy is lower on certain year (Thieler et al., 2005). In this study data uncertainty was ± 5 m and confidence interval was 95% determined as WLR parameter.

Several statistical methods were computed by the DSAS extension (end point rate, average of rates, linear regression, jackknife and average of endpoints). Linear regression was used to express the long-term rate of change for this study because it uses all of the available data and is an accepted method for computing long-term rates of shoreline change (Crowell and Leatherman, 1999). The resulted rates of shoreline changes (erosion or accretion) estimated at each transects are plotted alongshore of the study coastline in Fig. 3.

4. Results and discussion

In this research, coastline were extracted from satellite images for 1972, 1984, 1987, 1998, 2002 and 2009 by segmentation with histogram based on automatic thresholding method. The coastline rate of change was calculated using DSAS software and two different statistical techniques; End Point Rate (EPR) and Linear Regression Rate-of-Change (WLR). Baselines were constructed seaward of, and parallel to, the general trend of the shorelines. Using DSAS transects were spaced 100 m apart. Rates of shoreline change were calculated at each transect using linear regression. As a result of the analyses, the most significant changes were observed at the Kizilirmak and Yesilirmak wetlands. Summary statistics for the rate of change is given in Table 2.

Shoreline changes are presented with an emphasis on shoreline erosion, because it is an important natural coastal risk along coastal wetlands of Turkey. Table 2 summarizes rates of shoreline change as averages of all the changes, including both erosion and accretion, and as averages of only the erosion values and only the accretion values. Coastal area land loss is arising primarily because of natural changes in the coastal system, and as a consequence of human activities such as agriculture, irrigation, reclamation and fisheries. In Table 2 the positive rate of change shows the accretion and the negative rate of change indicates the erosion.

The Yumurtalik Ramsar wetland area was divided to 7 segments according to coastal morphology. In this area the net rate of erosion averaged over 353 transects was -4.13 m/yr. Accretion trend was around $+3.67$ m/yr for the same transects (Fig. 3d). Nine segments for the Goksu wetland were delineated accounting for -4.93 m/yr erosion rate and $+4.30$ m/yr accretion rate for 264 transects (Fig. 3c). Yesilirmak wetland represented by 6 segments with 301 transects which has -9.21 m/yr erosion and $+3.35$ m/yr accretion rates (Fig. 3b). For Kizilirmak wetland area only one segment was created with 70 transects due to the linearity of coastal morphology. Coastal erosion rate was found -16.10 m/yr and there was no accretion detected for studied period in this area (Fig. 3a). Yearly areal accretion in Gediz delta was around $+1.05$ km^2/yr and for the 34 yr period total change was $+35.57$ km^2 (Fig. 4).

The results of this study present that coastline changes such as erosion and accretion have caused the morphological changes at the

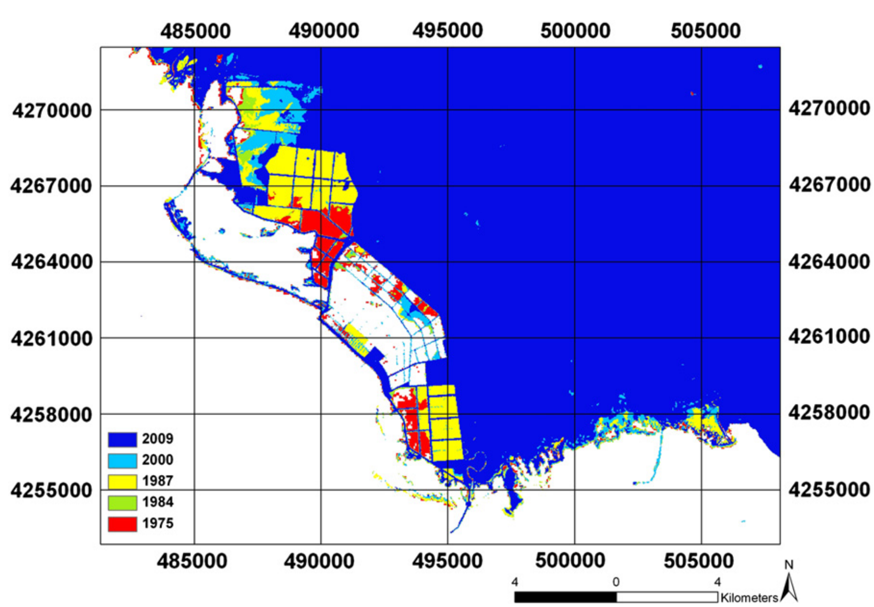

Fig. 4. The resulted rates of zonal changes of Gediz wetland.

Table 2
Coastline change trends for Ramsar wetlands of Turkey.

Region		A	B	C	D	E	F	G	Mean
YUMURTALIK									
Erosion trend	(m/yr)	−2.86	–	−5.27	–	−2.73	–	−5.67	−4.13
	(%)	13	–	13	–	21	–	24	71
Accretion trend	(m/yr)	–	+5.02	–	+3.79	–	+2.19	–	+3.67
	(%)	–	9	–	8	–	12	–	29
Number of transect (353)		46	33	45	27	74	41	87	–
Transect length (m)		2500	2500	2500	2500	2500	2500	2500	
Baseline length (m) (35,300)		4600	3300	4500	2700	7400	4100	8700	
Baseline distance from coastline (m)		1250	1250	1250	1250	1250	1250	1250	

Region		A	B	C	D	E	F	G	H	I	Mean
GOKSU											
Erosion trend	(m/yr)	−1.95	–	−11.14	–	−2.30	–	−1.68	–	−4.46	−4.93
	(%)	6	–	14	–	13	–	7	–	19	59
Accretion trend	(m/yr)	–	+7.47	–	+3.26	–	+3.87	–	+3.96	–	+4.30
	(%)	–	8	–	19	–	10	–	4	–	41
Number of transect (264)		15	21	36	50	35	25	19	12	52	–
Transect length (m)		1000	1000	1000	1000	1000	1000	1000	1000	1000	
Baseline Length (m) (26,400)		1500	2100	3600	5000	3500	2500	1900	1200	5200	
B. dist. from coastline (m)		1250	1250	1250	1250	1250	1250	1250	1250	1250	

Region		A	B	C	D	E	F	Mean
YESILIRMAK								
Erosion trend	(m/yr)	−3.13	–	−11.88	–	−8.31	–	−9.21
	(%)	13	–	36	–	17	–	66
Accretion trend	(m/yr)	–	+4.71	–	+1.20	–	+2.56	+3.35
	(%)	–	13	–	2	–	19	34
Number of transect (301)		40	41	108	5	50	57	–
Transect length (m)		1200	1200	1200	1200	1200	1200	
Baseline length (m) (16,000)		2000	2050	5400	250	2500	2850	
B. dist. from coastline (m)		500	500	500	500	500	500	

Region		–	Mean
KIZILIRMAK			
Erosion trend	(m/yr)	−16.10	−16.10
	(%)	100	100
Accretion trend	(m/yr)	–	–
	(%)	–	–
Number of transect (70)		70	–
Transect length (m)		1000	
Baseline length (m) (4000)		4000	
Baseline distance from coastline (m)		500	

Region		–	Mean
GEDIZ (*areal evaluation*)			
Erosion trend	(km^2/yr)	–	–
	(%/yr)	–	–
Accretion trend	(km^2/yr)	1.05	1.05
	(%/yr)	3	3
Total erosion (km^2)		–	–
Total accretion (km^2)		35.57	

coastal wetlands of Turkey. In Yumartalik and Goksu wetlands, coastal erosion is most significant at the Ceyhan river mouth and Kokar cape in Yumurtalik Ramsar shoreline, with the maximum coastline withdrawal about 765 m (Fig. 3c and d). Maximum erosion rate was found in Kokar cape coast line as −20.68 m/yr. This cape was moved about 765 m from east to west.

On the other hand coastal erosion is the most significant at the Incekum cape and Goksu River mouth in Goksu Ramsar shoreline, with the maximum coastline withdrawal about 650 m. Maximum erosion rate was found in Incekum cape coastline as −25.99 m/yr. In Kizilirmak and Yesilirmak wetlands, the highest rate of erosion was found −16.10 and −11.88 m/yr, respectively. Total erosion for the Kizilirmak wetland was observed around −16 m/yr and it was about −25 m/yr for Yesilirmak deltaic area (Fig. 3a and b). As a result of analysis in Gediz wetland, the coastline change was observed as zonal changes. This was caused by only human activities. The most remarkable change was considered as construction of a salt pan over a wetland and lagoon ecosystem in Homa Lagoon which is considered as a bird paradise by local authorities. These construction resulted loss of 35.57 km^2 of natural wetland. Also, the lagoon is a part of a large deltaic wetland ecosystem Gediz Delta which is under protection by Ramsar Convention.

According to findings of this study, local managers and decision makers should take into account the future of the wetlands under investigation by incorporating ecologic wetland management plans into city management projects. Furthermore, wetlands such as Kizilirmak and Yesilirmak should be preserved to avoid unrecoverable changes on their unique coastal environment as already erosion and accretion rates are very high mainly due to negative human impacts. Gediz wetland area is also under serious threat as zonal changes taking place in the region. State agriculture management bodies together with ministry of environment should raise public awareness in the region to leave this important wetland as ecologic tourism area and limit the agricultural practices by convincing local inhabitants of the region. Similar action plans are needed for Yumartalik and Goksu wetlands on the coast of Mediterranean sea. New regulations are also needed to monitor spatial and temporal changes of the wetlands of Turkey. Monitoring studies should be organized by municipalities of the regions and controlled by ministry of environment on a regular basis.

5. Conclusion

Ecologically and economically important deltaic coastal areas of Turkish coast have been under threat of erosion for many years. Human activities, sand extraction from beaches, reclamation for agriculture, agriculture on the sand dunes; fishery activities in lagoons, drainage (damming rivers or otherwise modifying their flows) have caused most of this threat. There are over 12 dams on Ceyhan rivers tributaries and they are used for hydroelectric generation, flood control and providing irrigation to agricultural region. Coastal erosion on Ceyhan river mouth was estimated as a result of dam's construction on river's basin, causing the loss of sediment transportation from hinterland of the river. Similar effects can also be observed for Kizilirmak, Yesilirmak and Gediz wetlands.

On the other hand, major threat is non-point agricultural discharges into the lakes and reedlands that contain high amounts of organic materials in wetlands. Also, dams that are planned or built could adversely affect on wetland shoreline. Tourism is another threat of the wetlands. The construction of holiday villages could degrade agricultural and natural values. Also illegal reed cutting and hunting affect natural values of the delta negatively.

Coastal accretion is most significant at the most part of the Black Sea that might be related to recently constructed international highway. Furthermore, coastal erosion is dramatically apparent at the some part of study area such as Kizilirmak and Yesilirmak wetlands. Goksu and Yumurtalik Ramsar wetlands are as an important part of Mediterranean coast. The alongshore patterns of shoreline changes along the Ramsar wetlands in Mediterranean Sea were highly variable, eroding and accreting beach segments were located close to one another. Slow but chronic erosion along the coast of Ramsar wetlands were common problem or threat at the Mediterranean, Aegean and Black Sea coasts in Turkey.

Landsat satellite images presents a useful tool for coastline extraction because of lower costs, moderate spatial resolution, and better spectral resolution than traditional survey works and other low spatial resolution satellite data.

One of the most important results of this study is the usage of temporal satellite images, because they are the most important data sources for coastal studies dealing with multi-temporal coastline change detection. Another important point of this study is that TOA reflectance instead of DN value was used and automatic detection techniques for shoreline delineation were studied. Moreover, the most significant importance of this study is to investigate shoreline changes on coastal wetlands that are very valuable ecological areas under protection of international conventions. Further studies are needed to see ecological health of the wetlands under investigation. Current regulations on wetlands management are not fully adequate to protect the deltaic areas. Even though, regulations regarding wetlands are very well written, control mechanism of application state is not the same. More effective control system should be considered to avoid illegal activities on coastal wetlands. Endemic species and ecologic state of the wetlands are very important issues as they also help to raise tourism attraction of the coastal areas. Therefore wetlands should be also taken into account in any coastal management activity.

Furthermore, it should be stressed that coastal wetland protection must be promoted in Turkey. Therefore, continuous monitoring of coastal areas can be achieved by using automatic detection methods based on efficient, accurate, objective, and replicable with multi-spectral satellite imagery. Due to anthropogenic stress on coastal regions as a permanent solution, public awareness must be triggered to overcome misusage of the coastal areas.

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