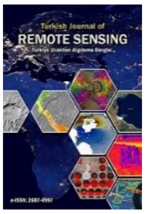
Araştırma Makalesi/Research Article
https://doi.org/10.51489/tuzal.1443490

2024; 6(1); 35-56

Turkish Journal of Remote Sensing

https://dergipark.org.tr/en/pub/tuzal

e-ISSN 2687-4997



Analysis of Manyas Lake Surface Area and Shoreline Change Over Various Periods with DSAS Tool

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Keywords
DSAS
Manyas Lake
Shoreline Change
Remote Sensing
GIS

ABSTRACT

In this study, the shoreline and lake surface area changes of Lake Manyas were analysed by using Geographical Information Systems (GIS) and Remote Sensing (RS) techniques for long term (1980-2020) and annual (2022) with DSAS tool. In the study, a formula was created using NDWI, MDWI, WRI water indices and NDVI, RVI, NDMI, GCI vegetation indices over Landsat satellite images of 1980, 1985, 1990, 1995, 2000, 2000, 2005, 2005, 2010, 2015, 2020 and all months of 2022, and shoreline extraction was performed. Then, shoreline and lake surface area change were analysed over different periods with NSM, EPR, SCE, LRR statistics in DSAS tool. According to the results of the analyses, the average shoreline changes between 1980 and 2020 was 139 m according to NSM statistics, 3,5 m/year according to EPR, 243.1 m according to SCE and 3.4 m/year according to LRR. While the shoreline extended a maximum of 1599 m, the minimum value was -403 m. From 1980 to 2020, 5.85 km^2 coastal accumulation, 1.03 km^2 coastal erosion and 146.5 km^2 permanent lake surface area data were determined on the surface area and shores of Lake Manyas. According to the monthly data of Lake Manyas for 2022, the shoreline is advancing by 18 m on average. Due to the natural dynamic process and the productive structure of the wetland system, the lake surface area reaches its widest size in April with 149.01 km^2 and its narrowest area is 146.05 km^2 in August. On the southern shores of Lake Manyas, reedbed development and coastal accumulation are intensely experienced with the progression of the Manyas Stream delta, while coastal erosion is observed on the northern shores.

Manyas Gölü Yüzey Alanı ve Kıyı Çizgisi Değişiminin Çeşitli Periyotlar Üzerinden DSAS Aracı ile Analizi

Anahtar Kelimeler:
DSAS
Manyas Gölü
Kıyı Çizgisi Değişimi
Uzaktan Algılama
CBS

ÖZ

Bu çalışmada Manyas Gölü'nün kıyı çizgisi ve göl yüzey alanı değişimi, Coğrafi Bilgi Sistemleri (CBS) ve Uzaktan Algılama (UA) teknikleri kullanılarak, uzun dönemli (1980-2020) ve yıllık (2022) olarak DSAS aracı ile analiz edilmiştir. Çalışmada 1980, 1985, 1990, 1995, 2000, 2005, 2010, 2015, 2020 yıllarına ait ve 2022 yılının bütün aylarına ait Landsat uydu görüntüleri üzerinden NDWI, MDWI, WRI su indeksleri ve NDVI, RVI, NDMI, GCI bitki indeksleri kullanılarak formül oluşturulmuş, kıyı çizgisi çıkarımı yapılmıştır. Daha sonra DSAS aracındaki NSM, EPR, SCE, LRR istatistikleri ile kıyı çizgisi ve göl yüzey alanı değişimi farklı periyotlar üzerinden analiz edilmiştir. Analiz bulgularına göre 1980-2020 yılları arasında ortalama kıyı çizgisi değişimi NSM istatistiğinde 139 m, EPR'ye göre 3,5 m/yıl, SCE'ye göre 243,1 m ve LRR'ye göre 3,4 m/yıl olarak saptanmıştır. Kıyı çizgisi maksimum 1599 m ilerken minimum değer olarak -403 m gerilemiştir. Manyas Gölü yüzey alanı ve kıyılarında 1980'den 2020 yılına kadar 5,85 km^2 kıyı birikimi, 1,03 km^2 kıyı erozyonu ve 146,5 km^2 daimî göl yüzey alanı verisi tespit edilmiştir. Manyas Gölü 2022 yılı aylık verilerine göre kıyı çizgisi ortalama 18 m ilerlemektedir. Doğal dinamik süreç ve sulak alan sisteminin üretken yapısı nedeniyle göl yüzey alanı en geniş boyutuna nisan ayında 149,01 km^2 ile ulaşmakta, ağustos ayında ise en dar alanı 146,05 km^2 olarak görülmektedir. Manyas Gölü güney kıyılarında sazlık alan gelişimi ve Manyas Çayı deltasının ilerlemesi ile kıyı birikimi yoğun şekilde yaşanırken, kuzey kıyılarda kıyı aşınımı gözlemlenmiştir.

Article Info

Received: 27/02/2024
Accepted: 28/04/2024
Published: 30/06/2024

Citation:

Uzun, M. (2024). Analysis of Manyas Lake Surface Area and Shoreline Change Over Various Periods with DSAS Tool. Turkish Journal of Remote Sensing, 6 (1), 35-56.

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1. INTRODUCTION

Coasts are geomorphological units that form the transition area between water bodies and land, develop and change with dynamic processes of different origin, and intersect various ecosystems (Erinç, 1986; Turoğlu, 2017). The boundary between land and water mass is formed by coastlines. Coastlines undergo changes in long and short periods under the influence of tectonic and eustatic movements, wave and sea currents, materials transported by fluvial processes and anthropogenic activities (Erol, 1989; Tian et al., 2020; Pouye et al., 2023). Temporal and spatial detection of the changes that occur and modelling with quantitative data play a very important role in the planning and management of coastal change and in determining the extent of change and risk of ecological conditions (Davidson-Arnott, 2010; Grottolli et al., 2023). In this respect, shoreline change in Turkey and the world is analysed by applying various techniques in many different areas (Tağıl & Cürebal 2005; Darwish et al., 2017; Ataol et al., 2019; Topuz, 2018; Kılar & Çiçek, 2018; Çoban, 2020; Song et al., 2021; Uzun, 2021; Yasir et al., 2021; Bombino et al., 2022; Gómez-Pazo et al., 2022; Kazı & Karabulut, 2023; Murray et al., 2023).

Detection of shoreline changes is carried out using Geographic Information Systems (GIS) and Remote Sensing (RS) techniques through maps, satellite images, LIDAR and UAV images (Hu & Wang, 2020). In analysing the data, access to images at the desired date, the width of the study area, resolution and cost are very important (Paz-Delgado et al., 2022). In this respect, Landsat satellite imagery, which is free of charge, provides many temporal data and provides medium resolution, is more preferred in many studies. In shoreline analyses based on satellite images, different techniques that provide quantitative data temporally and spatially can be used. One of these techniques is the Digital Shoreline Analysis System (DSAS) tool. DSAS reveals the distance, annual erosion and deposition amount and the spatial distribution of these quantitative data over shorelines of different time periods (Himmelstoss et al., 2018). The DSAS tool and its statistical analyses are widely used in shoreline change research (Kuleli, 2010; Hakkou et al., 2023; Kale et al., 2019; Nassar et al., 2019; Dereli & Tercan, 2020; Samra & Ali, 2021; Lazuardi et al., 2022; Siyal et al., 2022; Akdeniz & İnam, 2023; Dinç, 2023; Kaya et al., 2023; Kılar, 2023; Şenol et al., 2023; Uzun, 2023).

The advancement and retreat of the shoreline with different origins leads to coastal erosion and coastal accretion (Bird, 2008; Turoğlu, 2009; Pouye, et al., 2023). This situation can affect many natural and human elements on the coast and cause the emergence of different risks (Wu et al., 2022). In this respect, it is very important to examine coastal changes not only through the sea-land system but also as the intersection area of various hydrographic elements with terrestrial elements and to analyses the changes from different perspectives in terms of future planning. This situation reveals the necessity of analysing the coastal changes of many hydrographic and morphological elements such as lake coasts, river coasts, dam-pond coasts, marsh areas.

Lakes are very important natural resources in terms of geomorphological, hydrographic, climatological and floristic aspects. These natural environment conditions offer diversity in terms of different morphological, biological and chemical properties (Sikder et al., 2023). Some of the lakes also contain wetlands due to their depth of less than 6 meters, ecosystem structures, limnological units, terrestrial and aquatic floristic features (Davidson, & Finlayson, 2018; Ataol & Onmuş, 2021). Changes in lacustrine wetlands, which have a productive ecosystem structure, can occur due to natural and anthropogenic processes (Davidson & Finlayson, 2018; Woolway et al., 2020). In the last 100 years, surface and coastal changes have been experienced in many lake wetlands due to increasing anthropogenic demands, misuse and planning (Ataol & Onmuş, 2021). As a result of the accumulation of materials carried by the hydrographic elements that feed the lake, morphological changes may occur in the lake surface area and shoreline along with delta, reedbed, swamp and peatland areas (Zuzek et al., 2003; Hoşgören, 1994; Turoğlu, 2017). Anthropogenic factors such as basin-based use of lake wetland resources, eutrophication of different origins, direct and indirect water withdrawal for agricultural purposes, use as a freshwater source, wetland drying and agricultural land opening can also cause major changes in lake surface area and shoreline (Maltby & Barker, 2009; Ataol & Onmuş, 2021). These changes cause temporal and spatial changes in the lake surface area and shoreline, and the emergence of coastal accumulation and erosion areas (Duru, 2017). Temporal and spatial determination of changes can reveal very important data in terms of understanding natural dynamic processes, producing models for the future, revealing threats in the lake wetland and hydrographic structure and taking measures.

The aim of this study is to quantitatively analyse the changes in the surface area and shoreline of Manyas Lake, which is covered by the Ramsar Convention wetland, over different periods (long and short term) with DSAS tool and to determine the temporal and spatial dimensions of the changes.

The research area is located in the southern part of the Marmara Sea in northwestern Turkey. Located in the tectonic depression in the southern part of the Marmara Region, the lake forms the western part of the Karacabey depression. Manyas Lake surface area is administratively within the borders of Balıkesir province. According to the geographical coordinate system, Lake Manyas is located between 40°8'-

40°15' north latitude and 27°50' – 28°4' east longitude (Figure 1).

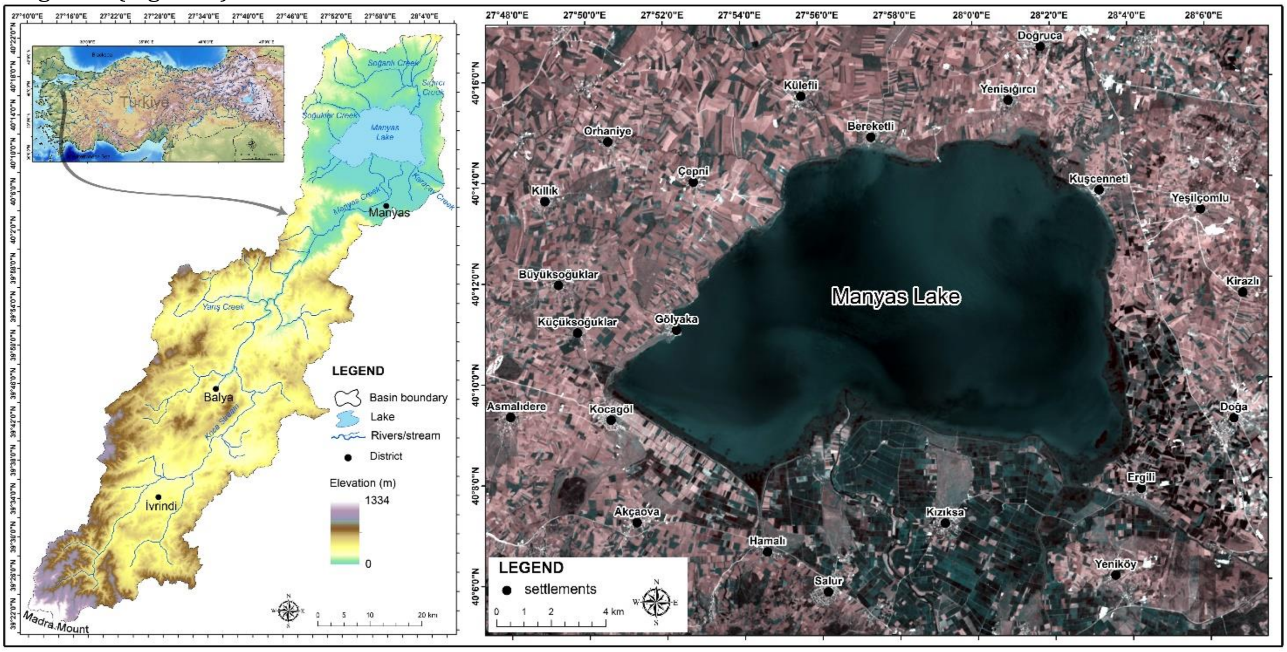

Figure 1. Location of the study area and Landsat satellite image of Manyas Lake in 2022

The average depth of the lake varies between 150-200 cm. The lake area, which is 14 m above sea level, varies seasonally, but is 146 km^2 on average. The main river source feeding the lake is Kocaçay Stream (Manyas Stream), which flows from the south to the north. The other main water source of the lake is the Sığırcı Stream flowing into the lake from the north. The outflow of the lake is Karaçay, which discharges from the southeastern part of the lake. The lake has been declared a Class A bird sanctuary due to its natural conditions, especially its ecosystem characteristics. In 1994, it constitutes Turkey's first five wetland lakes to be included in the scope of protection.

2. MATERIAL and METHOD

In the study, 1:25.000 scale topography sheets from HGM and Landsat satellite images from United States Geological Survey (USGS), written and printed sources of previous studies were used as materials. Firstly, the boundaries of Manyas Lake Basin were determined and a Digital Elevation Model (DEM) was created. Then, satellite images of 1980, 1985, 1990, 1995, 2000, 2005, 2010, 2015 and 2020 were obtained from Landsat (Table 1). In order to determine the monthly lake surface area and shoreline change, satellite images of each month of 2022 were also obtained from Landsat (Table 1). Atmospheric and radiometric adjustments of all satellite images were made in ArcGIS 10.8 software. In the long-term data to be analysed, a multispectral image was obtained by making a composite band without using the panchromatic band. In 2022, panchromatic band was used to capture the detail in the satellite images to be examined monthly and the bands were combined in this way. Then, the water surface band combination was applied to all satellite images and made suitable for examination before and after index analyses (Figure 3 and 12)

Before the analyses in the research, a systematic process of determining the shoreline in the most accurate way was established. Due to the presence of reeds on the shores of wetland lakes such as Lake Manyas, it is more difficult to determine the shoreline compared to other shores (Gao, 1996; Khorshiddoust et al., 2022; Şenol et al., 2023). For this reason, both water indices and green area and vegetation indices were used for shoreline determination (Table 2). In this respect, a study-specific formula was created using Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MDWI), Water Ratio Index (WRI) water indices and Normalized Difference Vegetation Index (NDVI), Ratio of Vegetation Index (RVI), Normalized Difference Moisture Index (NDMI), Green Chlorophyll Index (GCI) vegetation indices (Richardson & Wiegand, 1977; Myneni et al., 1995; McFeeters, 1996; Mcdonald et al., 1998; Xu, 2006; Shen & Li 2010; Janki et al., 2015) (Table 2). In the formula, vegetation index values were subtracted from water index values (Figure 2). The result obtained being greater than 0 indicates water surfaces. In this respect, the distribution of the formula result was reclassified. Shorelines were produced using the Threshold technique based on the binary classification (Pardo-Pascual et al., 2012; Hossain et al., 2021).

In the Threshold technique used in shoreline extraction, minimum and maximum threshold values in pixels are defined. In this respect, pixels smaller than the minimum threshold are excluded, pixels larger than the maximum threshold are considered strong and the water area is accepted (Hossain et al., 2021). The analysis was performed by assuming that the low-value pixels at the boundary between the land and water surface exceeded the threshold value in the neighbourhood of the high-value pixel. In the study, the lake surface area and shorelines of Manyas Lake were determined in the 5-year period between 1980-2020 and in all months in 2022 with the specified shoreline determination stages and finally the Threshold method.

In the study, Digital Shoreline Analysis System (DSAS) was used for spatial and statistical value analysis of shoreline changes. End Point Rate (EPR), Net Shoreline Movement (NSM), Shoreline Change Envelope (SCE) and Linear Regression Rate (LRR) statistics within the DSAS system were used in the study.

Table 1. Characteristics of the satellite images used in the study

5-year period from 1980 to 2020				**Months in 2022**			
Date	**Satellite and Sensor ID**	**Resolution (DPI)**	**Cloud Cover (%)**	**Date**	**Satellite and Sensor ID**	**Resolution (DPI)**	**Cloud Cover (%)**
07.09.1980	Landsat 2-MSS	60	0	07.01.2022	Landsat 9-OLI-TIRS	30	12,94
01.07.1985	Landsat 5-TM	30	0	05.02.2022	Landsat 9-OLI-TIRS	30	3,71
31.07.1990	Landsat 5-TM	30	0	25.03.2022	Landsat 9-OLI-TIRS	30	9,29
26.05.1995	Landsat 5-TM	30	0	10.04.2022	Landsat 9-OLI-TIRS	30	3,45
02.07.2000	Landsat 7-ETM	30	0	12.05.2022	Landsat 9-OLI-TIRS	30	0,24
08.07.2005	Landsat 7-ETM	30	1	05.06.2022	Landsat 8-OLI-TIRS	30	0,58
23.08.2010	Landsat 7-ETM	30	4	23.07.2022	Landsat 8-OLI-TIRS	30	0,17
17.05.2015	Landsat 8 OLI-TIRS	30	0,29	16.08.2022	Landsat 9-OLI-TIRS	30	0,95
01.07.2020	Landsat 8 OLI-TIRS	30	0,07	09.09.2022	Landsat 8-OLI-TIRS	30	0,12
				03.10.2022	Landsat 9-OLI-TIRS	30	3,57
				11.11.2022	Landsat 9-OLI-TIRS	30	1,77
				22.12.2022	Landsat 9-OLI-TIRS	30	0,85

Table 2. Water and vegetation indices used in the study

Index Name		**Formula**	**Reference**
Normalized Difference Water Index	**NDWI**	$NDWI = \frac{(P_{NIR} - P_{SWIR2})}{(P_{NIR} + P_{SWIR2})}$	(Tucker, 1979; McFeeters, 1996)
Modified Normalized Difference Water Index	**MNDWI**	$MNDWI = \frac{(P_{greem} - P_{SWIR2})}{(P_{green} + P_{SWIR2})}$	(Xu, 2006; Singh et al., 2015)
Water Ratio Index	**WRI**	$WRI = \frac{(P_{green} + P_{red})}{(P_{NIR} + P_{SWIR2})}$	(Shen & Li, 2010)
Normalized Difference Vegetation Index	**NDVI**	$NDVI = \frac{(P_{NIR} - P_{red})}{(P_{NIR} + P_{red})}$	(Myneni et al., 1995)
Ratio of Vegetation Index	**RVI**	$RVI = \frac{P_{red}}{P_{NIR}}$	(Richardson & Wiegand, 1977)
Normalized Difference Moisture Index	**NDMI**	$NDMI = \frac{(P_{NIR} - P_{SWIR1})}{(P_{NIR} + P_{SWIR1})}$	(Mcdonald et al., 1998)
Green Chlorophyll Index	**GCI**	$GCI = \frac{P_{NIR}}{P_{green}} - 1$	(Janki et al., 2015)

After the determination of the shoreline in the study, firstly, DSAS analyses were performed for 5-year periods between 1980-2020, and the changes in lake surface area and shoreline were examined. In 8 different periods between 1980-2020, analyses were made using DSAS tool and NSM and EPR statistics. Then, the lake surface area and shoreline changes in the 40-year period between 1980-2020 were analysed with NSM, EPR, SCE and LRR statistics.

Due to the hydrographic structure of Manyas Lake, the effect of climatological conditions and the presence of wetlands, it is known that the lake surface area and shoreline change seasonally and monthly. For this reason, satellite images of Lake Manyas for all months in 2022 were obtained. However, shoreline and lake surface analyses were performed in February, April, June, August, August, October and December due to cloudiness rates. The shoreline over the specified months was subjected to NSM, EPR, SCE and LRR statistics and analysed with the DSAS tool.

With all the findings obtained, Manyas Lake surface area and shoreline change were analysed with different statistics for short and long periods.

The amount of shore change, accumulation and erosion areas were determined and the annual lake surface area was modelled.

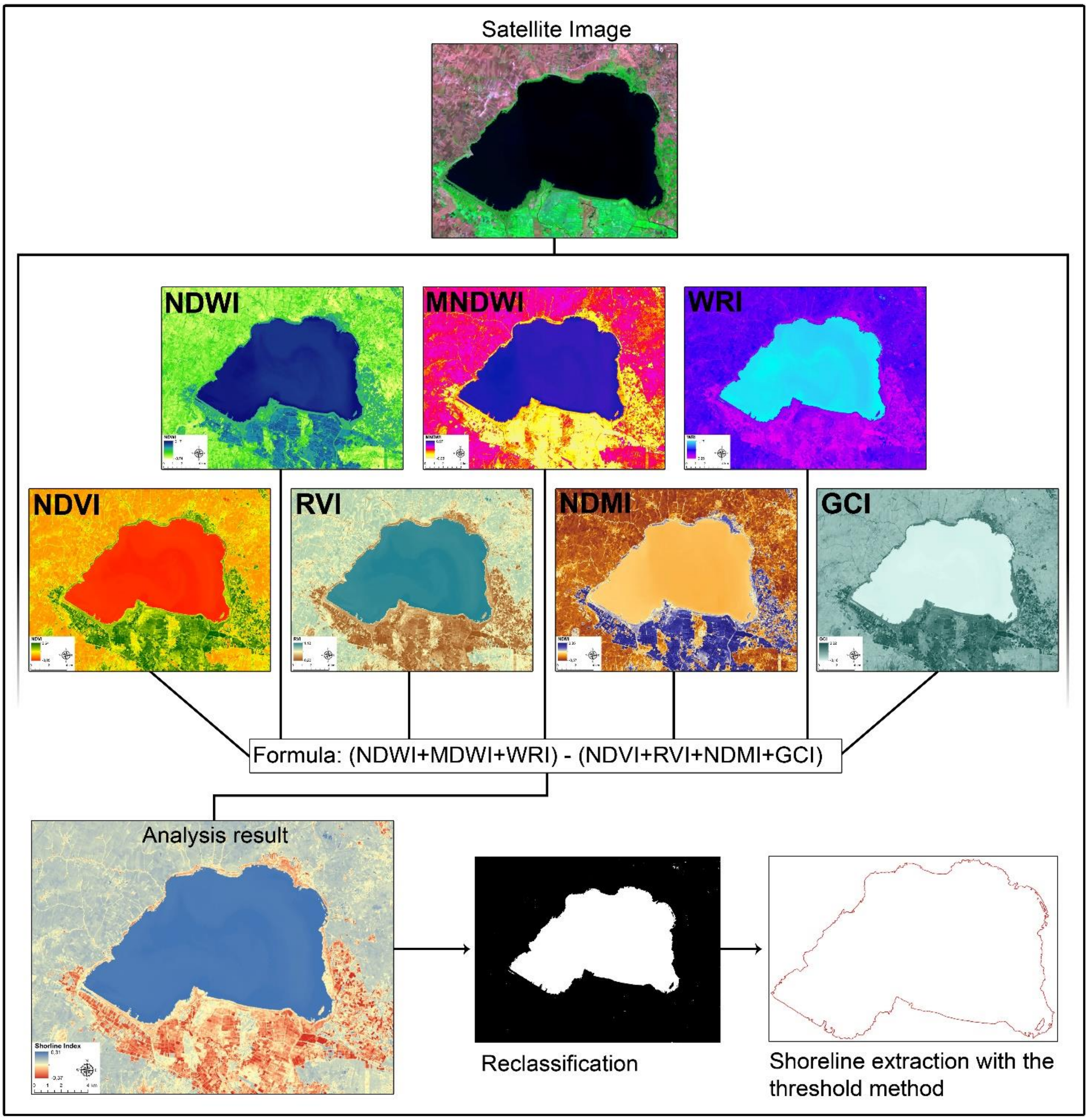

Figure 2. Work-flow diagram of the study and the method used to determine the shoreline

2.1. Analyses Used in Shoreline Change with DSAS Tool

The Digital Shoreline Analysis System (DSAS) enables statistical analysis of shorelines determined over different time periods uniformly and provides quantitative and distributional data (Himmelstoss et al., 2018). The basic working mechanism in the DSAS tool is based on drawing shorelines, drawing fixed baseline data, and assigning site- and width-specific transects. The shorelines analysed with DSAS also provide many quantitative data with statistical tests involving different algorithms. Net Shoreline Movement (NSM), End Point Rate (EPR), Shoreline Change Envelope (SCE) and Linear Regression Rate (LRR) statistics were utilized in the study.

The NSM statistic reveals the distance between the old and new shorelines during the periods analysed (Himmelstoss et al., 2018). With the NSM statistic, the average, maximum and minimum amount of the change value of the shorelines in the determined periods can be determined. The EPR statistic is calculated by dividing the old and new shoreline change distance in the determined period by time (Kılar & Çiçek, 2018). EPR results are used to explain the amount of annual coastal erosion and deposition (Song et al., 2021). SCE represents the greatest distance between all shorelines temporally over a given transect. Since there is no sign of the total distance between two shorelines temporally, the SCE value is always positive and expressed in meters. LRR is calculated by dividing all shorelines in the determined profile by time. LRR analysis allows calculations to be made by minimizing the error in shoreline change (Himmelstoss et al., 2018).

In the study, the baseline was first drawn to determine the shoreline change of Manyas Lake in the DSAS V5.0 tool installed as an ArcGIS plug-in, and then the shoreline dates and uncertainty value were entered (Himmelstoss et al., 2018). The transect (profile) interval determined for shoreline change is 50 meters in long and short-term analyses. NSM and EPR statistics were used for the 5-year periods between 1980-2020, NSM, EPR, SCE and LRR statistics were used for the long-term analysis including all shorelines 1980-2020 and for the monthly analyses in 2022.

Each period data analysed from the lake surface area and shoreline change analyses were then converted to polygon in ArcGIS software. Using ArcGIS-geoprocessing-union feature, coastal erosion and coastal accretion areas and quantitative values were determined between the past and present periods.

3. FINDINGS

3.1. Analysis of Manyas Lake Surface Area and Shoreline Change over Short Periods between 1980-2020

Landsat satellite images of 1980, 1985, 1990, 2000, 2005, 2010, 2015 and 2020 were analysed for the surface area and shoreline change of Manyas Lake (Figure 3). The shorelines of each year were determined based on the water band combination of satellite images and the index formula. From the analyses, it was determined that the shoreline and lake surface area of Manyas Lake were changed by deposition and erosion in certain areas.

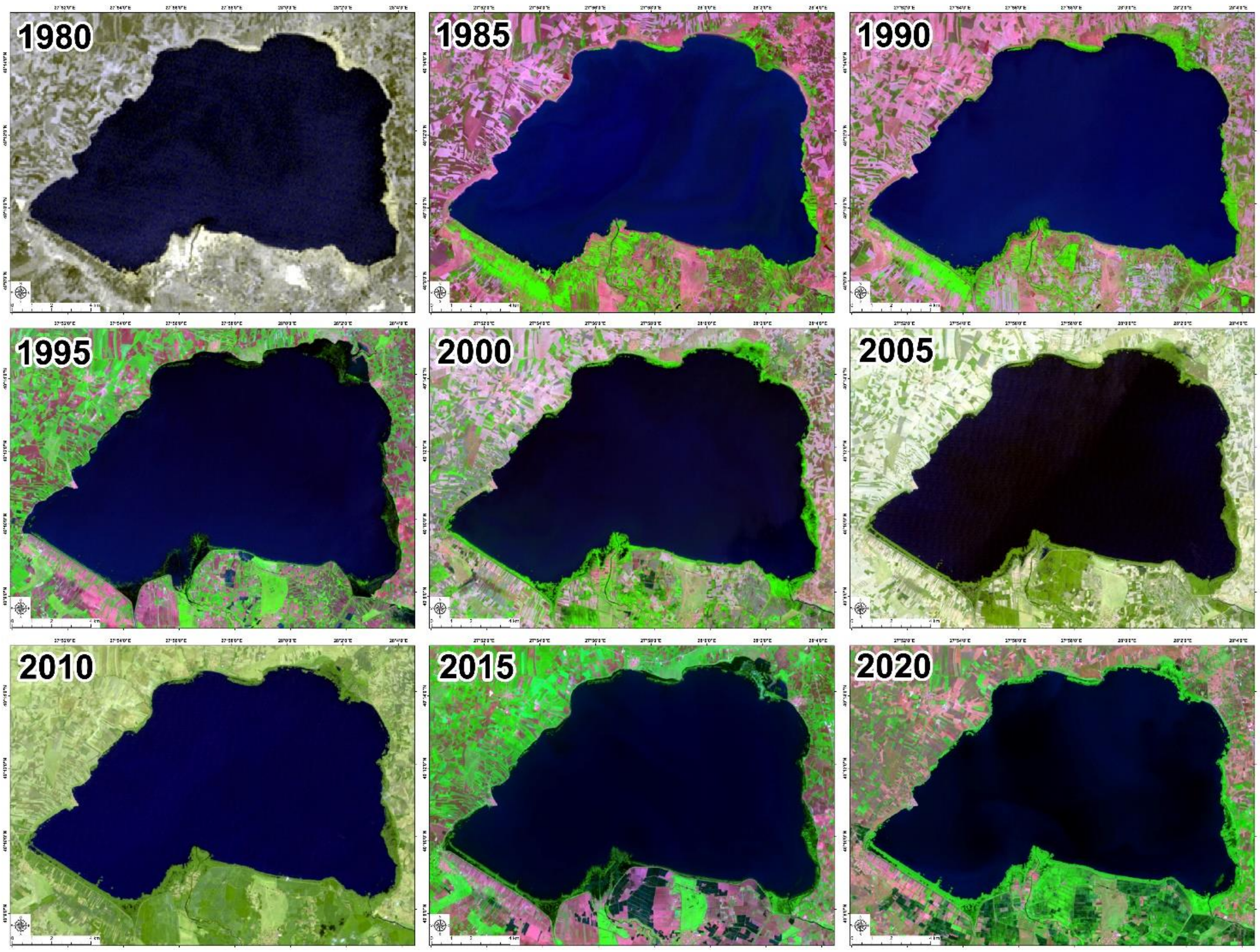

Figure 3. Five-year satellite images of Manyas Lake used in the study (1980-2020)

The shoreline length of Manyas Lake was calculated as 63.1 km in 1980, 64.6 km in 1985, 67.9 km in 1990, 81.1 km in 1995, 71.6 km in 2000, 68.7 km in 2005, 74.6 km in 2010, 69.7 km in 2015 and 73.5 km in 2020 (Figure 4). Natural dynamic processes, materials transported to the shore, seasonal and periodic climatological conditions, productive ecosystem structure of wetlands and vegetation factors have been effective in the variation of shoreline lengths. In this respect, the increase in the length of the shoreline in 1995 is related to the increase in the lake surface area due to seasonal precipitation according to the satellite image date (May) (Figures 3 and 4). Other temporal changes were due to the expanding delta area in the south of the lake, small islets emerging due to reed areas and the increase in the indentation and protrusion structure in the lagoonal environment. This change in the shoreline length of Manyas Lake indicates that the ecosystem structure of the lake is variable and affected by geomorphological processes and climatological conditions.

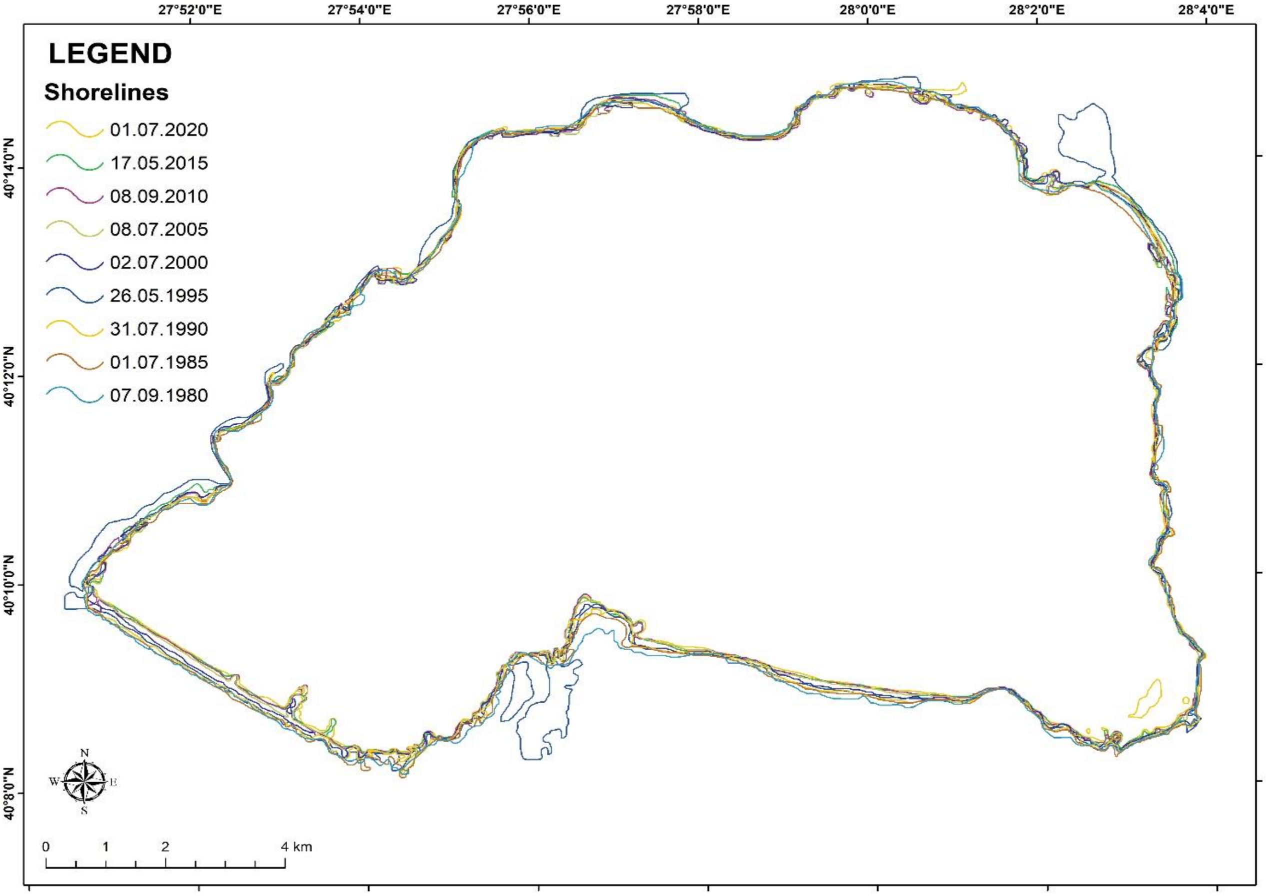

Figure 4. Shoreline of Manyas Lake in 5-year periods between 1980-2020

From the shoreline change analysis, it was determined that there is coastal accumulation in the southern part of Manyas Lake and the shoreline is advancing. In addition, the dynamic process formed by the rivers carrying material to the lake shores caused the shore progression to be observed in the Manyas Creek delta in the south of the shore and the expansion of reed beds and small islets. However, it was determined that coastal erosion occurred and coastal stretching occurred in the delta areas formed by short streams in the west and north of the lake. From the findings obtained, it was determined that different changes occurred in both shorelines and lake surface area in terms of quantitative and spatial distribution between 5-year periods. The change in the shorelines of Manyas Lake was analysed with NSM and EPR statistics in 5-year periods between 1980-2020 (Figures 5 and 6).

According to the results of NSM statistics, the maximum distance change of 796.9 m, minimum distance change of -213.8 m and average distance change of 28.5 m were determined in the shoreline of Manyas Lake during the 1980-1985 period (Table 3). In this period, coastal accumulation was observed in Manyas Stream (Kocaçay) delta and on the northern shores of the lake, while coastal erosion was observed on the eastern and western shores of the lake (Figure 5). According to NSM statistics, maximum 374 m, minimum -132.8 m and average 8.1 m distance change was observed in the shoreline during 1985-1990 period (Table 3). In this period, the positive shore change area is in the form of coastal accumulation in the southern part of the lake and especially in the delta area. Coastal erosions are concentrated in the reeds and delta areas in the western part of the lake (Figure 5). According to the NSM analysis in the 1990-1995 period, the maximum shoreline change was 208.1 m, the minimum was -567.6 m and the average was -37.2 m (Table 3). 1995 satellite image is taken from the seasonally wetter period and due to the climatological conditions, it is observed that the negative coastal progression peaks in the change data. Especially in the deltas of Sığırcı Creek in the north and Manyas Creek in the south, it was determined that the lagoonal environments expanded and the lake surface area moved into the land area (Figure 5). In the 1995-2000 period, according to the NSM statistics, a maximum distance of 600.8 m, a minimum distance of 173.8 m and an average shoreline change distance of 64 meters were determined (Table 3). Contrary to the previous period, in the 1995-2000 period, coastal erosion areas increased especially on the southern shores due to the shrinkage of the lake area (Figure 5).

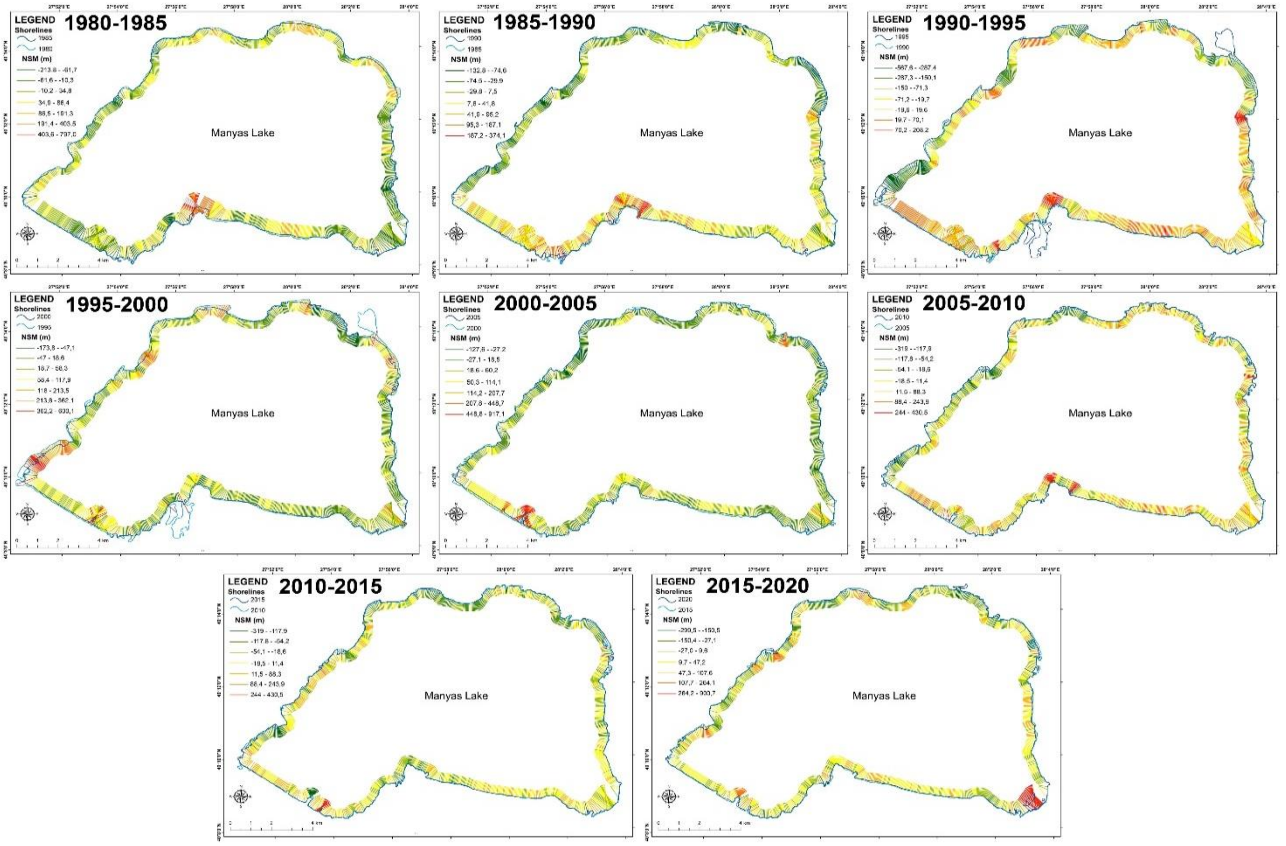

Figure 5. The result of NSM statistical analysis of the shoreline change of Manyas Lake in 5-year periods between 1980-2020

According to the NSM analysis between 2000-2005, a maximum of 917.1 m, a minimum of -127.6 m and an average shoreline change of 46.3 meters were determined (Table 3). Especially the plant development in the reed areas in the southwest of the lake caused the shoreline progression to reach its maximum extent. Coastal erosion areas are observed on the eastern and western shores of the lake (Figure 5). In the period between 2005-2010, according to the NSM analysis, a maximum distance change of 212.5 m, a minimum distance change of -215.3 m and an average distance change of 4.4 meters were determined (Table 3). In this period, as in the other periods, it is observed that there is coastal accumulation in the reeds and delta area in the south of the lake, and coastal erosion on the western and northern shores (Figure 5). According to the results of NSM statistics in the period between 2010-2015, the maximum distance change of 430.4 m, minimum distance change of -319 m and average distance change of -15.7 m were analysed (Table 3). During this period, shore accumulation is observed in the reed areas in the southwest of the lake, and shore erosion is observed on the western and northern shores (Figure 5). In the period between 2015 and 2020, a maximum distance change of 900.6 m, a minimum distance change of -359 m and an average distance change of 62.9 meters were recorded (Table 3). As in other periods, the accumulation areas on the southern shores of the lake attract attention in this period. Coastal erosion is observed in some reed areas on the northern and western shores of the lake (Figure 5).

Table 3. NSM and EPR statistical results of Lake Manyas shoreline in the determined periods

	NSM (m)			EPR (m/year)		
Period	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**	**Minimum**
1980-1985	28,5	796,9	-213,8	5,9	165,6	-44,4
1985-1990	8,1	374	-132,8	1,6	73,6	-26,1
1990-1995	-37,2	208,1	-567,6	-7,7	43,1	-117,7
1995-2000	64	600,8	-173,8	12,5	117,7	-34,1
2000-2005	46,3	917,1	-127,6	9,2	182,9	-25,4
2005-2010	4,4	212,5	-215,3	0,8	41,1	-41,6
2010-2015	-15,7	430,4	-319	-3,3	91,8	-68
2015-2020	32,7	900,6	-299,5	6,3	175,7	-58,4

When the average values of the NSM data analysed in 5-year periods of the shoreline change of Lake Manyas are examined, the maximum shoreline change distance of 555 m, minimum -256.1 and average 16.3 m were calculated. This situation shows that the lake surface area is shrinking and coastal accumulation is increasing, although there are different change sizes on the shores. Especially the reeds on the southern shores of the lake and the coastal accumulation areas in Manyas Creek delta attract attention.

According to the results of the EPR statistics of the shoreline change of Manyas Lake for the period between 1980-1985, the maximum shoreline change value of 165.6 m/year, minimum shoreline changes value of -44.4 m/year and average shoreline change value of 5.9 m/year were calculated (Table 3). During this period, positive changes were found in Manyas Creek delta and other deltas with various small areas, and negative changes were found in the east and west of the lake (Figure 6). In the period between 1985-1990, according to the results of EPR statistics, maximum 73.6 m/year, minimum -26.1 m/year and average 1.6 m/year changes in the shoreline were calculated (Table 3). During this period, coastal accretion occurred on the southern shores of the lake, while coastal erosion was observed on the northern and western shores (Figure 6). According to the EPR result between 1990-1995, the maximum change of 43.1 m/year, minimum change of -117.7 m/year and average change of -7.7 m/year were calculated (Table 3). It is seen from the findings that the lake surface area expansion in the 1995 satellite image is reflected in the data in the EPR analysis as in the NSM statistics (Figure 6). According to the results of the EPR statistics between 1995 and 2000, a maximum change of 117.7 m/year, a minimum change of -34.1 m/year and an average change of 12.5 m/year were determined (Table 3). Contrary to the previous period, it is seen that the positive values are more in this period and the coastal accumulation is concentrated on the lake shores (Figure 6).

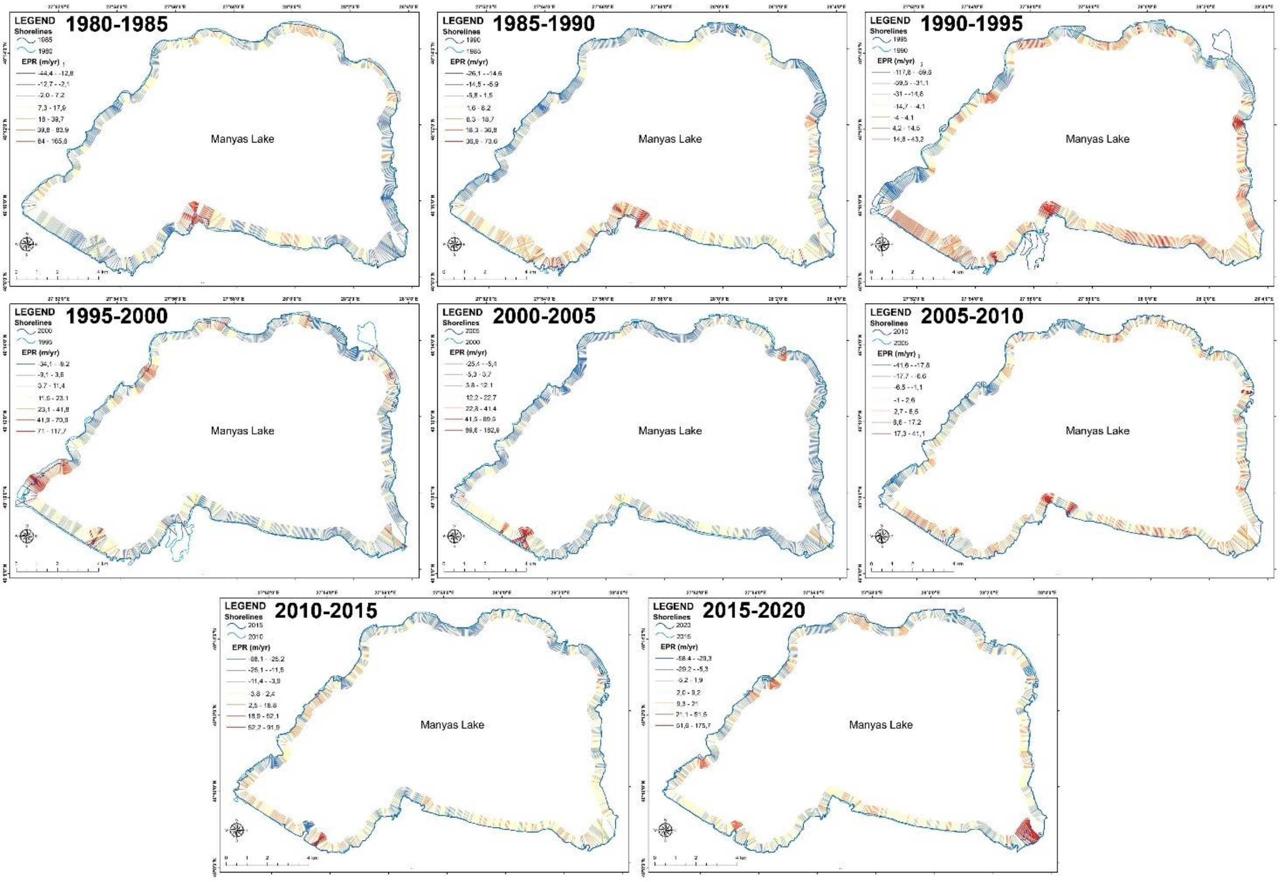

Figure 6. EPR statistical analysis results of the shoreline change of Manyas Lake in 5-year periods between 1980-2020

According to the EPR statistic data, maximum 182.9 m/year, minimum -25.4 m/year and average 9.2 m/year changes were recorded between 2000-2005 (Table 3). During this period, positive changes (coastal accumulation) on the southern shores of the lake and negative changes on the western shores are noteworthy (Figure 6). In the period between 2005-2010, according to the EPR analysis, a maximum change value of 41.1 m/year, a minimum change value of -41.6 m/year and an average change value of 0.8 m/year were obtained (Table 3). In this period, it was determined that the shoreline change was in the reed marsh areas in the west and southwest, while the extent of change in other areas showed very low values (Figure 6). In the period between 2010-215, according to EPR statistics, maximum

91.8 m/year, minimum -68 m/year and average -3.3 m/year changes in the shoreline were determined (Table 3). In this period, coastal advancement in the reeded area in the southwest of the lake and coastal stretching on the eastern and northern shores constitute the dominant processes (Figure 6). In the period between 2015 and 2020, according to the EPR statistics, a maximum change distance of 175.7 m/year, a minimum change distance of -58.4 m/year and an average change distance of 6.3 m/year were calculated (Table 3). During this period, shore advancement is observed in the reed areas and delta area on the southern shores of the lake, and shore retreat is observed in various parts of the northern shores (Figure 6).

When the average values of the EPR data analysed in 5-year periods of the shoreline change of Manyas Lake were examined, it was found that the maximum shoreline change was 111.4 m/year, the minimum was -51.9 m/year and the average was 3.1 m/year. Although there are different areas and sizes of change between the periods, it was determined that coastal accumulation occurred on the southern shores of Manyas Lake and coastal erosion occurred in certain areas of the western and northern shores. From the analyses, it is seen that the changes in NSM and EPR statistics are spatially similar. Since Manyas Lake is fed by short streams with low flow rates from the north and west, it was determined that coastal erosion occurs on these shores, while in the south, coastal accumulation is high due to the delta progression with the material carried by Manyas Creek, which is the continuation of Kocaçay, and the expansion of the reed area in the southwest.

With the change in the shoreline of Manyas Lake, changes also occur in the surface area of the lake over the years (Figures 7 and 8). The surface area of Lake Manyas was 152.4 km² in 1980, 151.1 km² in 1985, 150.8 km² in 1990, 155.1 km² in 1995, 149.7 km² in 2000, 147.8 km² in 2005, 147.8 km² in 2010, 148.6 km² in 2015 and 147.5 km² in 2020 (Figure 8). Although increasing and decreasing trends are observed in the lake surface area in certain periods, it was determined that the surface area of Manyas Lake was in a decreasing trend between 1980-2020. This situation reveals that the accumulation and erosion areas on the lake shore vary between the periods, but the coastal accumulation is more in the long term.

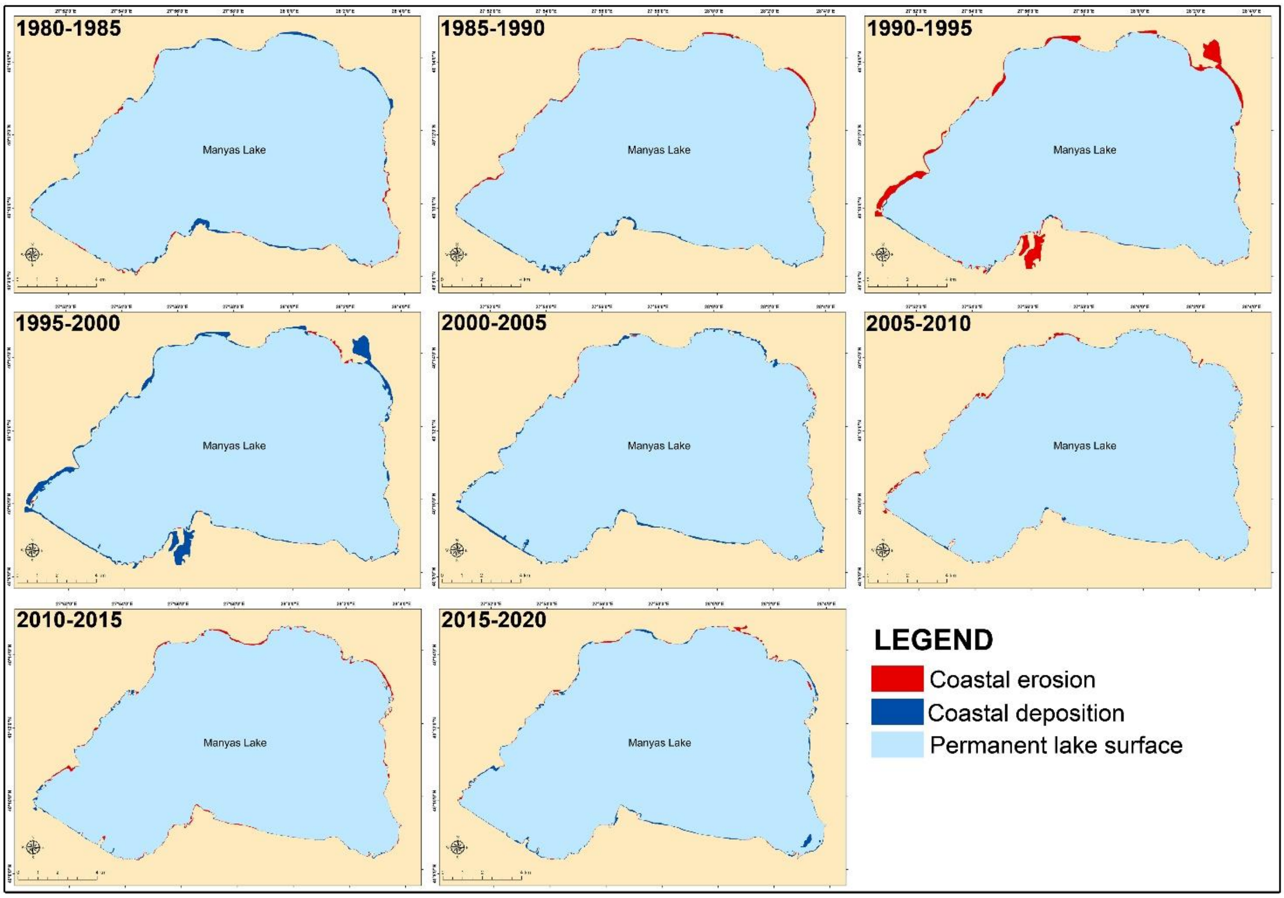

Figure 7. Distribution of coastal erosion and coastal deposition of Manyas Lake in 5-year periods between 1980-2020

The change in the surface area and shoreline of Manyas Lake between 1980 and 1985 resulted in 2.06 km² of coastal accumulation and 0.72 km² of coastal erosion (Figures 7 and 8). During this period, the permanent lake surface area was calculated as 150.3 km². During this period, coastal accumulation was observed most prominently in the Manyas Creek delta and in the reed areas in the north of the lake.

Coastal erosion was observed at various places on the eastern and western shores of the lake. Between 1985 and 1990, 1.3 km² of shore accumulation, 1.04 km² of shore erosion and 149.7 km² of permanent lake surface area were calculated (Figures 7 and 8). During this period, coastal accretion was completely observed in the southern and eastern parts of the lake, while coastal erosion intensity was detected on the northern and western shores. Between 1990-1995, 0.71 km² of coastal accumulation, 5.02 km² of coastal erosion and 150.1 km² of permanent lake surface area were determined in Manyas Lake (Figures 7 and 8). The observation of a large area of water surface spread in Manyas Creek and Sığıcı Creek deltas in this period is due to the fact that the satellite data of 1995 was temporally in May and the lake water input was higher in this period compared to the summer months. In the period between 1995 and 2000, 5.67 km² of coastal accumulation, 0.28 km² of coastal erosion and 149.4 km² of permanent lake surface area were detected (Figures 7 and 8). In contrast to the previous period, the fact that the coastal accumulation was observed at a value much higher than the general trend in this period is related to the fact that the satellite data coincides with the time that provides more hydrographic input periodically. In the period between 2000-2005, 2.2 km2 of coastal accretion, 0.27 km² of coastal erosion and 147.5 km² of permanent lake surface area were detected in Manyas Lake (Figure 8). In this period, the most prominent coastal accumulation was observed in the delta area and reeds in the southern part, while coastal erosion was observed in various areas on the east and west coasts (Figure 7). In the period between 2005 and 2010, 0.76 km2 coastal accumulation, 0.81 km² coastal erosion and 147.06 km² permanent lake surface area were determined. In this period, narrow shore deposits were detected in the southern part of the lake and shore erosion was detected in the reeds and wetlands in the west. Between 2010 and 2015, 0.62 km² of coastal accumulation, 1.34 km² of coastal erosion and 147.2 km² of permanent lake surface area were detected (Figure 7 and 8). In this period, the change in the satellite data dates increased the lake surface area and coastal erosion areas. In the period between 2015-2020, 1.66 km² of coastal accumulation, 0.63 km² of coastal erosion and 146.9 km² of permanent lake surface area were detected in Manyas Lake. During this period, accumulation areas were found on the southern shores of the lake and coastal erosion was found on various shores in the north (Figure 7).

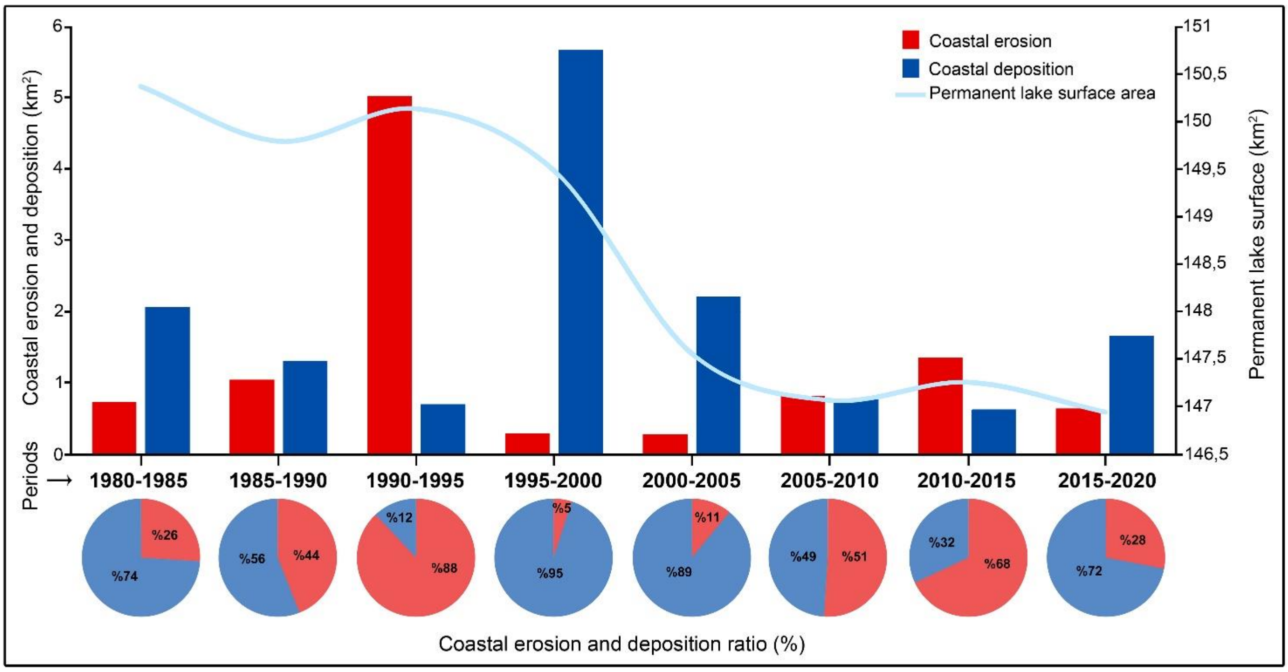

Figure 8. Numerical values of coastal erosion and coastal accretion of Manyas Lake in 5-year periods between 1980-2020

Although coastal erosion and coastal accretion show periodic differences in the surface area and shoreline of Manyas Lake between 1980 and 2020, it is understood from the analyses that the trend is in the direction of coastal accretion. In addition, it was determined that the trend of permanent lake surface area in the specified periods was in the direction of decrease (Figure 8). This situation quantitatively reveals that there is a decreasing trend in the sources that make up the water budget of the lake. In addition, the expansion in the Manyas Creek delta and the coastal stretching in the Sığırcı Creek delta, which has a narrower basin area, show the role of natural dynamic geomorphological processes in the coastal change of Manyas Lake. The change in the water budget due to the seasonal variation of the climatological conditions in Lake Manyas and its basin was also observed in the change data on certain dates (Figure 7 and 8).

3.2. Long-term Change Analysis of Manyas Lake Surface Area and Shoreline between 1980-2020

NSM, EPR, SCE and LRR statistics were analysed on 9 shorelines of Manyas Lake between 1980 and 2020 (Figure 9 and Table 4). According to the results of NSM statistics, the maximum distance change of 1585.5 m, the minimum distance change of -403.7 m and the average distance change of 139.8 m were determined on the shoreline of Manyas Lake as in the long period between 1980-2020 (Table 4). In the 40-year long term interval, the change in the shoreline of Manyas Lake was realised in the form of coastal accretion in the Manyas Creek delta and in the reedy area extending NW-SE to the west, in the reedy islets around the Karaçay gorge and in small deltas on the eastern shores (Figure 9). During this period, the changes were concentrated on the western and northern shores of Manyas Lake, and coastal erosional changes occurred in the Sığırcı Creek delta and Soğuklar Creek delta. The quantitative data of the NSM analysis show that the surface area of Manyas Lake has shrunk over the 40-year period and an average coastal advance of 134 metres has occurred.

When the graph of the NSM statistics of the shoreline change of Manyas Lake between 1980-2020 is analysed, it is seen that the coastal accumulation is more intense and wider in terms of dimension (Figure 10). It is understood that the coastal accumulation above 1000 metres, especially on the southern shores of the lake, is concentrated around the Manyas Creek delta, reedbed area and Karaçay Creek gorge. While the accumulation and erosion areas on the eastern shore of the lake form the geomorphological process together, erosion areas on the northern and western shores attract attention.

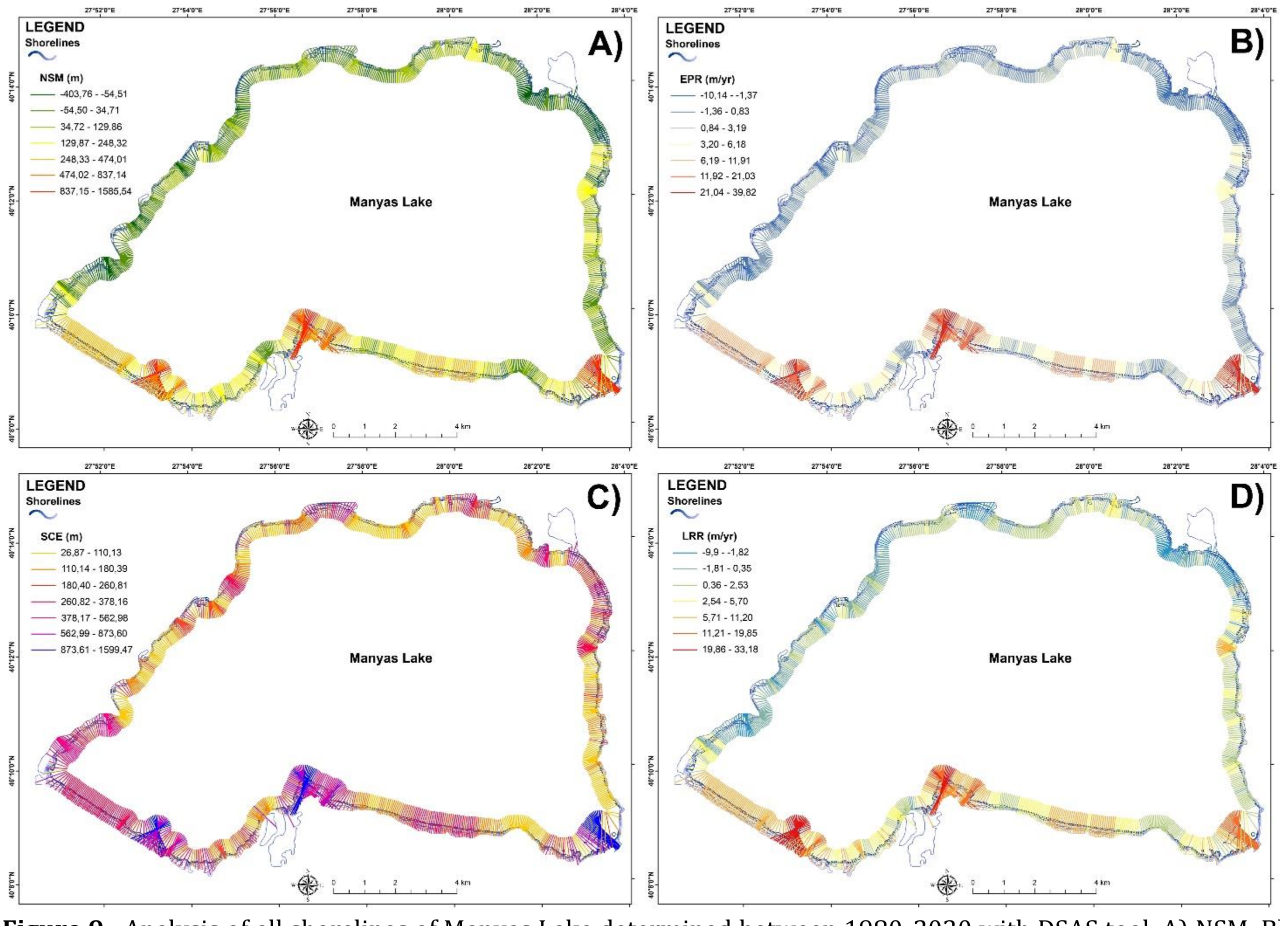

Figure 9. Analysis of all shorelines of Manyas Lake determined between 1980-2020 with DSAS tool. A) NSM, B) EPR, C) SCE and D) LRR

According to the results of EPR statistics in the long term between 1980 and 2020, maximum 39.82 m/year, minimum -10.14 m/year and average 3.51 m/year changes in the shoreline of Manyas Lake were calculated (Table 4). During this period, it was determined that changes were experienced in the form of coastal advancement on the southern shores of Manyas Lake, especially in the Manyas Creek delta, the shores of Karaçay gorge and the reeds in the southwest, and coastal retreat on the western and northern shores of the lake (Figure 9).

According to the SCE statistics, the maximum, minimum and average distance change of 1599.4, 26.8 and 243.1 metres, respectively, were determined in the shoreline of Manyas Lake between 1980 and 2020 (Table 4). The highest shore advance was found in the Manyas Creek delta, the reed area in the west and the reed area in the southeast of the lake. Minimum values were observed in various areas on the north, east and west coasts (Figure 9). According to LRR statistics, the maximum change of 33.18 m/year, minimum change of -9.9 m/year and average change of 3.44 m/year were calculated for the period between 1980 and 2020 (Table 4). The areas with the highest change are the southern shores of the lake, especially the Manyas Creek delta and reed areas (Figure 9). According to the LRR statistic, the areas with minimum change in the long term are the Sığırcı Creek delta and the western shores of the lake.

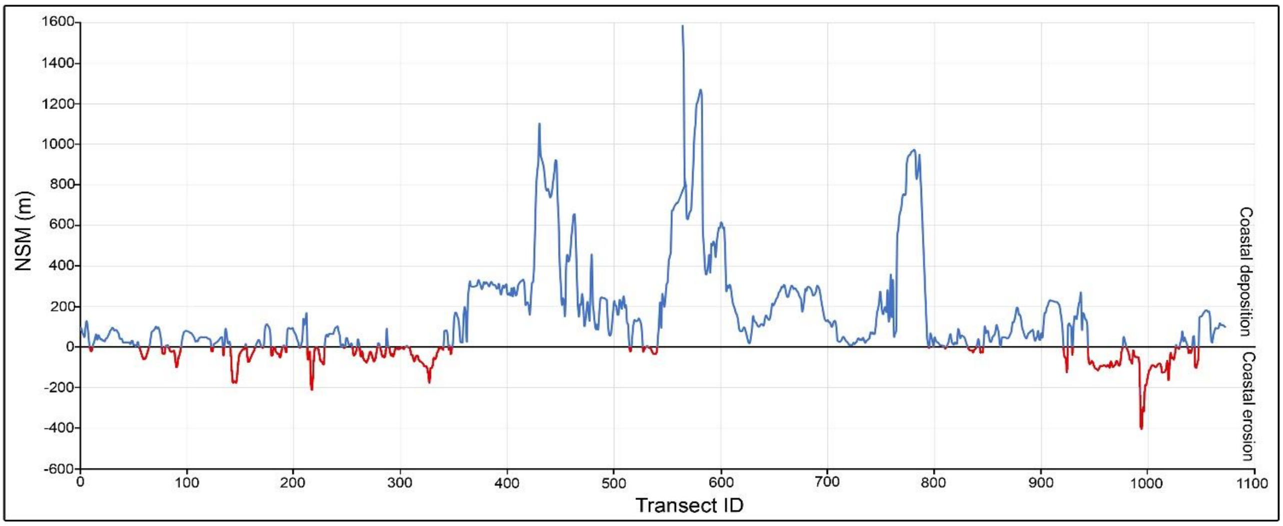

Figure 10. NSM graph of the shoreline change of Manyas Lake between 1980-2020

Table 4. Numerical data of NSM, EPR, SCE, LRR statistics of shoreline change of Manyas Lake between 1980-2020

	NSM (m)			EPR (m/year)		
Period	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**	**Minimum**
1980-2020	139,8	1585,5	-403,7	3,51	39,82	-10,14
	SCE (m)			**LRR (m/year)**		
Period	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**	**Minimum**
1980-2020	243,1	1599,4	26,8	3,44	33,18	-9,9

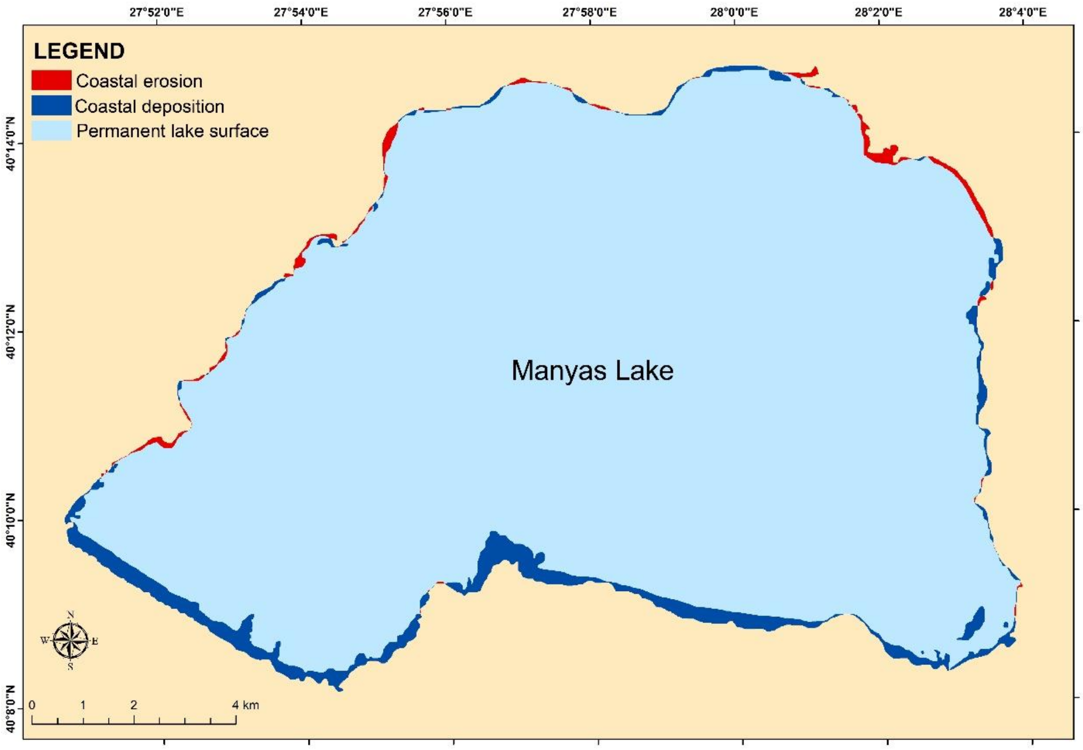

Figure 11. Distribution of coastal erosion and coastal deposition on the shores of Manyas Lake in the 40-year period between 1980-2020

From 1980 to 2020, 5.85 km^2 of coastal accretion and 1.03 km^2 of coastal erosion were determined on the surface area and coasts of Manyas Lake. Permanent lake surface area data of 146.5 km^2 was determined from the long-term analysis. From the change analysis, coastal accumulation areas are observed on the entire southern shores of the lake and in various places on the other shores (Figure 11). Coastal erosion is concentrated in the small deltas in the west of the lake and in and around the Sığırcı Creek delta in the north. During the 40-year temporal period, the surface area of Manyas Lake has shrunk and accumulation areas have occurred on the shores (especially the southern shores). The reason for the shrinkage of the surface area of the lake is the decrease in the water budget of the lake due to anthropogenic and natural causes, the increase in reed areas with the delta development in the south of the lake, anthropogenic interventions on some coasts and illegal water use in the surrounding agricultural areas.

3.3. Monthly Change Analysis of Manyas Lake Surface Area and Shoreline

In the long-term changes of the surface area and shoreline of Manyas Lake, even the recent changes in the dates of satellite data caused differences in areal and linear changes. For this reason, satellite images of Manyas Lake for each month in 2022 were obtained from Landsat and analysed (Figure 12). However, due to seasonal conditions, high cloudiness in some satellite images may cause some errors. For this reason, linear and areal calculations were made based on the months of February, April, June, August, August, October and December of Manyas Lake in the analyses in the DSAS tool.

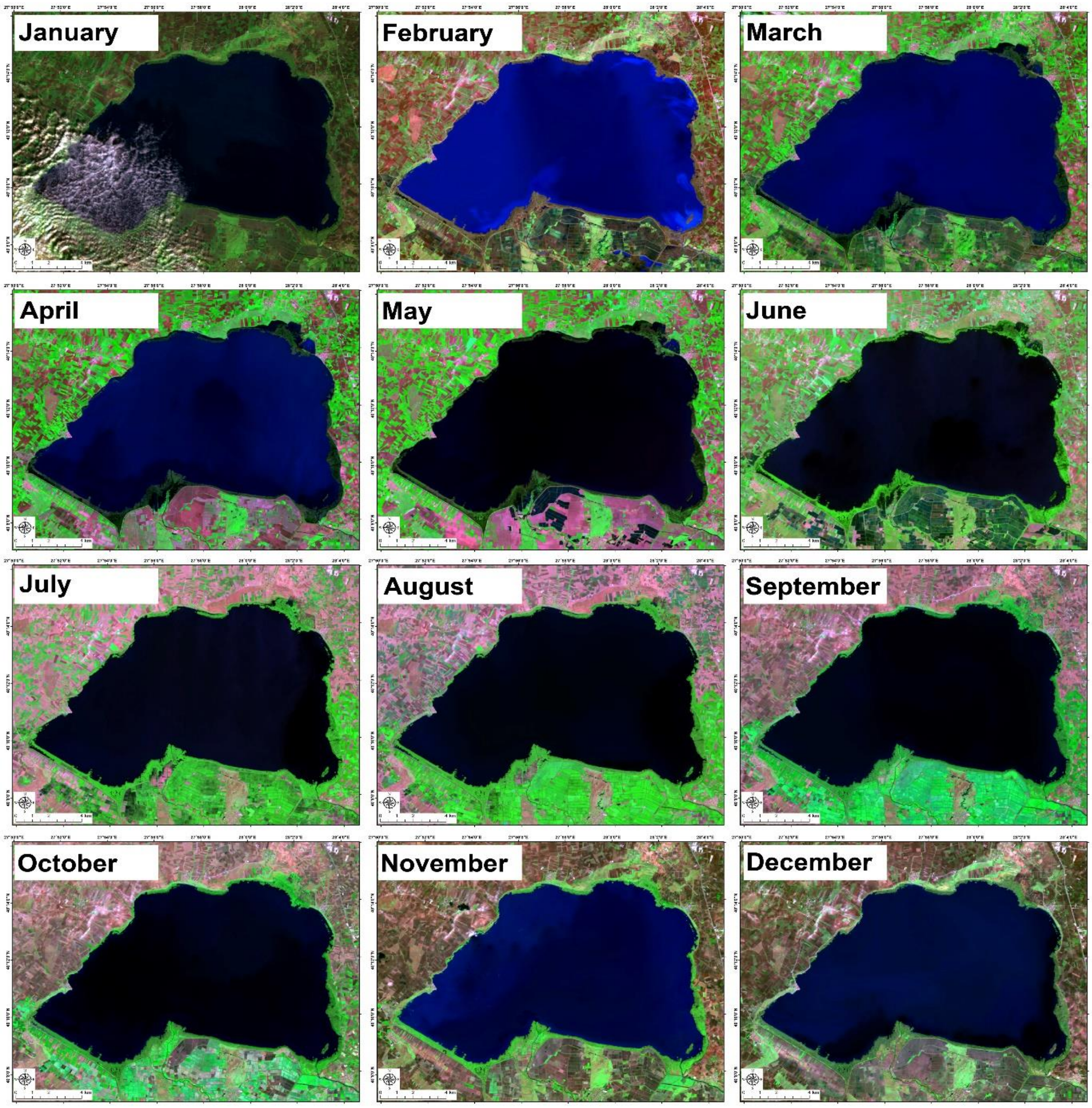

Figure 12. Satellite images of Manyas Lake for each month in 2022 used in the study

The shoreline length of Manyas Lake was calculated as 77.52 km in February 2022, 73.58 km in April, 78.87 km in June, 80.67 km in August, 79.96 km in October and 78.47 km in December. The obtained data reveal that the shoreline lengths decrease in winter and spring seasons and increase in summer season. Factors such as the increase in the water budget of the lake especially in the spring season, the productive structure of the wetland ecosystem, and the amount of evaporation play a role in this situation.

It is understood from the analyses that the monthly shoreline change of Lake Manyas is concentrated in certain areas (Figure 13). Especially in the southwest, northeast and north lagoon areas and delta areas, shoreline distance changes are observed. This situation can be explained by factors such as the wetland characteristic of the shores of Lake Manyas, the presence of reed marsh areas, the water budget of the lake, and the lake's outflow.

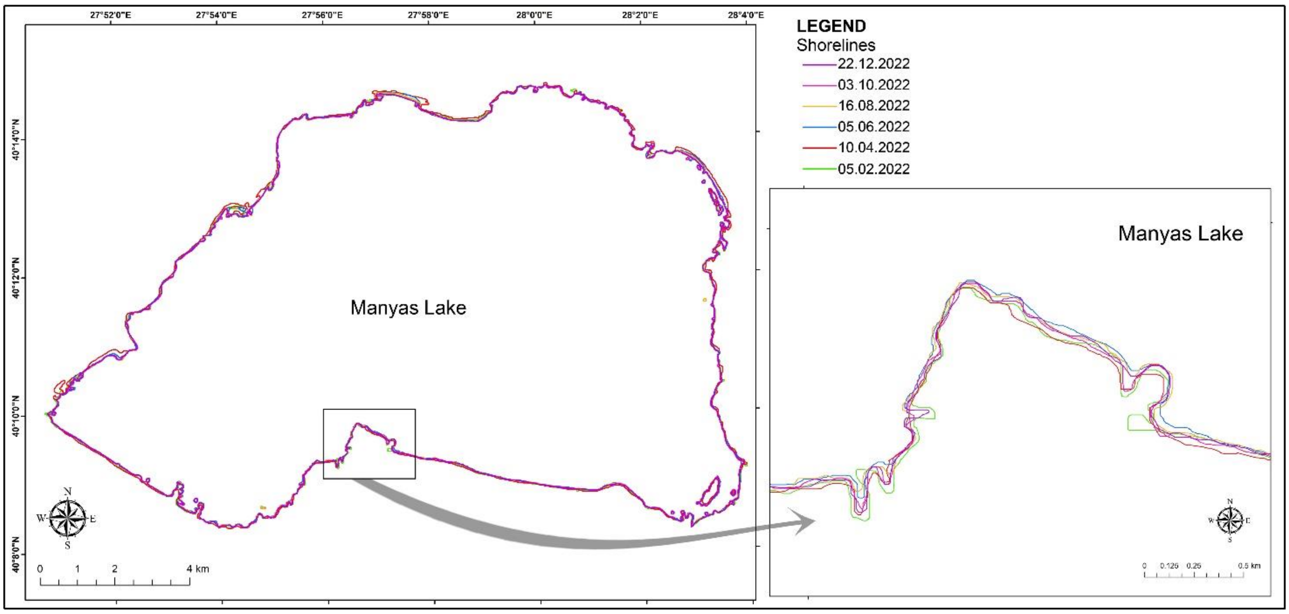

Figure 13. The shoreline of Manyas Lake in certain months determined in 2022

NSM, EPR, SCE and LRR statistical analyses were performed on the monthly shorelines of Manyas Lake in 2022 and the quantitative and spatial status of the change was explained (Figure 14 and Table 5). According to NSM statistics, the maximum change of 514.4 m, minimum change of -77.4 m and average change of 18.9 m were determined in the 2022 monthly shorelines of Manyas Lake (Table 5). According to the NSM analysis, in the monthly data, coastal advancement is observed in the reed area in the southwest of the lake, in all deltas on the lake shore, and coastal retreat is observed especially on the eastern and western shores of the lake (Figure 14). According to the EPR statistics, maximum 587.1 m/year, minimum -88.3 m/year and average 21.6 m/year changes were determined in the shorelines of the lake in 2022 (Table 5)

Table 5. Numerical data of the results of NSM, EPR,) SCE and LRR statistics over all shorelines of Manyas Lake determined in 2022

	NSM (m)			EPR (m/year)		
Period	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**	**Minimum**
2022	18,9	514,4	-77,4	21,6	587,1	-88,3
	SCE (m)			**LRR (m/year)**		
Period	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**	**Minimum**
2022	74,3	829,6	8,3	43,1	667,6	-156

When the distribution of EPR data was analysed, it was found that the changes were concentrated in delta and reed areas. The shoreline changes of Manyas Lake in 2022 was calculated as 829.6 m, minimum 8.3 m and average 74.3 m according to the SCE statistical analysis (Table 5). SCE is always positive as it reveals the maximum and minimum values of the profiles in shoreline change. In the distribution of SCE data, as in other data, it was determined that there is a density of change in reed areas and delta areas (Figure 14). According to the LRR statistic results of the monthly shorelines of Manyas Lake in 2022, a change value of 667, 6 m/year, a minimum of -156 m/year and an average change value of 43.1 m/year were calculated (Table 5). Numerical data reveal that the annual shoreline and surface change of the lake is quite high (Figure 14). Especially the changes in the reed and delta areas revealed in all analyses show that the geomorphological, climatological, hydrographic and floristic features of the lake are affected by the distribution and dynamic processes. This situation reveals the basis of the wetland feature that makes the lake different and the productive-variable structure of the wetland ecosystem through annual and monthly data.

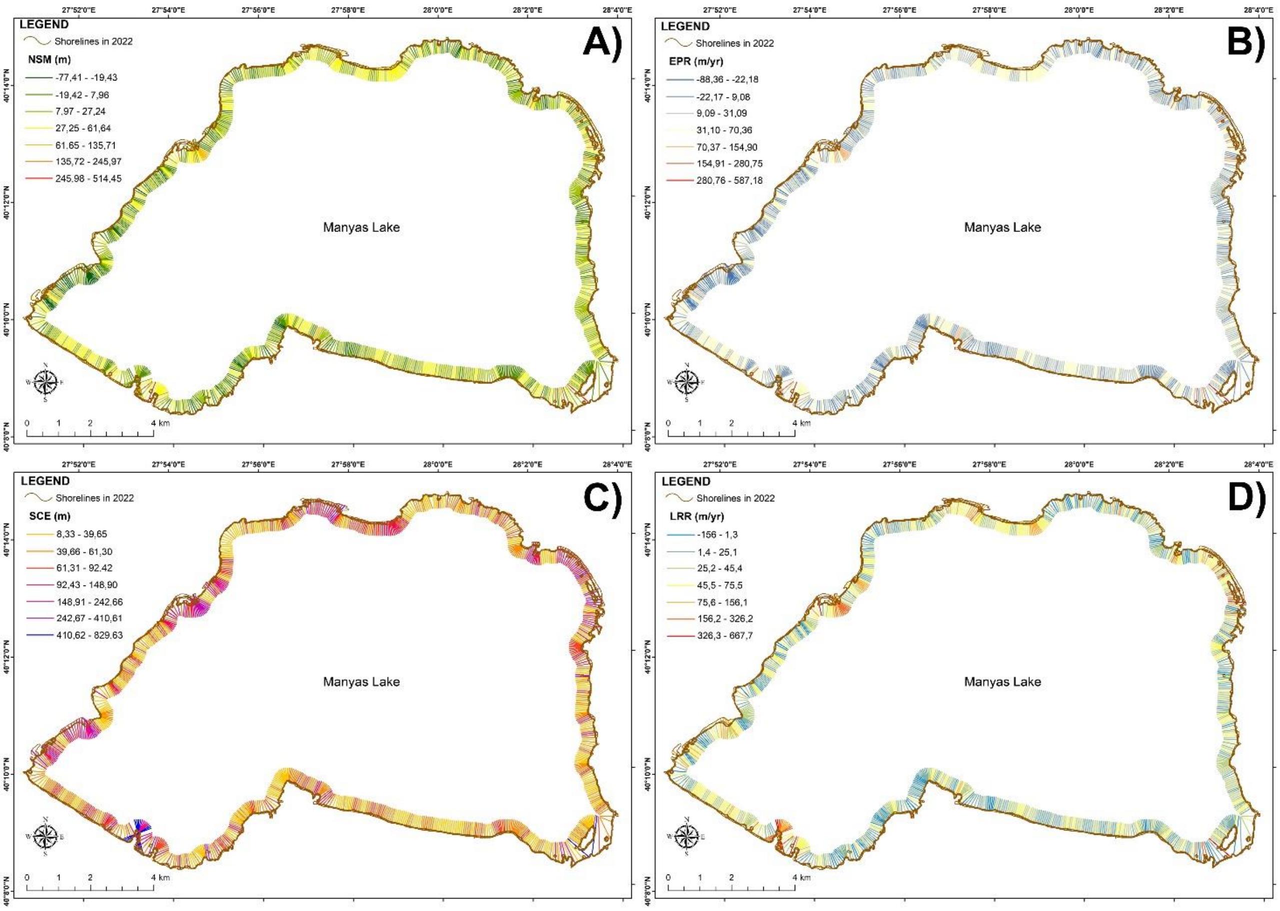

Figure 14. Distribution of the results of A) NSM, B) EPR, C) SCE and D) LRR statistics over all shorelines of Manyas Lake determined in 2022

Analyses of the monthly shoreline change of Manyas Lake also show that the surface area of the lake changes throughout the year (Figures 15 and 16). The surface area of the lake was 147.6 km^2 in February, 149.01 km^2 in April, 146.2 km^2 in June, 146.05 km^2 in August, 146.2 km^2 in October and 146.4 km^2 in December (Figure 16). The maximum value of the lake surface area is in April and the minimum value is in August. When the surface area change between April and August was analysed, it was found that coastal accumulation was 2.98 km^2, coastal erosion was 0.03 km^2 and permanent lake surface area was 146.02 km^2 (Figure 15). The findings show that the reedbed and terrestrial areas increased due to the decreasing water input from April onwards and 99% of the change was in the form of coastal accumulation. The areas of change extend as a narrow strip on the shore and consist of reed areas formed by the lagoonal environment (Figure 15).

When the monthly surface area changes of Manyas Lake in 2022 was modelled, it was found that peak values were observed in April, the lake surface area decreased to the minimum level in the summer season and then started to increase again (Figure 16). From the data obtained, the average surface area of the lake was found to be 146.91 km^2. According to the lake surface area change model, 4 months (February, March, April and May) were above the average value, while the surface area remained below the average value in the other months.

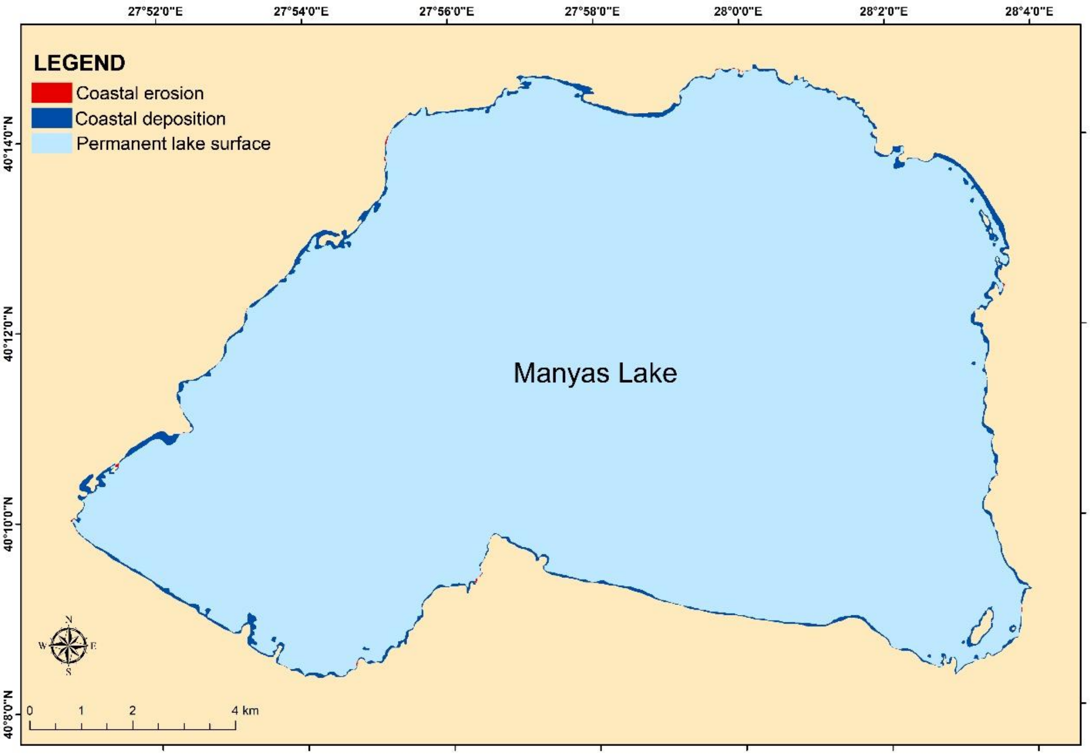

Figure 15. Coastal accretion and coastal erosion of Manyas Lake from April to August 2022

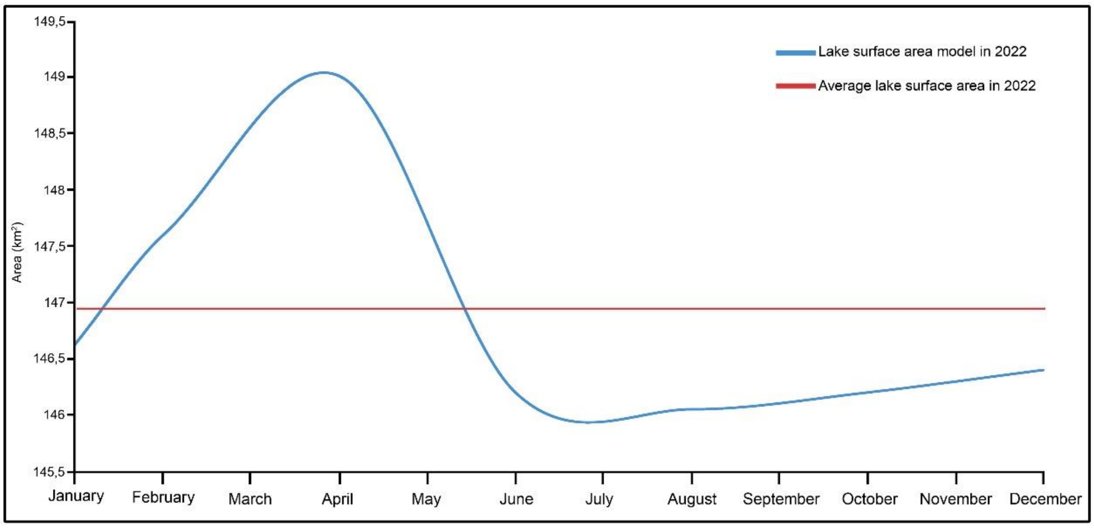

Figure 16. Change model of Manyas Lake surface area for the year 2022

4. DISCUSSION

In many studies on lake surface area and shoreline change in Turkey, it has been determined that the surface areas of lakes have shrunk from the past to the present, changes in the shoreline have been experienced, and this situation has occurred due to natural and anthropogenic factors (Bahadır, 2013; Duru, 2017; Aksoy et al., 2019; Aydın et al., 2020; Dereli & Tercan, 2020; Ataol & Onmuş, 2021; Topçu & Atatanır, 2021; Alevkayalı et al., 2023; Dinç, 2023). However, in some lakes in wetlands, changes occur at a large scale, while in others, changes occur at a more micro scale (Ataol & Onmuş, 2021; Sakaoğlu & Çepni, 2022). At the same time, many of the lakes change during the year by being affected by geomorphological, climatological, hydrographic and anthropogenic factors in their catchment basins. Manyas Lake, on the other hand, has been found to have a narrower long-term change dimension among the wetland lakes and other lakes in Turkey (Ataol & Onmuş, 2021). However, some previous studies have obtained different data on lake surface area and shoreline (Sakaoğlu & Çepni, 2022). In obtaining these data, the resolution of the data source and satellite image, the techniques and methods used may cause differences in the change results (Himmelstoss et al., 2018; Khorshiddoust et al., 2022). For this reason, in order to ensure that coastal flora is taken into account in wetland lakes and to determine the water surface and shoreline more accurately, a formula that provides water-land separation specific to the study was produced by using 3 different water indices and 4 different vegetation indices. Based on this formula, the long-term (1980-2022) and monthly change of Manyas Lake in 2022 was determined. From the findings obtained, it was determined that the surface area of the lake decreased by 4.9 km^2 over a long period of 40 years. When the change data are compared with the change in surface area in other lakes and wetlands in Turkey, it is understood that the decrease in Manyas Lake is narrower (Bahadır, 2013; Aksoy et al., 2019; Aydın et al., 2020; Ataol & Onmuş, 2021; Topçu & Atatanır, 2021; Sakaoğlu & Çepni, 2022; Alevkayalı et al., 2023; Kaya et al. 2023; Şenol et al., 2023). Especially the natural dynamic geomorphological process originating from the Manyas Creek delta has provided delta development within the lake. However, the dam constructed on Manyas Creek in recent years weakened the material transport and caused the delta progression to slow down. In addition, the development of reeds in many areas, especially in the southwest of the lake, has caused the shrinkage of the lake surface area. The fact that the Manyas Lake drainage basin harbours rivers of longer length than the southern part and the material transport of these rivers is of higher dimension has caused coastal accumulation to occur intensively in the southern part of the lake. When the changes occurring in the lake in a 40-year period were analysed by NSM statistics, it was found that there was an average shoreline advance of 139 m and 243 m in SCE analysis. According to EPR statistics, the annual shoreline change is 3.5 m and according to LRR statistics it is 3.4 m. DSAS statistical analyses show that in some areas of the lakeshore there is a shoreline advance of up to 1500 m and in some areas, there is a shoreline retreat of 400 m. While the highest coastal advancement is observed in Manyas delta and the reed areas to the west, coastal retreat is intensely experienced in the Sığırcı Creek delta in the north of the lake. When Manyas Lake shore change and lake surface area are modelled through monthly analyses, it is found that the lake surface area reaches the largest dimensions in April, while the lake surface area reaches the smallest size in July and August. This situation shows that climatic conditions affect the hydrographic budget of the lake like many lakes in Turkey (Ataol & Onmuş, 2021). The mentioned situations reveal that the shoreline change may be different in morphological elements that show wetland characteristics such as Manyas Lake. For this reason, the use of more than one index and method in the determination of the shoreline and lake surface area using GIS and UA techniques will give more accurate results. In addition, it was revealed in the study that the lake surface area and shoreline change during the year in wetlands, which have a productive structure as an ecosystem, will also differ and this can be modelled with the DSAS tool.

5. CONCLUSION

In order to determine the surface area and shoreline change of Manyas Lake, Landsat satellite images were analysed in 5-year periods between 1980-2020 and all months of 2022. Due to the wetland characteristic of the lake, problems may arise in determining the water-land distinction in the study. For this reason, a study-specific formula was created using NDWI, MDWI, WRI water indices and NDVI, RVI, NDMI, GCI vegetation indices. The formula was applied to 9 different satellite images between 1980-2020 and 6 different monthly satellite images in 2022 with favourable cloudiness conditions. According to the results obtained, the shoreline length of Manyas Lake was calculated as 63.1 km in 1980 and 73.5 km in 2020. The shoreline length also showed different changes in other time intervals. The increase in the length of the shoreline has been influenced by the delta progression and the formation of islets by reeds. The shore of Manyas Lake was analysed with the DSAS tool for each 5-year consecutive period using NSM and EPR statistics, and the long term between 1980-2020 was analysed with NSM, EPR, SCE and LRR statistics. According to the results, extreme coastal changes occurred between 1990-1995 and 1995-2000. Especially in 1995, the width of the lake surface area resulting from the satellite image in May was reflected in the data. According to the results of NSM statistics, maximum 1585.5 m, minimum -403.7 m and average 139.8 m distance change was determined in the shoreline of Manyas Lake in the 40-year long period between 1980-2020. According to the EPR statistic, maximum 39.82 m/year, minimum -10.14 m/year and average 3.51 m/year changes were calculated. According to the SCE statistic, a maximum distance change of 1599.4, a minimum distance change of 26.8 and an average distance change of 243.1 metres were determined on the shoreline of Manyas Lake. According to the LRR statistic, a maximum change of 33.18 m/year, a minimum change of -9.9 m/year and an average change of 3.44 m/year were calculated on the shoreline of Manyas Lake. From 1980 to 2020, 5.85 km2 coastal accretion, 1.03 km2 coastal erosion and 146.5 km2 permanent lake surface area data were determined on the surface area and shores of Manyas Lake. The data reveal that the lakeshore is progressing in the long term and the lake surface area is shrinking. Especially in the Manyas Creek delta and the reedbed area to the west, in the reed islets around the Karaçay drainage and in the small deltas on the eastern shores, coastal accumulation and coastal erosion in the north of the lake were detected. When the NSM, SCE, EPR and LRR analyses of the monthly satellite images of Manyas Lake in 2022 were examined, it was calculated that the change amplitude exceeded 800 m. The lake surface area reaches the peak width in April and the narrowest area in July-August for the year 2022. This situation is observed as the natural dynamic process of the wetland ecosystem structure of the lake. It was determined that the average shore change distance of Manyas Lake in 2022 was 18 m and the average change in linear regression was 43 m/year. All the findings obtained show that Manyas Lake has experienced less water loss than other lakes in Turkey in the 40-year period, but the loss of lake surface area in the future may be higher. It was also determined in the study that shoreline changes in Manyas Lake are intensely experienced as a result of natural and anthropogenic processes. In particular, it was determined that the lake surface area narrowed in the long term and the shoreline progressed in the southern part. This situation shows that the lake, which is within the scope of Ramsar, is open to future threats and the ecological structure may be affected. In particular, water use originating from agricultural areas around the lake should be modelled and controlled accordingly, and basin-based planning should be made in the rivers that source the lake.

Author contributions

The study was conducted by a single author.

Conflicts of Interest

The author declares no conflict of interest.

Research and publication ethics statement

In the study, the author declares that there is no violation of research and publication ethics and that the study does not require ethics committee approval.

REFERENCES

Akdeniz, H. B. & İnam, Ş. (2023). Spatio-temporal analysis of shoreline changes and future forecasting: the case of Küçük Menderes Delta, Türkiye. *Journal of Coastal Conservation*, 27, 34. https://doi.org/10.1007/s11852-023-00966-8

Aksoy, T., Serhat, S. A. R. I., & Çabuk, A. (2019). Sulak alanların yönetimi kapsamında su indeksinin uzaktan algılama ile tespiti, Göller Yöresi (in Turkish). *GSI Journals Serie B: Advancements in Business and Economics*, 2(1), 35-48.

Alevkayalı, Ç., Atayeter, Y., Yayla, O, Bilgin, T. & Akpınar, H. (2023). Long-term coastline changes and climate relationship in Burdur Lake: Spatio-temporal trends and forecasts. *Turkish Geographical Review,* 82, 37-50. https://doi.org/10.17211/tcd.1287976

Ataol, M., Kale, M. M. & Tekkanat, İ. S. (2019) Assessment of the changes in shoreline using digital shoreline analysis system: a case study of Kızılırmak Delta in northern Turkey from 1951 to 2017. *Environ Earth Sci*, 78, 579. https://doi.org/10.1007/s12665-019-8591-7

Ataol, M. & Onmuş, O. (2021). Wetland loss in Turkey over a hundred years: implications for conservation and management. *Ecosystem Health and Sustainability,* 7(1), 1-13. https://dx.doi.org/10.1080/20964129.2021.1930587

Aydın, F., Erlat, E. & Türkeş, M. (2020). Impact of climate variability on the surface of Lake Tuz (Turkey), 1985–2016. *Reg Environ Change*, 20, 68. https://doi.org/10.1007/s10113-020-01656-z

Bahadır, M. (2013). Determination of Spatial Changes of Akşehir Lake with Remote Perception Techniques. *Marmara Geographical Review,* 28, 246-275.

Bombino, G., Barbaro, G., D'Agostino, D., Denisi, P., Foti, G., Labate, A. & Zimbone, S. M. (2022). Shoreline change and coastal erosion: the role of check dams. first indications from a case study in Calabria, Southern Italy. *CATENA*, 217. https://doi.org/10.1016/j.catena.2022.106494

Bird, E. (2008). Coastal geomorphology: An introduction Second edition. *John Wiley & Sons.*

Çoban, H., Koç, Ş. & Kale, M. M. (2020). Shoreline changes (1984 – 2019) in the Çoruh delta (Georgia/Batumi). *International Journal of Geography and Geography Education (IGGE),* 42, 589-601. https://doi.org/10.32003/igge.741573

Darwish, K., Smith, S. E., Torab, M., Monsef, H. & Hussein, O. (2017). Geomorphological Changes along the Nile Delta Coastline between 1945 and 2015 Detected Using Satellite Remote Sensing and GIS. *J. Coast. Res,* 33(4): 786–794. http://dx.doi.org/10.2112/JCOASTRES-D-16-00056.1

Davidson-Arnott, R. (2010). Introduction to Coastal Processes and Geomorphology. *University Press Cambridge.*

Davidson, N. C. & Finlayson, C. M. (2018). Extent, Regional Distribution and Changes in Area of Different Classes of Wetlands.” *Marine and Freshwater Research,* 69, 1525–1533. http://dx.doi.org/10.1071/MF17377

Dereli, M. A. & Tercan, E. (2020). Assessment of Shoreline Changes using Historical Satellite Images and Geospatial Analysis along the Lake Salda in Turkey. *Earth Sci Inform*,13, 709–718. https://doi.org/10.1007/s12145-020-00460-x

Dinç, G. (2023). Unveiling shoreline dynamics and remarkable accretion rates in Lake Eğirdir (Turkey) using DSAS. The implications of climate change on lakes. *Tema. Journal of Land Use, Mobility and Environment*, 95-108. http://dx.doi.org/10.6092/1970-9870/10111

Duru, U. (2017). Shoreline change assessment using multi-temporal satellite images: a case study of Lake Sapanca, NW Turkey. *Environ Monit Assess,* 189, 385. https://doi.org/10.1007/s10661-017-6112-2

Erinç, S. (1986). Kıyılardan Yararlanmada Hukuki Düzenlemelere Jeomorfolojinin Katkısı. Jeomorfolojisi Dergisi, 14, 1-5 (in Turkish).

Erol, O. (1989). Türkiye'de Kıyıların Doğal Niteliği, Kıyı ve Kıyı Varlıklarının Korunmasına İlişkin Kıyı Kanunu ve Uygulamaları Konusunda Jeomorfolojik Yaklaşım. *İstanbul Üniversitesi Deniz Bilimleri ve Coğrafya Enstitüsü,* 6, 15-46 (in Turkish).

Gao, B. C. (1996). NDWI-A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment,* 58(3), 257–266. https://doi.org/10.1016/S0034-4257(96)00067-3

Gómez-Pazo, A., Payo, A., Paz-Delgado, M. V. & Delgadillo-Calzadilla, M. A. (2022). Open digital shoreline analysis system: ODSAS v1. 0. *Journal of Marine Science and Engineering*, 10(1), 26. https://doi.org/10.3390/jmse10010026

Grottolli, H. Biausque, M. Jackson, D. & Cooper, J. A. (2023). Long-term drivers of shoreline change over two centuries on a headland-embayment beach. *Earth Surface Processes and Landforms,*, 1-21. https://doi.org/10.1002/esp.5641

Hakkou, M., Maanan, M., Belrhaba, T., El khalidi, K., El Ouai, D. & Benmohammadi, A. (2018). Multi-decadal assessment of shoreline changes using geospatial tools and automatic computation in Kenitra coast, Morocco. *Ocean & Coastal Management,* 163, 232–239. https://doi.org/10.1016/j.ocecoaman.2018.07.003

Himmelstoss, E. A., Henderson, R. E., Kratzmann, M. G. & Farris, A. S. (2018). Digital Shoreline Analysis System (DSAS) Version 5.0 User Guide (No. 2018-1179). *US Geological Survey*.

Hossain, S. Yasir, M. Wang, P. Ullah, S. Jahan, M., Hui, S. & Zhao, Z., (2021). Automatic shoreline extraction and change detection: A study on the southeast coast of Bangladesh. *Marine Geology,* 441, 1-15. https://doi.org/10.1016/j.margeo.2021.106628

Hoşgören, M. Y. (1994). Lakes of Turkey. *Turkish Geographical Review*, 29, 19-51.

Hu, X. & Wang, Y. (2020). Coastline Fractal Dimension of Mainland, Island, and Estuaries Using Multi-temporal Landsat Remote Sensing Data from 1978 to 2018: A Case Study of the Pearl River Estuary Area. *Remote Sensing*, 12, 2482. https://doi.org/10.3390/rs12152482

Janki, S., Klop, K. W., Dooper, I. M., Weimar, W., Ijzermans, J. N. & Kok, N. F. (2015). More than a decade after live donor nephrectomy: a prospective cohort study. *Transplant International,* 28(11), 1268-1275. https://doi.org/10.1111/tri.12589

Kale, M. M., Ataol, M. & Tekkanat, İ. S. (2019). Assessment of shoreline alterations using a Digital Shoreline Analysis System: a case study of changes in the Yeşilırmak Delta in northern Turkey from 1953 to 2017. *Environ Monit Assess,* 191, 398. https://doi.org/10.1007/s10661-019-7535-8

Kaya, Y., Sanli, F. B. & Abdikan, S. (2023). Determination of long-term volume change in lakes by integration of UAV and satellite data: the case of Lake Burdur in Türkiye. *Environ Sci Pollut Res*, 30, 117729–117747. https://doi.org/10.1007/s11356-023-30369-z

Kazı, H. & Karabulut, M. (2023). Monitoring the shoreline changes of the Göksu Delta (Türkiye) using geographical information technologies and predictions for the near future. International *Journal of Geography and Geography Education,* 50, 329-352. https://doi.org/10.32003/igge.1304403

Khorshiddoust, A. M., Patel, N., Khalilzadeh, E. Bostanaba, A. S. & Tajbar, S., (2022). A comparative study of the surface level changes of Urmia Lake and Aral Lake during the period of 1988 to 2018 using satellite images*. Front. Earth Science*. https://doi.org/10.1007/s11707-022-1010-5

Kılar, H. & Çiçek, İ. (2018). Shoreline Change Analysis in Göksu Delta by Using DSAS. *Turkish Journal of Geographical Sciences,* 16(1), 89-104. https://doi.org/10.1501/Cogbil_0000000192

Kılar, H. (2023). Shoreline change assessment using DSAS technique: A case study on the coast of Meriç Delta (NW Türkiye). *Regional Studies in Marine Science,* 57, 102737. https://doi.org/10.1016/j.rsma.2022.102737

Kuleli, T. (2010). Quantitative analysis of shoreline changes at the Mediterranean Coast in Turkey *Environ. Monit. Assess*., 167, 387–397. https://doi.org/10.1007/s10661-009-1057-8

Lazuardi, Z., Karim, A. & Sugianto, S. (2022). Analisis Perubahan Garis Pantai Menggunakan Digital Shoreline Analysis System (DSAS) di Pesisir Timur Kota Sabang. *Jurnal Ilmiah Mahasiswa Pertanian,* 7(1), 662-676.

Maltby, E. & Barker, T. (2009). The Wetlands Handbook. *John Wiley & Sons*. ISBN:978-0-632-05255-4.

McDonald, A. J., Gemmell, F. M. & Lewis, P. E. (1998). Investigation of the utility of spectral vegetation indices for determining information on coniferous forests. *Remote Sensing of Environment,* 66(3), 250-272. https://doi.org/10.1016/S0034-4257(98)00057-1

McFeeters, S. K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features, *International Journal of Remote Sensing,* 17:7, 1425-1432, http://doi.org/10.1080/01431169608948714

Myneni, R. B., Hall, F. G., Sellers, P. J. & Marshak, A. L. (1995). The interpretation of spectral vegetation indexes. *IEEE Transactions on Geoscience and remote Sensing*, 33(2), 481-486. https://doi.org/10.1016/0034-4257(94)00073-V

Murray, J., Adam, E., Woodborne, S., Miller, D., Xulu, S. & Evans, M. (2023). Monitoring shoreline changes along the southwestern coast of South Africa from 1937 to 2020 using varied remote sensing data and approaches. *Remote Sensing*, 15(2), 317. https://doi.org/10.3390/rs15020317

Nassar, K., Mahmod, W. E., Fath, H., Masria, A., Nadaoka, K. & Negm, A. (2019). Shoreline change detection using DSAS technique: Case of North Sinai coast, Egypt. *Marine Georesources & Geotechnology*, 37(1), 81-95. https://doi.org/10.1080/1064119X.2018.1448912

Pardo-Pascual, J. E., Almonacid-Caballer, J., Ruiz, L. A. & Palomar-Vázquez, J. (2012). Automatic extraction of shorelines from Landsat TM and ETM+ multi-temporal images with subpixel precision. *Remote Sensing of Environment*, 123, 1-11. https://doi.org/10.1016/j.rse.2012.02.024

Paz-Delgado, M. V., Payo, A., Gómez-Pazo, A., Beck, A. L. & Savastano, S. (2022). Shoreline Change from Optical and Sar Satellite Imagery at Macro-Tidal Estuarine, Cliffed Open-Coast and Gravel Pocket-Beach Environments. *Journal of Marine Science and Engineering*, 10(5), 561. https://doi.org/10.3390/jmse10050561

Pouye, I., Adjoussi, D.P., Ndione, J.A., Sall, A. (2023). Topography, Slope and Geomorphology's Influences on Shoreline Dynamics along Dakar's Southern Coast, Senegal. *Coasts*, 2023(3), 93–112. https://doi.org/10.3390/coasts3010006

Richardson, A. J. & Wiegand, C. L. (1977). Distinguishing vegetation from soil background information. *Photogrammetric engineering and remote sensing*, 43(12), 1541-1552.

Sakaoğlu, E. & Çepni, O. (2022). Türkiye'deki Tektonik Kökenli Ramsar Göllerinin Uzaktan Algılama Teknikleri ile Analizi (in Turikish). *İksad Pulished House. ISBN: 978-625-8377-54-5.*

Samra, R. M. & Ali, R. R. (2021). Applying DSAS tool to detect coastal changes along Nile Delta, Egypt. The Egyptian *Journal of Remote Sensing and Space Science*, 24(3-1), 463-470. https://doi.org/10.1016/j.ejrs.2020.11.002

Shen, L. & Li, C. (2010) Water body extraction from Landsat ETM+ imagery using adaboost algorithm 18th International *Conference on Geoinformatics, IEEE (2010)*, 1-4. https://doi.org/10.1109/GEOINFORMATICS.2010.5567762

Sikder, M. S., Wang, J., Allen, G. H., Sheng, Y., Yamazaki, D., Song, C., Ding, M., Crétaux, J. F. & Pavelsky, T. M. (2023). Lake-TopoCat: a global lake drainage topology and catchment database, *Earth Syst. Sci. Data*, 15, 3483–3511, https://doi.org/10.5194/essd-15-3483-2023

Singh, K. V., Setia, R., Sahoo, S., Prasad, A. & Pateriya, B. (2015). Evaluation of NDWI and MNDWI for assessment of waterlogging by integrating digital elevation model and groundwater level. *Geocarto International*, 1-12. https://doi.org/10.1080/10106049.2014.965757

Siyal, A. A., Solangi, G. S., Siyal, P., Babar, M. M. & Ansari, K. (2022). Shoreline change assessment of Indus delta using GIS-DSAS and satellite data. *Regional Studies in Marine Science*, 102405 http://dx.doi.org/10.1016/j.rsma.2022.10245

Song, Y., Shen, Y., Xie, R. & Li, J. (2021). A DSAS-based study of central shoreline change in Jiangsu over 45 years. *Anthropocene Coasts*, 4(1), 115-128. http://dx.doi.org/10.1139/anc-2020-0001

Şenol, H. İ., Kaya, Y., Yiğit, A. Y. & Yakar, M. (2023). Extraction and geospatial analysis of the Hersek Lagoon shoreline with Sentinel-2 satellite data. *Survey Review*, 1–16. https://doi.org/10.1080/00396265.2023.2257969

Tağıl, Ş. & Cürebal, İ. (2005). Remote Sensing and GIS Monitoring of Coastline in Altınova Coast Turkey. Fırat University Journal of Social Siciennces, 15(2), 51-68.

Tian, H., Xu, K., Goes, J. I., Liu, Q., Gomes, H. d. R. & Yang, M. (2020). Shoreline Changes Along the Coast of Mainland China—Time to Pause and Reflect? *ISPRS Int. J. Geo-Inf*, 9, 572. https://doi.org/10.3390/ijgi9100572

Topçu, H. & Atatanır, L. (2021). Determination of temporal changes in Bafa and Azap Lake Surface Areas. *Akademik Ziraat Dergisi*, 10(1), 115-122. https://doi.org/10.29278/azd.792589

Topuz, M. (2018) Investigations Occurred Changes in The Coastal Line of Sarikum Lagoon (Sinop) by Using the Remote Sensing Techniques. *International Journal of Social Science*, 71, 481-493. http://dx.doi.org/10.9761/JASSS7853

Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment,* 8(2), 127-150. https://doi.org/10.1016/0034-4257(79)90013-0

Turoğlu, H. (2009). The Coastal Law (number 3621) and Its Applied Problems. *Turkish Geographical Review*, 53, 31-40.

Turoğlu, H. (2017). Deniz ve Göllerde Kıyı, Yasal ve Bilimsel Boyutlarıyla Kıyı, *Jeomorfoloji Derneği Yayını,* 1 (in Turkish).

Uzun, M. (2021). Human-Induced Geomorphological Changes and Processes on the Coasts of the Gulf of Izmit. *Journal of Geomorphological Researches*, 7, 61-81. https://doi.org/10.46453/jader.983465

Uzun, S. M. (2023) Analysis of Changing Shoreline with Natural and Anthropogenic Factors in Riva (Istanbul) Coast with Dsas Tool. *Journal of Geomorphological Researches*, 2023(11), 95-113. https://doi.org/10.46453/jader.1335105

Xu, H. (2006). Modification of Normalised difference water index NDWI to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing*, 27(14), 3025-3033.

https://doi.org/10.1080/01431160600589179

Woolway, R. I., Kraemer, B. M., Lenters, J. D., Merchant, C. J., O'Reilly, C. M. & Sharma, S. (2020). Global lake responses to climate change. *Nature Reviews Earth & Environment*, 1, 388–403, https://doi.org/10.1038/s43017-020-0067-5

Wu, Q., Miao, S., Huang, H., Guo, M., Zhang, L., Yang, L. & Zhou, C. (2022). Quantitative Analysis on Coastline Changes of Yangtze River Delta based on High Spatial Resolution Remote Sensing Images. *Remote Sensing,* 14, 310. https://doi.org/10.3390/rs14020310

Yasir, M., Hui, S., Hongxia, Z., Hossain, S., Fan, H., Zhang, Li. & Jixiang, Z. (2021). A Spatiotemporal Change Detection Analysis of Coastline Data in Qingdao, East China. *Hindawi Scientific Programming,* 1-10. https://doi.org/10.1155/2021/6632450

Zuzek, P. J., Nairn, R. B. & Thieme, S. J. (2003). Spatial and Temporal Considerations for Calculating Shoreline Change Rates in the Great Lakes Basin*. Journal of Coastal Research*, 125–146.