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Research Article

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An evaluation of the long-term changes in the shoreline of Lake Eğirdir in relation to climate and anthropogenic factors

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Abstract

This study quantifies shoreline changes in Lake Eğirdir between 1984 and 2024 by examining the direction, distance, and rate of change, along with climatic and anthropogenic influences. Landsat satellite images were used to delineate the lake's shoreline using the Modified Normalised Difference Water Index (MNDWI). Shoreline change rates were then calculated using the Digital Shoreline Analysis System (DSAS), employing metrics such as the End Point Rate (EPR), Linear Regression Rate (LRR), and Net Shoreline Movement (NSM). Results indicated the highest EPR value of 61,06 m/yr at transect 2035, while the highest LRR value was 39,78 m/yr. The NSM analysis revealed a maximum positive value of 2444,6 m, indicating significant recession in specific shoreline areas.

The key factors driving these changes include climate change and agricultural irrigation practices. Mann-Kendall trend analysis demonstrated a rising trend in maximum temperatures, although precipitation levels showed no significant variation. The expansion of fruit orchards around Lake Eğirdir has intensified water demand, resulting in a marked decline in water levels. This study highlights the combined impact of climatic shifts and human activities on shoreline dynamics, highlighting the need for sustainable water management strategies to mitigate further environmental degradation.

Keywords DSAS · Shoreline change · Eğirdir Lake

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Introduction

The rapid increase in global temperatures in recent years clearly demonstrates, based on scientific evidence, that climate change has emerged as an urgent and irreversible threat. Analyses conducted using six comprehensive datasets indicate that the five-year average global temperatures between 2019 and 2023 reached the highest levels in recorded history, with 2023 being the hottest year ever documented (Climate Change Service, 2024). At the same time, according to the IPCC reports (2023), the frequency and intensity of such extreme temperature events are directly linked to the increase in human-induced greenhouse gas emissions. Such events demonstrate that the concept of "***climate urgency***" has reached a level that can no longer be ignored (Steffen et al., 2020). The year 2023 not only experienced a hot summer but also set the stage for an unusually warm winter (Esper et al., 2024; Zheng et al., 2024). According to studies conducted by the WMO, ocean warming accelerates glacier retreat and raises sea levels. Extreme weather-related events adversely impact socioeconomic development, and the cost of inaction on climate change exceeds the cost of taking climate action (WMO, 2024).

Agricultural activities are increasingly dependent on the intensive consumption of surface and groundwater resources due to the changing temperature factors of global climate change. Agricultural activities, driven by the impact of global climate change and shifting temperature factors, contribute to the increased consumption of surface and groundwater resources and further intensification of such practices. As a result of these activities, the rapid depletion of groundwater resources also leads to the rapid withdrawal of water from surface wetlands, and in some areas, it paves the way for their irreversible depletion (Çankal & Alkın, 2024). In Turkey's Konya Plain, which is characterised as a closed basin, studies have shown that the groundwater level has rapidly decreased over time due to agricultural irrigation, accelerating the formation of sinkholes and leading to a significant decline in water levels within these sinkholes (Bozyiğit & Tapur, 2009; Tapur & Bozyiğit, 2015; Yılmaz, 2010). In the Lakes Region, the factors causing changes in the shorelines of lakes, and in some cases leading to the gradual shrinkage of lake surfaces and ultimately the complete disappearance of lakes over time, are similar to those observed in areas of Central Anatolia where sinkholes have formed rapidly due to groundwater depletion.

In summary, lakes are also significantly affected by drought and evaporation, and with the addition of uncontrolled groundwater usage (without considering balance calculations), they have been observed to recede substantially, starting from their shorelines (Alevkayalı et al., 2023; Aydın & Doğu, 2018; Bahadır, 2013). Today, in our country, particularly in the Lakes Region, some lakes no longer accumulate more water on their surface than what currently exists, or only a minimal amount accumulates. Some of the lakes that no longer retain water on their surfaces today include Yarışlı (Burdur) (Aksoy et al., 2019), Akgöl (Burdur), Karataş (Burdur), and Akşehir (Konya). In addition, lakes that have experienced rapid water withdrawal include Acıgöl (Denizli), Burdur, Beyşehir, Eğirdir, and Salda lakes (Cengiz & Kahya, 2011).

The studies conducted on Eğirdir (Aslan & Koc San, 2021), Burdur (Alevkayalı et al., 2023; Sarp & Özçelik, 2017), and Beyşehir (Yarar & Onüçyıldız, 2009) lakes, which are the largest lakes in the Lakes Region in terms of area, particularly those focused on Lake Burdur, confirm that the decline in water levels in these lakes is not solely due to temperature increases caused by global climate change but is also significantly influenced by the high demand for groundwater usage.

Lake Eğirdir is one of the most significant wetlands in the Lake District, with a freshwater reserve of high ecological and economic importance. This study reveals the long-term shoreline changes in Lake Eğirdir by analysing satellite imagery recorded between 1984 and 2024. In this study, in addition to analysing changes in the lake surface, the temporal and spatial trends of climate parameter datasets and changes in agricultural patterns were evaluated. Based on the findings, the causes of the water level decline in Lake Eğirdir and the potential adverse effects thereof were also assessed.

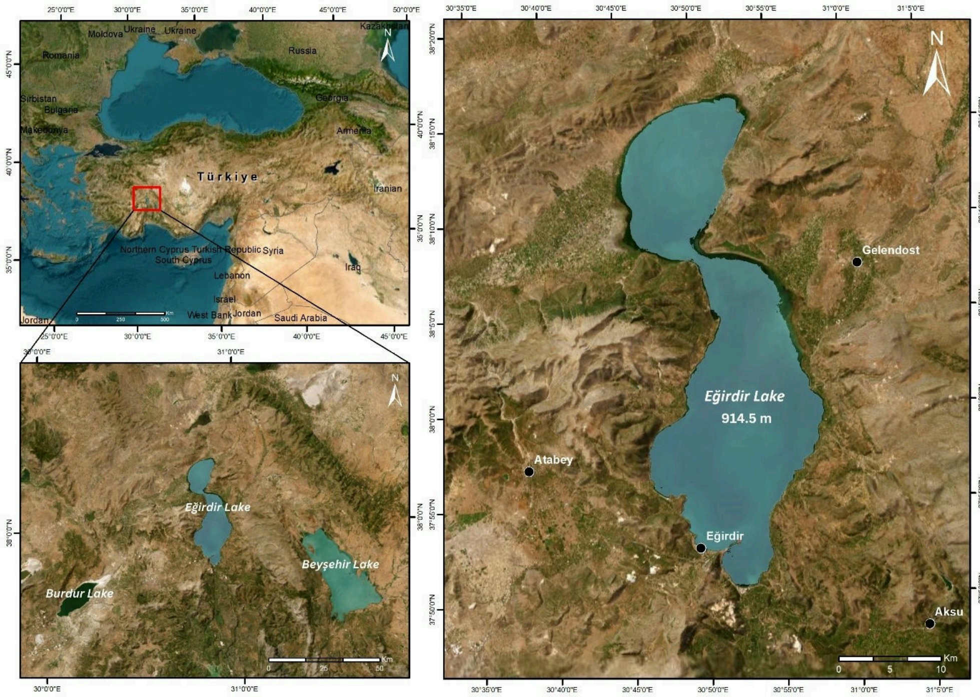
Method

Study Area

This study was conducted on the surface area of Lake Eğirdir, one of Turkey's significant wetlands located in the Lakes Region, which holds great importance as a freshwater resource for the surrounding area. Lake Eğirdir is located between the coordinates 37° 50′ 41′′–38° 16′ 55′′N and 30° 44′ 39′′–30° 57′ 43′′E (Figure 1). This open-basin lake drains its waters into Lake Kovada and subsequently into the Aksu River through an epigenic valley and an incised meander. Between Lake Eğirdir and Lake Kovada lies a polje-like plain called Boğazova, through which a canal extends all the way to Lake Kovada. The Kovada Canal provides a surface connection between Lake Eğirdir and Lake Kovada while also draining the plain, making it suitable for agricultural use (Atayeter, 2005). Due to the above-mentioned features, Lake Eğirdir is significantly affected by climate parameters and

Figure 1

Location Map of the Study Area



anthropogenic factors. This process leads to significant water withdrawal from the lake, particularly during periods that are not supported by precipitation (Figure 2).

Figure 2

Bölük Island, now above water because of the lake's recession at Kemerboğazı location (31.10.2024)

The hydrological system of Lake Eğirdir is largely based on a cycle of groundwater inputs. In the 2000s, the shoreline of Lake Eğirdir was located at an elevation of 916 metres (Atayeter, 2011), whereas recent studies have determined the lake level to be 915.08 metres (Güner & Özgür, 2023). Field studies have determined that the current elevation of the lake is 914.5 m.

Lake Eğirdir has experienced level fluctuations at various times throughout its history (USGS, 2024). Historical records indicate that during the 1960s, marshes and water pools formed in certain areas of the plains surrounding Lake Eğirdir, where groundwater levels were very close to the surface. These high water levels caused the formation of marshes and water pools, creating unfavourable conditions for agricultural activities. One of these areas is Boğazova, located between Lake Eğirdir and Lake Kovada. In the 1960s, Boğazova was drained and reclaimed for agricultural production through the construction of the Kovada Canal.

Studies on the hydrological and hydrogeological characteristics of Lake Eğirdir have identified various sources of water for the lake. These studies demonstrated that Lake Eğirdir primarily receives water from precipitation, surface water, and groundwater sources. The main surface water sources feeding Lake Eğirdir include the Hoyran Basin, Olukköprü, and Dumanlı karst springs (Değirmenci & Günay, 1992; Sipahi, 1987). Among the significant continuous sources feeding Lake Eğirdir are Pupa (Üyüllü) Creek from the west, Ilgın Stream, which crosses the Kumdanlı Plain and reaches Hoyran, and Öz Stream, originating from the northeastern foothills of the Sultan Mountains with a large catchment area, along with its tributaries Yukarı Çamlıca, Kocaçay, and Keklik Creek. Sarıidris Stream, Kapız Creek, and Koca Creek, located in the southeast of the lake, are among the significant watercourses (Atayeter, 2011).

The surroundings of Lake Eğirdir exhibit diverse geological characteristics across its mountainous and plain areas. Materials eroded from mountainous areas primarily form Quaternary-aged alluvial units that accumulate in the flat and plain areas of the Senirkent, Kumdanlı, Yalvaç, and Gelendost districts. The mountainous areas around the lake are mostly covered with neritic limestones, dating from Triassic to Cretaceous. The Barla Mountain massif to the west of Lake Eğirdir is predominantly composed of Triassic and Upper Jurassic-Lower Cretaceous neritic limestones. The south side of these limestones contains Mesozoic-aged peridotites is notable. To the east of Lake Eğirdir, limestones are less widespread than in the west, and Pliocene-aged clastic and carbonate units are observed around Yalvaç and Gelendost. In the region between Hoyran Lake and Yalvaç, the presence of Miocene-aged lacustrine deposits indicates the existence of ancient lake environments in this area. These Miocene-aged units consist of lacustrine deposits such as sandstone, marl, and silt. In the southeast, unlike the limestones and lacustrine units, peridotites and occasionally imbricated ophiolites are found (MTA).

Mann-Kendall Trend Test

Temperature and precipitation are the most commonly used climate elements to determine the effects of climate change in a region because these elements continuously vary over time and space. To analyse these changes using long-term data and to understand the increasing or decreasing trends in temperature and precipitation values, the non-parametric Mann-Kendall trend test (Mann, 1945; Kendall, 1975) is widely preferred in many scientific studies due to its reliability (Alahacoon et al., 2018; Alevkayalı et al., 2023; Hirsch & Slack, 1984; Gocic & Trajkovic, 2013; Kahya & Kalaycı, 2004; Kızılelma et al., 2015; Polat & Sunkar, 2017; Şen, 2017; Tağıl & Alevkayalı, 2014; Topuz et al., 2016; Topuz et al., 2018; Topuz et al., 2021;).

As emphasised above, the Mann-Kendall trend test is a nonparametric method used to detect trends in a dataset and does not require data to follow a normal distribution (Onoz & Bayazit, 2003). The Mann-Kendall test is less sensitive to sudden shifts caused by non-homogeneous time series (Taberi, 2011). The primary purpose of the Mann-Kendall test is to determine whether a monotonic increasing or decreasing trend exists in a dataset. According to this test, the null hypothesis H0 assumes that no trend exists (data are independent and randomly ordered, with no significant trend in the time series) and is tested against the alternative hypothesis H_1, which assumes that a significant trend exists in the time series (Karmeshu, 2012).

The Mann-Kendall statistical test was performed using the following formulas:

In the Mann-Kendall test, the SS statistic is computed using the sign of the difference between two observations. The test evaluates whether each observation value in a time series is greater or lesser than all preceding values for each pair of data points.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\,(x_j - x_i)$$

Here:

- x_i, and x_j are two distinct values in the dataset, respectively.
- *where n* is the total number of observations,
- *the sgn* (Signum) function indicates the sign of the difference between two data points and is defined as follows:

$$sgn(x_j - x_i) = \begin{cases} +1 \ if \ x_j > x_i \\ 0 \ if \ x_j = x_i \\ -1 \ if \ x_j < x_i \end{cases}$$

*(Pozitif Trend: **S> 0,** Negatif Trend**: S <0,** No Trend: **S = 0)***

In this formula, the sign of the difference between each pair of observations is determined and summed for all pairs. When no ties exist in the dataset (no equal observation values), the variance Var(S)Var(S) is calculated as follows:

$$Var\,(S) = \frac{n(n-1)(2n+5)}{18}$$

If the dataset contains tied values (ties), the variance Var(S)Var(S) is adjusted as follows:

$$Var\,(S) = \frac{n\,(n-1)(2n+5) - \sum t_p(t_p-1)(2t_p+5)}{18}$$

- t_p, represents the count of repeated observation values for each tie.

The Z-statistic is used to determine whether a trend exists in the dataset. Then, it is calculated using the following formula;

$$z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \ if \ S > 0 \\ 0 \qquad if \ S = 0) \\ \frac{S+1}{\sqrt{Var(S)}} \ if \ S < 0 \end{cases}$$

Finally, the calculated Z-value is compared with the critical Z-value obtained from the standard normal distribution table at a specific confidence level (e.g., 95%). This comparison determines whether there is a "trend" in the data.

Satellite images

In this study, Landsat satellite images from different dates over a long period (1984–2024) were used to analyse shoreline changes in Lake Eğirdir (Table 1). These images were obtained from the United States Geological Survey (USGS) database. The selection of satellite images for the study focused on ensuring that they represented different dates, reflected similar periods, and had high image quality. Therefore, data recorded during July, August, and September—when cloud cover is minimal—were preferred (Table 1).

Table 1

Key Characteristics of the Satellite Images

Satellite	Date	Image ID	Resolution (m)
Landsat 5	16/07/1984	LT05_L1TP_178034_19840716_20200918_02_T1	30
Landsat 5	02/08/1990	LT05_L1TP_178034_19900802_20200915_02_T1	30
Landsat 5	16/08/1995	LT05_L1TP_178034_19950816_20200912_02_T1	30
Landsat 5	29/08/2000	LT05_L1TP_178034_20000829_20200906_02_T1	30
Landsat 5	12/09/2005	LT05_L1TP_178034_20050912_20200901_02_T1	30
Landsat 5	25/08/2010	LT05_L1TP_178034_20100825_20200823_02_T1	30
Landsat 8 OLI/TIRS	07/08/2015	LC08_L1TP_178034_20150807_20200908_02_T1	30
Landsat 8 OLI/TIRS	04/08/2020	LC08_L1TP_178034_20200804_20200915_02_T1	30
Landsat 8 OLI/TIRS	30/07/2024	LC08_L1TP_178034_20240730_20240801_02_T1	30

Determination of Shorelines

Advances in satellite technologies have made it possible to monitor the Earth on a global scale and identify changes on the surface through remote sensing (Lillesand et al., 2015). The images provided by satellite systems consist of channels representing different spectral bands (Richards, 2013). Depending on the study's objective, greyscale single-channel or colour composite images can be created by combining different spectral bands. In this process, the "image ratioing" method is used, where spectral reflectance values in one band are compared and divided by those in another band to produce a new image derived from the ratios (Lu & Weng, 2007; Sabins, 1997). The rationing process can vary depending on the characteristics of a specific satellite image and the study area; therefore, researchers often rely on the most suitable band combinations identified in the literature or through trial and error (Alevkayalı et al., 2023). The shoreline, as a dynamic geographical boundary, can be defined as a line formed by connecting points where water meets land in seas, lakes, rivers, and artificial bodies, excluding flood conditions (Turoğlu, 2017). In this study, after obtaining satellite images of Lake Eğirdir, shorelines from different dates were identified. During the determination of the shorelines, image rationing techniques were employed, and the Modified Normalised Difference Water Index (MNDWI) was utilised. In this index, the 2nd and 5th bands are used for Landsat 5 TM and the 3rd and 6th bands are used for Landsat 8 OLI (Sarp & Ozcelik, 2017).

MNDWI is a highly effective method for identifying water bodies by reducing noise from vegetation and soil (McFeeters, 1996; Xu, 2006). When using the Normalised Difference Water Index (NDWI) method, water and built-up areas near water bodies can sometimes mix, particularly in urbanised regions, leading to an overestimation of water bodies. To address this issue, MNDWI is recommended, especially in areas where water and built-up regions overlap, as it minimises noise from built-up areas (Guha & Govil, 2021). Therefore, the MNDWI method was used in this study to identify the shorelines of Lake Eğirdir on different dates. The raster data obtained by the proposed method were reclassified and converted into vector data.

$$MNDWI = \frac{Green - SWIR}{Green + SWIR}$$

Determination of Shoreline Changes

Landsat satellite images provide spectrally resolved data that are designed to monitor the geophysical characteristics of the Earth's surface. These data are particularly effective in distinguishing between land and water surfaces and offer high accuracy and repeatability for monitoring coastal areas (Dwyer et al., 2018). Since the 1970s, Landsat imagery has been a valuable resource for coastal management and environmental monitoring studies (Moore, 2000; Mishra et al., 2019; Woodcock et al., 2008).

The Digital Shoreline Analysis System (DSAS) is an extension integrated into the ESRI ArcGIS software, enabling the calculation of shoreline change rates based on shoreline data from multiple time periods (Himmelstoss et al., 2021). DSAS uses statistical analysis methods to assess changes in the shoreline, allowing for the examination of trends in coastal erosion, accretion, and stability. These analyses are crucial to gain a better understanding of the long-term impacts of changes in coastal regions.

The primary reason for preferring these methods in shoreline analyses is their complementary features, which enable a more comprehensive examination of coastal changes. MNDWI provides high accuracy in delineating shorelines by distinguishing water from land in satellite imagery. The shorelines obtained through this method can then be analysed with DSAS to determine key parameters such as changes over time (erosion or accretion) and the rates of these changes. The proposed approach provides detailed insights into both the location of the shoreline and its temporal variations.

In this study, the current state of Lake Eğirdir was evaluated using the DSAS tool, and change rate statistics were calculated for the shoreline data. The DSAS tool requires shoreline and baseline layers for operation. After completing the shoreline extraction process, a shoreline layer was created using the data obtained on different dates (Figure 3a). Three methods can be used to create the baseline layer: generating a line layer at a specific distance from the shoreline, drawing a baseline based on an older shoreline as a reference, or using the buffer analysis method (Yiğit et al., 2022). In this study, we employed buffer analysis, which is considered more reliable than the other methods. This method has been widely used in similar studies (Nassar et al., 2019). In this approach, a 300-m buffer analysis was performed on the shoreline layer, and the boundary facing the lake was designated as the baseline. Using the resulting shoreline and baseline layers, the DSAS tool was run, and transects were generated (Figure 3b).

In the subsequent analysis, statistical methods, including the end point rate (EPR), Linear Regression Rate (LRR), and Net Shoreline Movement (NSM), were applied to monitor and evaluate shoreline changes.

The End Point Rate (EPR) is calculated by dividing the distance (in metres) between two shorelines by the number of years between their respective dates (Ayadi et al., 2016; Dereli & Tercan, 2020; Hwang et al., 2014; Dolan et al., 1991; Hwang et al., 2014; Thieler et al., 2005). This statistical method is widely recognised as a common approach for calculating shoreline change rates and is frequently preferred by many researchers in this field.

$$EPR = \frac{L1 - L2}{t1 - t2}$$

In the equation, L1 and L2 represent the distance between the two shorelines, and t1 and t2 indicate the temporal difference between the two shorelines.

The LRR method examines multiple shorelines to understand how they change over time using a statistical model. The proposed model works by fitting a best-fit line to points along the shorelines. However, to yield accurate results, the shorelines must be precisely delineated. Errors in shoreline identification can significantly impact critical information, such as the rate of erosion or accretion (Dereli & Tercan, 2020; Nassar et al., 2019; Yiğit et al., 2022).

$$D = mt + a$$

In the equation, D represents the distance from the baseline (in metres), t denotes the time variation of the shoreline (in years), m is the slope of the fitted line (in metres per year), and a is the y-intercept.

The NSM statistic represents the distance between the old and new shorelines over the analysed periods (Himmelstoss et al., 2018). Using the NSM statistic, the average, maximum, and minimum values of shoreline changes can be determined for the specified periods (Uzun, 2024).

Results

Lake Eğirdir, one of Turkey's largest freshwater reservoirs, supplies drinking water to the local population and meets irrigation needs for agriculture in the region. However, due to factors such as excessive water usage within the lake and its basin, climate change, and poor watershed management practices, alongside changes in climate data, Lake Eğirdir has experienced significant water recession in recent years, particularly in 2024 (Figure 4 ve Figure 5).

The Digital Shoreline Analysis System (DSAS) was originally developed for use along marine coastlines, and its terminology, parameters, and threshold values are defined

Figure 3

Creation of baseline layer using buffer analysis and generation of transects

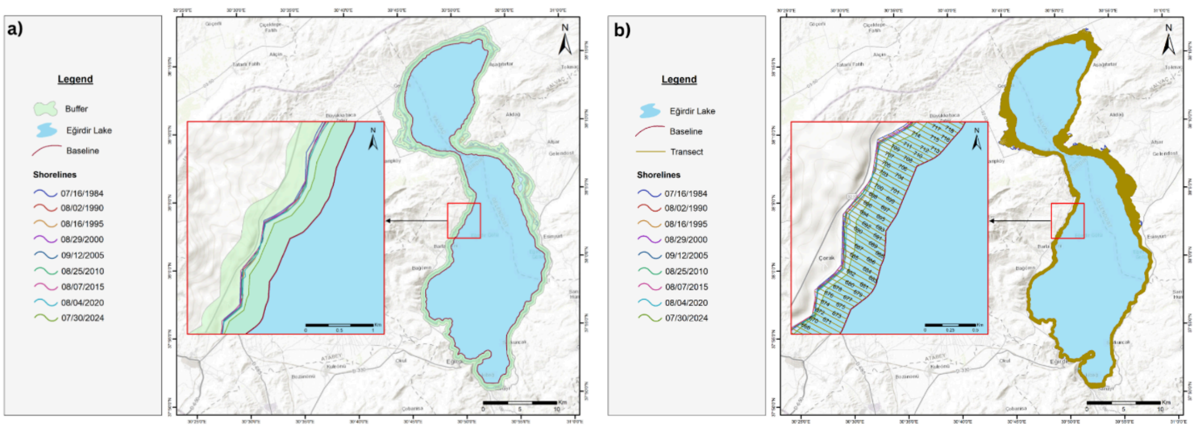
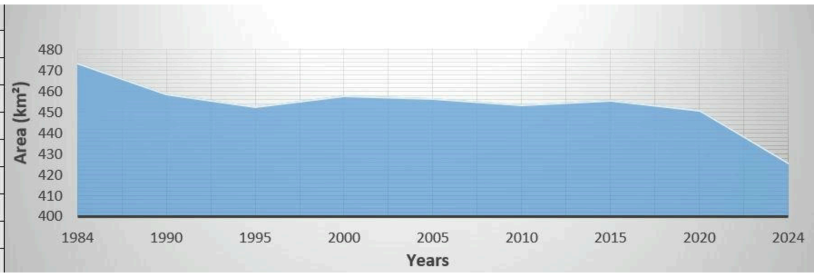


Figure 4

Long-term (1984–2024) areal changes of Lake Eğirdir

Date	Area (km²)
1984	474
1990	459
1995	453
2000	458
2005	457
2010	454
2015	456
2020	451
2024	426



based on coastal marine dynamics. However, this method has also proven to be applicable and effective in studies on lakes and their shorelines, providing meaningful results and guiding the interpretation of shoreline change trends. Nevertheless, processes driving shoreline retreat and advance differ significantly between marine and lacustrine environments. In coastal areas, shoreline advancement generally results from the transport and accumulation of alluvium driven by external forces, whereas retreat is often caused by sea level rise associated with climate change and tectonic activity, which increases coastal erosion. In contrast, in lake environments, the process works in the opposite direction: shoreline retreat is typically linked to sediment accretion, whereas shoreline advancement is associated with rising water levels and the resulting shoreline erosion. Therefore, the terminology and parameters used in the DSAS should be carefully interpreted with respect to the fundamental differences between lake and marine systems.

This recession has caused the narrowing of Kemerboğazı, the point at which the eastern and western shores of the lake are closest to each other (Figure 5). This phenomenon has increased the risk of the lake splitting into two separate bodies of water, named Eğirdir and Hoyran. Such potential changes are expected to have significant impacts on the lake's ecosystem and environmental balance.

Figure 5

Current view of Kemerboğazı location (31.10.2024)

Figure 6

Long-term (1984–2024) areal changes in the surface area of Lake Eğirdir

Source: Google Earth, 20.10.2024/16:30

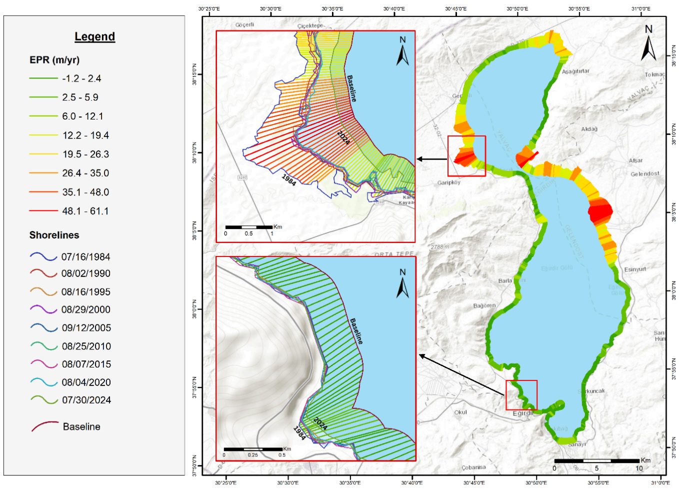
In this study, to obtain concrete findings regarding this recession, statistical analyses of EPR, LRR, and NSM were conducted using the DSAS tool at a 99% confidence level. The results of these statistical analyses are displayed on maps. In the obtained statistical values, negative values indicate erosion and positive values represent accretion. The findings derived from the applied EPR, LRR, and NSM statistical analyses are as follows:

End-point Rate (EPR)

EPR is a statistical method used to quantify the rate of shoreline change at specific locations. The findings from this analysis reveal how quickly the shoreline changes in m/year, whether the change indicates accretion or erosion, and which areas exhibit higher rates of change. The results show that the maximum accretion rate on the shoreline was 61.1% m/year, west of Akdağ (Figure 7). The maximum erosion rate was recorded northwest of Eğirdir, with a value of −1,2 m/year (Table 2).

Figure 7

Long-term (1984–2024) EPR results across the entire shoreline of Lake Eğirdir (2744 transects)

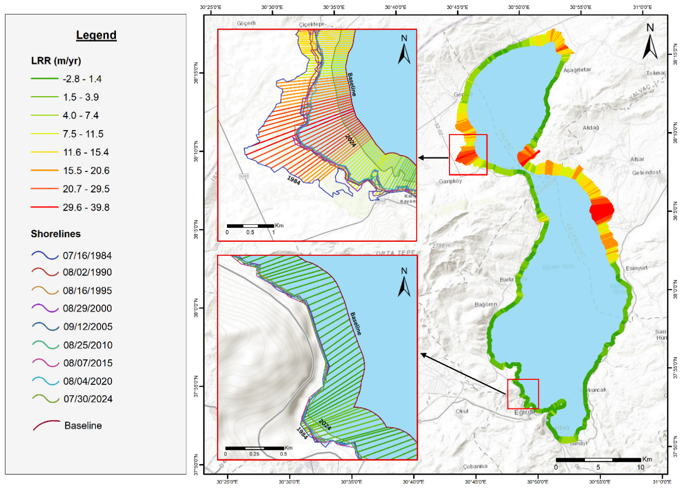


Linear Regression Rate (LRR)

The LRR provides the general trend and temporal rate of shoreline change. According to the results, the maximum rate of shoreline accretion occurred west of Akdağ and was calculated as 39,8 m/year (Figure 8). The maximum rate of erosion was recorded northwest of Eğirdir at a value of −2,8 m/year (Table 2).

Figure 8

Long-term (1984–2024) LRR results in the entire shoreline of Lake Eğirdir (2744 transects)



Net Shoreline Movement (NSM)

The NSM method shows the net movement of the shoreline in metres. According to the analysis, the maximum positive NSM value was calculated as 2444.6 m west of Akdağ. Out of 2744 transects, 2698 (98.32%) exhibited positive displacement, indicating shoreline sediment accretion. The maximum negative NSM value was recorded 47 m northwest of Eğirdir (Figure 9). A total of 46 transects (1.68%) showed negative displacement, indicating shoreline erosion (Table 3).

The analyses performed on the entire shoreline of Lake Eğirdir yielded positive values, indicating a retreat of the shoreline towards the lake. When evaluating the entire shoreline of Lake Eğirdir, the highest EPR, LRR, and NSM values were found on the western side of Akdağ, southwest of the Gelendost district centre (Figure 2a), and along the shores northeast of Garipköy. These areas were observed to have the highest rates and magnitudes of shoreline retreat.

Table 2

EPR (End Point Rate, m/year) and LRR (Linear Regression Rate, m/year) Results

	Analysis Type	***EPR (m/yr)***	***LRR (m/yr)***
EROSION	Number of erosional transects	46	101
	percentage of all erosional transects	1.68%	3.68%
	Maximum value erosion	−1.17	−2.82
	Maximum value erosion transect ID	317	167
	Average erosional rate	−0.24	−0.25
ACCRETION	Number of accretion transects	2698	2643
	Percentage of all accretional transects	98.32%	96.32%
	Maximum value accretion	61.06	39.78
	Maximum value accretion transect ID	2035	2055
	Average of all accretion rates	9.45	5.82

Figure 9

Long-term (1984–2024) NSM results in the entire shoreline of Lake Eğirdir (2744 transects)

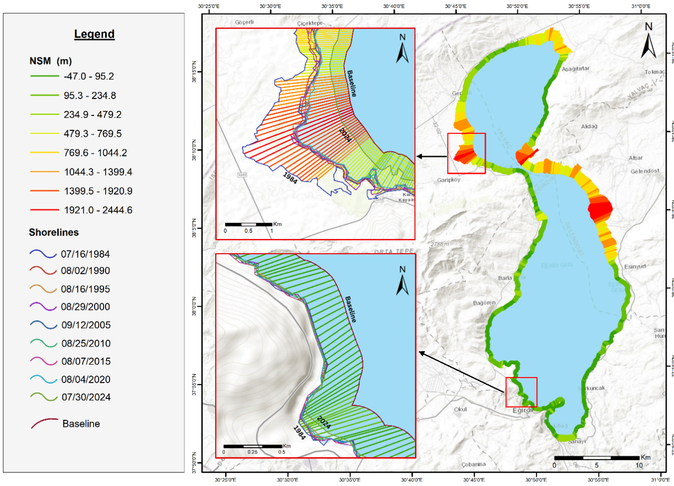


Table 3

NSM (Net Shoreline Movement, m) results

NSM (Net Shoreline Movement, m)	Value
Total transect number	2744
Average distance	372.03
Number of transects with negative distances	46
Percentage of all transects with negative distances	1.68%
Maximum negative distance	−46.96
Maximum negative distance of transect ID	317
Average negative distances	−9.66
Number of transects with positive distances	2698
Percentage of all transects with positive distances	98.32%
Maximum positive distance	2444.6
Maximum positive-distance transect ID	2035
Average positive distances	378.53

The lowest values were observed in the northwestern and southeastern parts of Eğirdir, to the east of Barla Mountain, southeast of Karakuş Mountains, west of Kirişli Mountain, and along the shores northwest of Sorkuncak Village. In these areas, the rate and magnitude of shoreline retreat were determined to be lower than those in other regions.

Different rates and magnitudes of shoreline retreat have been identified in various areas along the shoreline of Lake Eğirdir. This variation can be attributed to the topographic and bathymetric conditions. In shallow and wide areas, the shoreline retreat distance is greater, whereas in areas with steep slopes, the retreat distance is smaller. This explains why greater retreat is observed along the shores southwest of Gelendost, where the slope is gentle (Figure 10a), and less retreat is observed along the shores west of Sorkuncak Village, where the slope is steep (Figure 10b).

Evaluation of Temperature and Precipitation Trends

In this study, the Mann-Kendall trend analysis, which is frequently used in the literature, was employed to examine the relationship between temporal changes in the shoreline of Lake Eğirdir and climatic parameters. The analysis was conducted using the ±1.96 critical z-score thresholds of 1.96 at 95% confidence level. For this purpose, long-term monthly average temperature, maximum temperature, minimum temperature, and total precipitation data from meteorological stations closest to Lake Eğirdir (Eğirdir, Isparta, Senirkent Uluborlu, Yalvaç) were used.

According to the Mann-Kendall statistical test applied to the study area, a positive trend was observed in the monthly average, maximum, and minimum temperature values obtained from the Eğirdir station, while no significant increase or decrease was detected in precipitation values (Table 4). Similarly, at Yalvaç Station, a positive trend was identified in the monthly average, maximum, and minimum temperature values (Table 4). Although the precipitation values at this station did not exhibit a significant trend

Figure 10

(a) Changes observed along the shore southwest of Gelendost and (b) west of Sorkuncak Village

Source: Google Earth/10.11.2024, 16:30

in either direction, Yalvaç showed the strongest decreasing trend in precipitation among all stations (-1.69). At the Senirkent station, the maximum and minimum temperature values exhibited a positive trend, while no significant increase or decrease was observed in the average temperature and precipitation values (Table 4). At Uluborlu Station, a positive trend in maximum temperature was detected. Conversely, no significant trend was observed for average temperature, minimum temperature, or precipitation values (Table 4). At Isparta Station, a positive trend was observed for average, maximum, and minimum temperature. However, no significant increase or decrease in precipitation values was identified at this station (Table 4).

Evaluation of the Anthropogenic Impact

Lake Eğirdir has undergone significant changes over the past century as a result of anthropogenic impacts resulting from human activities. These impacts have caused notable alterations in the lake's shoreline and substantial declines in its water level. As a source of drinking water, the intensive use of groundwater for irrigating orchards within the lake catchment area, along with the extraction of water directly from the lake for surrounding orchards, has led to serious issues in the lake's water balance.

According to these findings, disruption of the water balance is a key factor that drives changes in the shoreline. Rising temperatures due to climate change, particularly with 2023 being the hottest year in history, have further increased the pressure on the lake. Excessive water usage for fruit production around the lake is one of the major factors contributing to the rapid decline in the lake's water levels.

The spatial and temporal distribution of fruit orchards around Lake Eğirdir was examined using data from the Turkish Statistical Institute (TÜİK). The analyses were conducted based on fruit orchard area data from the districts of Eğirdir, Gelendost, Senirkent, Yalvaç and Uluborlu from 2004 to 2023.

The analysis revealed that between 2004 and 2023, the area of fruit plantations expanded in nearly all districts bordering Lake Eğirdir. Although there were occasional fluctuations in certain years, the overall trend indicates an increase in the area of fruit orchards around the lake from 2004 to 2023 (Figure 11). This upward trend in the area of water-intensive fruit orchards poses a significant threat, contributing to the recession of the lake.

The increasing trend in temperature values, as revealed by climate data, combined with the continued demand for water to sustain the fruit orchards around the lake, has further

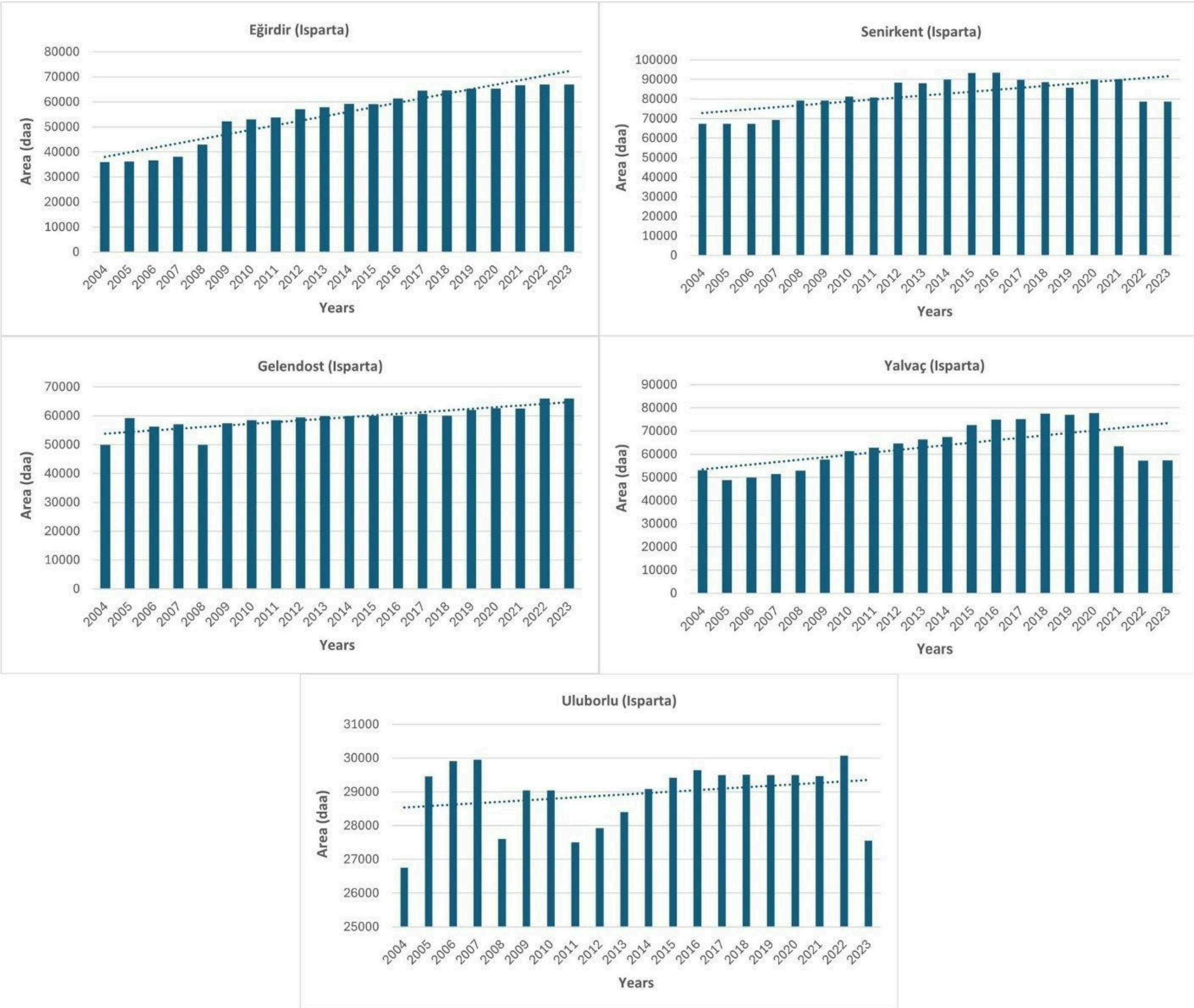
Table 4

Mann-Kendall Trend Analysis and Results in the Study Area.

Station	Parameter	Z- Score	Trend Direction	H_1 Hypothesis	Za/2 (+/-)
	Average Temperature (°c)	2,33	*Increasing Trend*	*Accept*	1,96
	Max. Tempt (°c)	2,04	*Increasing Trend*	*Accept*	1,96
	Min. Tempt (°c)	2,52	*Increasing Trend*	*Accept*	1,96
Eğirdir (1984-2024)	Rainfall (mm)	0,29	No increase or decrease	Reject	1,96
	Average Temperature (°c)	2,46	*Increasing Trend*	*Accept*	1,96
	Max. Tempt (°c)	1,79	*Increasing Trend*	*Accept*	1,96
	Min. Tempt (°c)	3,97	*Increasing Trend*	*Accept*	1,96
Yalvaç (1984-2024)	Rainfall (mm)	-1,69	No increase or decrease	Reject	1,96
	Average Temperature (°c)	1,78	No increase or decrease	Reject	1,96
	Max. Tempt (°c)	2,52	*Increasing Trend*	*Accept*	1,96
	Min. Tempt (°c)	2,11	*Increasing Trend*	*Accept*	1,96
Senirkent (1984-2024)	Rainfall (mm)	-0,20	No increase or decrease	Reject	1,96
	Average Temperature (°c)	1,83	No increase or decrease	Reject	1,96
	Max. Tempt (°c)	2,59	*Increasing Trend*	*Accept*	1,96
	Min. sıcaklık	1,40	No increase or decrease	Reject	1,96
Uluborlu (1984-2024)	Rainfall (mm)	-0,75	No increase or decrease	Reject	1,96
	Average Temperature (°c)	2,40	*Increasing Trend*	*Accept*	1,96
	Max. Tempt (°c)	2,17	*Increasing Trend*	*Accept*	1,96
	Min. Tempt (°c)	3,19	*Increasing Trend*	*Accept*	1,96
Isparta (1984-2024)	Rainfall (mm)	0,35	No increase or decrease	Reject	1,96

Figure 11

Changes and trends in fruit orchard area from 2004 to 2023



exacerbated the negative development of the water balance. The convergence of these adverse factors resulted in a significant decline in the lake's water level and a substantial retreat of the shoreline.

Discussion and Conclusion

The reduction in the surface area of Lake Eğirdir has been highlighted multiple times in various studies conducted at different times (Aksoy et al., 2019; Aslan & Koç-San, 2021; Büyükyıldız & Yılmaz, 2011; Göncü et al., 2017; Kale & Erişmiş, 2024). In recent years, the decline in the lake's water level has become a focal point of research. This study examined the changes in the shoreline of Lake Eğirdir between 1984 and 2024 and evaluated the climatic and anthropogenic factors contributing to these changes. To calculate the magnitude and rate of shoreline changes, the Digital Shoreline Analysis System (DSAS), an extension of ArcGIS, was used. Statistical values for the end-point rate (EPR), Linear Regression Rate (LRR), and Net Shoreline Movement (NSM) were calculated.

The changes in the shoreline of Lake Eğirdir were calculated in m/year using EPR and LRR analyses, while the NSM method was used to determine the direction and magnitude of these changes. The results show that accretion is characterised by shoreline recession, indicating a reduction in lake water levels. Positive EPR and LRR values indicate the continuity of accretion due to shoreline retreat. In particular, the highest EPR value of 61,06 m/yr and the highest LRR value of 39,78 m/yr calculated west of Akdağ highlight the speed and consistency of the retreat. Similarly, the highest positive NSM value of 2444,6 m indicates a significant long-term retreat in this region.

The negative NSM value (-46,96 m) indicates that erosion is effective in limited areas; however, it supports the overall observation that the shoreline has predominantly experienced retreat. This reflects a long-term trend of declining lake water levels and ongoing changes in shoreline dynamics.

These findings are consistent with similar studies in the literature. For instance, the methods developed by Thieler et al. (2003) have been noted for producing reliable results, particularly with the EPR and LRR methods providing consistent outputs for measuring the shoreline change rates. Additionally, previous studies specific to Lake Eğirdir (Büyükyıldız & Yılmaz, 2011; Göncü et al., 2017) emphasised the reduction in the lake's surface area, whereas this study has analysed specific shoreline change rates in greater detail. Furthermore, the effectiveness of the DSAS method in understanding shoreline dynamics has been highlighted by Rio et al. (2013) and Oyedotun (2014). In this context, the consistency of results obtained using different analytical methods in this study confirms the accuracy and reliability of the methods. These consistent results indicate a distinct linear trend in changes along the shoreline of Lake Eğirdir.

Mann-Kendall trend analysis was performed on the study area. The results indicate a notable increase in maximum temperatures across all stations. In addition to Uluborlu station, an increasing trend was also observed in minimum temperatures at the other stations. Average temperature trends showed an upward tendency at the Eğirdir, Yalvaç, and Isparta stations. As a general finding, there was no significant increase or decrease in precipitation at any station. The observed increasing temperature trends from the stations contributed to higher evaporation rates in the study area, while the lack of a corresponding increase in precipitation values (ranging from zero to negative trends) emerged as a contributing factor to the retreat of Lake Eğirdir's shoreline. Similar to the findings of this study, an increasing trend in maximum temperature values and a decreasing trend in precipitation values have been observed over the past 30 years, both in the study area (Şen, 2013; Coşkun, 2020) and across Turkey (Demir et al., 2008; Şen, 2013). Data from the Gelendost station were excluded from the trend analysis in this study because recordings at the station only began in 2012. As the number of data points increased, the statistical power of the Mann-Kendall trend test also improved (Yue et al., 2002). Therefore, trend tests were conducted using 40 years of data for the other stations, yielding significant results.

Compared to other lakes, the shoreline change rates in Lake Manyas are relatively lower, with a maximum EPR of 39,82 m/year and an LRR of 33,18 m/year. This study revealed that sediment accretion dominated along the southern shores due to alluvial input from the Manyas Stream, while shoreline erosion persisted along the northern shores. The observed changes in Lake Manyas can be attributed not only to the sediment transported by the Manyas Stream but also to anthropogenic factors such as agricultural water use and dam construction (Uzun, 2024).

In a similar study conducted at Lake Salda, the EPR and LRR were calculated as 16,35 and 12,91 m/year, respectively, with the primary drivers of change identified as rising temperatures, variations in precipitation, and dam construction (Dereli & Tercan, 2020). In contrast, the shoreline change in Lake Burdur occurred at a much faster rate. Between 2013 and 2023, the maximum EPR and LRR were 543,12 m/year and 610,07 m/year. This rapid change has been primarily attributed to intensive agricultural water use (Baş, 2023).

Compared to these studies, the highest EPR value calculated for Lake Eğirdir was 61,06 m/year, while the highest LRR value was 39,78 m/year, indicating the rate and ongoing nature of shoreline retreat. In comparison to Lakes Manyas and Salda, shoreline change rates in Lake Eğirdir are higher, yet they remain lower than the extreme rates observed in Lake Burdur. The primary drivers of shoreline changes in Lake Eğirdir have been identified as rising temperatures and, in particular, the irrigation demand of water-intensive fruit orchards.

The anthropogenic impacts observed in and around Lake Eğirdir have various effects, ranging from the diversity of flora and fauna to declines in water levels. Although wild irrigation is no longer as prevalent as it once was, agricultural irrigation in the basin, where the water balance has been disrupted, continues to be a factor contributing to the reduction in the surface area of Lake Eğirdir. This claim is supported by the findings of the study.

Land use data extend back approximately six years and do not fully reflect the current situation. Therefore, the distribution and condition of fruit orchards around Lake Eğirdir were examined through observations and field studies. Observations revealed that fruit orchards are highly preferred in the region due to their high economic returns. This finding is also supported by Karatepe's (2004) study, which noted that agricultural activities with high economic returns have caused significant changes in land use around the lake. However, watershed planning in and around lakes is significantly lacking. The current watershed management is insufficient to reduce the pressure of water consumption on the lake. Therefore, re-evaluating and redesigning watershed management practices. Crops to be cultivated in the watershed should be selected based on their water consumption levels, and agricultural activities with high water use should be managed in a controlled manner. These measures will contribute to both the preservation of the lake's water levels and to ensuring agricultural sustainability.

Water resources around Lake Eğirdir are under significant changes due to the pressure of human activities. Agricultural irrigation, land use, and other anthropogenic impacts at the watershed scale directly contribute to shoreline retreat and water level declines. In particular, the cumulative effects of human activities on river channels and water resources are critical for sustainable river management. Downs and Piégay (2019) emphasised that human-induced activities within watersheds alter the morphology of river channels, and this impact must be integrated into sustainable water management strategies. Similarly, Rybkina (2023) highlighted that the methodological evaluation of anthropogenic pressure on water resources forms the basis for improving water use efficiency and conserving resources. In this context, strategies are needed to reduce water consumption in Lake Eğirdir and ensure watershed management sustainability.

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REFERENCES

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

Alevkayalı, Ç., Atayeter, Y., Yayla, O., Bilgin, T., & Akpınar, H. (2023). Burdur Gölü'nde uzun dönemli kıyı çizgisi değişimleri ve iklim ilişkisi: Zamansal-mekânsal eğilimler ve tahminler. *Türk Coğrafya Dergisi*, (82), 37-50.

Aslan and Koc-San (2021). Investigation of the changes in lake surface temperatures and areas: Case study of Burdur and Egirdir Lakes, Turkey. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *43*, 299-304.

Atayeter, Y. (2005). *Aksu Çayı Havzası'nın Jeomorfolojisi*. Fakülte Kitabevi.

Atayeter, Y. (2011). *Eğirdir Gölü Depresyonu ve Yakın Çevresinin Genel Fiziki Coğrafyası. Fakülte Kitabevi.*

Ayadi, K., Boutiba, M., Sabatier, F., & Guettouche, M. S. (2016). Detection and analysis of historical variations in the shoreline using digital aerial photos, satellite images, and topographic surveys DGPS: case of Bejaia Bay (East Algeria). *Arabian Journal of Geosciences*, 9, 1-12.

Aydin, FA, & Dogu, AF (2018). Level changes in lakes and their causes: Van Lake example. *Journal of Yuzuncu Yil University Social Sciences Institute*, (41), pp. 183-208.

Bahadır, M. (2013). Akşehir Gölü'nde Alansal Değişimlerin Uzaktan Algilama Teknikleri ile Belirlenmesi. *Marmara Coğrafya Dergisi*, (28), 246-275.

Baig, M. H. A.; Zhang, L.; Shuai, T.; Tong, Q. (2020). Derivation of a tasselled cap transformation based on Landsat 8 at-satellite reflectance. *Remote Sensing Letters*, *11*(1), 66–75. https://doi.org/10.1080/2150704X.2020.1714329

Baş, N. (2023). An effective approach for analysis of shoreline change and determination of its future location using satellite imagery: A case study of Lake Burdur, Turkey. *Gümüşhane Üniversitesi Fen Bilimleri Dergisi*, *14*(1), 61-72.

Bozyiğit, R., and Tapur, T. (2009). Konya ovası ve çevresinde yeraltı sularının obruk oluşumlarına etkisi. *Selçuk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, (21), 137-155.

Cengiz, T. M., & Kâhya, E. (2011). Türkiye göl su seviyelerinin eğilim ve harmonik analizi. *İTÜDERGİSİ/d*, *5*(3).

Coşkun, S. (2024). Göller Yöresi'nde sıcaklık, yağış ve akım değerlerinde meydana gelen eğilimler (Akdeniz Bölgesi-Türkiye). *Social Sciences Studies Journal (SSSJournal)*, *6*(66), 3142-3155.

Çankal, G., & Alkın, R. C. (2024). İklim Değişikliği, Bilinçsiz Tarım ve Afet Yönetimi: Karapınar Obruklarına Bir Bakış. *Afet ve Risk Dergisi*, *7*(2), 410-425.

Demir, İ., Kılıç, G., Coşkun, M., & Sümer, U. M. (2008). Türkiye'de maksimum, minimum ve ortalama hava sıcaklıkları ile yağış dizilerinde gözlenen değişiklikler ve eğilimler. *TMMOB İklim Değişimi Sempozyumu, Bildiriler Kitabı*, *69*, 84.

Dereli, M. A., & Tercan, E. (2020). Assessing shoreline changes using historical satellite images and geospatial analysis along the Lake Salda in Turkey. *Earth science informatics*, 13(3), 709-718.

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. 2013; 13*(3): 709-718.

Dolan, R., Fenster, M. S., & Holme, S. J. (1991). Temporal analysis of shoreline recession and accretion. *Journal of coastal research*, 723-744.

Dönmez, S. (2018). Akşehir Gölü su seviyesinin çekilmesinin meteorolojik ve uydu verileri ile incelenmesi. *Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, 33(1).

Dwyer, J. L., D. P. Roy, B. Sauer, C. B. Jenkerson, H. K. Zhang, and L. Lymburner (2018). Analysis of ready data: Enabling Landsat archive analysis. *Remote Sensing, 10*(9), 1363. https://doi.org/10.3390/rs10091405

Esper, J., Torbenson, M., & Büntgen, U. (2024). 2023 summer warmth unparalleled over the past 2,000 years. *Nature*, 1-2.

European Centre for Medium-Range Weather Forecasts. (2024). *Climate change services: Annual climate report 2024*. Copernicus Climate Change Service. Retrieved from https://climate.copernicus.eu/annual-climate-report-2024.

Hamed, K. H., & Rao, A. R. (1998). A modified Mann-Kendall trend test for autocorrelate data. *Journal of Hydrology, 204*(1-4), 182-196. https://doi.org/10.1016/S0022-1694(97)00125-X,

)[https://doi.org/10.1016/S0022-1694(97)00125-X];

Himmelstoss, E. A., Henderson, R. E., Kratzmann, M. G., & Farris, A. S. (2021). Digital Shoreline Analysis System (DSAS), Version 5.1 User Guide (No. 2021-1053). U.S. Geological Survey. https://doi.org/10.3133/ofr20211053

Hwang, C. S., Choi, C. U., & Choi, J. S. (2014). Shoreline changes interpreted from multi-temporal aerial photographs and high resolution satellite images. A case study in Jinha beach. *Korean Journal of Remote Sensing*, 30(5), 607-616.

Karmeshu, N. (2012). Trend detection in annual temperature & precipitation using the Mann–Kendall test–a case study to assess climate change on select states in the northeastern United States. *Master of Environmental Studies Capstone Projects*, *47*, 1-33.

Lillesand, T., Kiefer, R. W., & Chipman, J. (2015). *Remote sensing and image interpretation*. John Wiley & Sons.

Lu, D., & Weng, Q. (2007). A survey of image classification methods and techniques for improving classification performance. *International Journal of Remote Sensing*, 28(5), 823-870.

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica, 13*(3), 245-259. https://doi.org/10.2307/1907187

McFeeters, S. K. (1996). Use of the normalised difference water index (NDWI) for delineating open water features. *International Journal of Remote Sensing*, 17(7), 1425-1432.

Mishra, R., Gupta, R. D., & Vishwakarma, A. K. (2019). Change detection analysis of coastlines using multi-temporal satellite images. *Applied Geography, 102*, 74–81. https://doi.org/10.1016/j.apgeog.2018.11.010

Moore, L. J. (2000). Shoreline mapping techniques. *Journal of Coastal Research, 16*(1), 111–124. https://doi.org/10.1006/ecss.1999.0587

Moustafa, A. A., Elganainy, R. A., and Mansour, S. R. (2023). Insights into the UNSG announcement: The end of climate change and the arrival of the global boiling era, July 2023 confirmed as the hottest month recorded in the past 120,000 years. *Catrina: The International Journal of Environmental Sciences, 28*(1), 43–51.

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 and Geotechnology*, *37*(1), 81-95.

Onoz, B., and Bayazit, M. (2003). The power of statistical tests for trend detection. *Turkish Journal of Engineering & Environmental Sciences*, *27*(4).

Richards, J. A. (2013). *Remote sensing digital image analysis: An introduction*. Springer.

Sabins, F. F. (1997). *Remote sensing: Principles and interpretation*. W. H. Freeman & Company.

Sarp, G., & Özcelik, M. (2017). Water body extraction and change detection using time series data: A case study of Lake Burdur, Turkey. *Journal of Taibah University for Science*, 11(3), 381-391.

Selçuk Biricik, A. S. (2014). *Türkiye Sular Atlası.* Oray Basım Yayın ve Matbaacılık.

Sipahi, M. H. (1987). *Aksu Çayı Havzası'nın (Antalya) Karst'ı ve Hidrojeolojisi.* [Doktora tezi, İstanbul Üniversitesi].

Şen, C. (2013). *Isparta İlinde Sıcaklık ve Yağış Verilerinin Trend Analizi*, [Yüksek lisans tezi, Süleyman Demirel Üniversitesi]. YÖK Tez Merkezi.

Taberi, H., Marofi, S., Aeini, A., Talaee, P.H., Mohammadi, K., 2011. Trend Analysis of Reference Evapotranspiration in the Western half of Iran. Agricultural and Forest Meteorology 151, 128-136.

Tapur, T., & Bozyiğit, R. (2015). Konya Ilinde Güncel Obruk Oluşumlari. *Marmara Coğrafya Dergisi*, (31), 415-446.

Thieler, E. R., Himmelstoss, E. A., Zichichi, J. L., and Miller, T. L. (2005). Digital shoreline analysis system (DSAS) version 3.0. *An ArcGIS© extension for calculating shoreline change: US Geological Survey Open-File Report*, *1304*.

Thieler, E. R., Mart'in, D., & Ergul, A. (2003). *Digital Shoreline Analysis System (DSAS) version 2.0: An ArcView extension for calculating shoreline change* (No. 2003-76). US Geological Survey.

Thieler, E. R., J. F. O'Connell, and C. A. (2009). The Digital Shoreline Analysis System (DSAS) version 4.0-An ArcGIS extension for calculating shoreline change (No. 2008-1278). U.S. Geological Survey. https://doi.org/10.3133/ofr20081078

Turoğlu, H. (2017). Deniz ve Göllerde Kıyı. (Editörler: H. Turoğlu ve H. Yiğitbaşıoğlu), and Yasal ve Bilimsel Boyutlarıyla KIYI. *Jeomorfoloji Derneği Yayınları*, (1), 1-32,

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

Woodcock, C. E., Allen, R. G., & Anderson, M. C. (2008). Landsat 5 TM and Landsat 7 ETM+ data for land surface monitoring. *Remote Sensing of Environment*, *112*(1), 215–219. https://doi.org/10.1016/j.rse.2008.03.010

World Meteorological Organisation. (2024). *United in Science 2024: A multi-organisation high-level compilation of the latest weather, climate, water, and related environmental and social sciences for the future*. World Meteorological Organisation. https://library.wmo.int/idurl/4/69018

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), pp. 3025-3033.

Yarar, A., & Onüçyıldız, M. (2009). Yapay sinir ağları ile Beyşehir Gölü su seviyesi değişimlerinin belirlenmesi. *Selçuk Üniversitesi Mühendislik, Bilim ve Teknoloji Dergisi*, *24*(2), 21-30.

Yılmaz, M. (2010). Karapınar çevresinde yeraltı suyu seviye değişimlerinin yaratmış olduğu çevre sorunları. *Ankara Üniversitesi Çevrebilimleri Dergisi*, *2*(2), 145-163.

Yigit, A. Y., Senol, H. I., & Kaya, Y. (2022). Çok zamanlı multispektral uydu verilerinin Marmara Gölü kıyı değişimi analizinde kullanılması. Geomatik, 7(3), 253-260.

Yue, S., Pilon, P., & Cavadias, G. (2002). Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of hydrology*, 259(1-4), 254-271.

Zheng, F., Hu, S., Ma, J., Wang, L., Li, K., Wu B, et al. & Zhu, J. (2024). The world will encounter the warmest winter in 2023.