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Impacts of Hydrological Losses on Surface Temperatures in the Lakes Region: A Remote Sensing–Based Assessment

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Abstract: Global climate change and escalating anthropogenic pressures are driving increasingly severe hydrological crises within the freshwater reserves of the Mediterranean Basin. This study employs remote sensing techniques to examine changes in the water surface areas of nine selected lakes in the Lakes Region, one of Türkiye's most ecologically sensitive zones, between 1990 and 2025. Additionally, it assesses the subsequent impacts of these changes on the lakes' thermal regimes and their immediate vicinities. The main aim is to analyze trends in land and water surface temperatures to determine whether the long-term reduction in lake surfaces triggers a positive feedback mechanism. Results from the Modified Normalized Difference Water Index (MNDWI), derived from Landsat satellite imagery, show a clear, systematic, and continuous trend of water loss across the Lakes Region over the 35-year period. Shifts in thermal processes were evaluated using the Land Surface Temperature (LST) and Land Surface Water Temperature (LSWT) indices. The findings indicate that Akşehir, Karataş, and Yarışlı lakes have completely desiccated during summer periods, transforming into terrestrial surfaces. Lake Burdur has experienced approximately a 40% reduction in surface area, while Lake Eber has suffered an 80% reduction. Although Lakes Beyşehir and Eğirdir have relatively minor areal fluctuations, they have experienced significant volume losses. Conversely, Lakes Salda and Gölhisar have maintained their surface areas relatively well, primarily owing to their deep morphologies, favorable hydrogeological recharge conditions, and protected status. The Mann–Kendall trend analysis employed in this study identified a robust positive correlation between lake surface recession and increasing surface temperatures. These results demonstrate that the decline in lake area is not solely a hydrological issue but also a mechanism that disrupts the surface energy balance, thereby intensifying regional and local warming.

Keywords: Lake District of Türkiye, Land Surface Temperature/Land Water Surface Temperature (LST/LWST), Remote Sensing, Positive Feedback Mechanism, Trend Analysis.

Göller Yöresi'nde Hidrolojik Kayıpların Yüzey Sıcaklıkları Üzerindeki Etkileri: Uzaktan Algılama Tabanlı Bir İnceleme

Özet: Küresel iklim değişikliği ve artan antropojenik baskılar, Akdeniz Havzası'ndaki tatlı su rezervleri üzerinde giderek derinleşen hidrolojik sorunlara yol açmaktadır. Bu çalışma Türkiye'nin ekolojik açıdan en hassas bölgelerinden biri olan Göller Yöresi'nde yer alan dokuz seçilmiş gölün 1990–2025 yılları arasındaki su yüzey alanı değişimlerini ve bu değişimlerin göl ve yakın çevresindeki termal rejim üzerindeki etkilerini uzaktan algılama yöntemleriyle incelemektedir. Çalışmanın temel amacı göl yüzeylerinde meydana gelen uzun süreli daralmaların kara ve su yüzey sıcaklıkları üzerinden eğilim analizleri ile pozitif bir geri besleme mekanizması oluşturup oluşturmadığını belirlemektir. Bu kapsamda Landsat uydu görüntüleri kullanılarak hesaplanan Modifiye Edilmiş Normalize Fark Su İndeksi sonuçları otuz beş yıllık süreçte Göller Yöresi genelinde belirgin sistematik ve süreklilik arz eden bir su kaybı eğilimini ortaya koymuştur. Termal süreçlerdeki değişimler Kara Yüzeyi Sıcaklık İndeksi ve Su Yüzeyi Sıcaklık İndeksi kullanılarak değerlendirilmiştir. Bulgular Akşehir, Karataş ve Yarışlı göllerinin yaz dönemlerinde tamamen kuruyarak karasal yüzeylere dönüştüğünü göstermektedir. Burdur Gölü yaklaşık %40, Eber Gölü ise %80 oranında su yüzey alanı kaybı yaşamıştır. Türkiye'nin en büyük tatlı su rezervleri olan Beyşehir ve Eğirdir göllerinde alansal değişim fazla olmasa da su hacmi açısından önemli kayıplar gerçekleşmiştir. Buna karşılık Salda ve Gölhisar gölleri derin morfolojileri, hidrojeolojik beslenme koşulları ve koruma statülerinin etkisiyle yüzey alanlarını görece olarak koruyabilmiştir. Çalışmada kullanılan yöntemlerden Mann–Kendall trend analizleri göl yüzeylerindeki gerileme ile yüzey sıcaklıkları arasında güçlü bir pozitif ilişki belirlenmiştir. Sonuçlar göl alanı kayıplarının yalnızca hidrolojik bir sorun olmadığını aynı zamanda yüzey enerji dengesini bozarak yerel ve bölgesel ölçekte ısınmayı destekleyen bir mekanizma oluşturduğunu göstermektedir.

Anahtar Kelimeler: Göller Yöresi, Yüzey Sıcaklığı (LST/LWST), Uzaktan Algılama, Pozitif Geri Besleme, Trend Analizi

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1. Introduction

Climate change is widely recognized as predominantly caused by anthropogenic activities, characterized by rising greenhouse gas emissions and a decline in ecosystems' capacity to sequester carbon, with the latter associated with land-use changes (Legg, 2021). The most apparent climatic indicators of these global transformations include various thermal alterations, ranging from rising sea surface temperatures (Tagil et al., 2024) to the expansion of urban heat islands (Aksak et al., 2023) and the poleward and altitudinal shifts of climate zones (Şen, 2022). These thermal changes are further exacerbated by pronounced temporal and spatial irregularities in precipitation patterns (Vicente-Serrano et al., 2025). Contemporary climate projections consistently indicate that this global warming trend will intensify in the coming decades (Karahan, 2025), placing immense pressure on vulnerable regions. The Mediterranean Basin, in particular, encounters increasingly severe meteorological and hydrological droughts, resulting in substantial reductions of critical water bodies (Türkeş, 2021). Under these escalating conditions, lakes and rivers are among the hydrographic units most vulnerable to climatic variability.

Lakes are among the principal reservoirs of Earth's surface freshwater, playing indispensable roles in maintaining ecosystem equilibrium and biodiversity while supporting human activities such as agriculture, potable water supply, and energy production (Yıldız, 2025). However, hydro-climatological shifts in the Mediterranean Basin have significantly disrupted the regional water cycle, thereby jeopardizing the sustainability of numerous water resources (Ayva, Atalay Dutucu, and Ustaoğlu, 2022; Karahanlı and Mutlu, 2025). Rising temperatures and deviations in precipitation patterns in the Mediterranean region expose the basin to water stress and desertification risks (Türkeş et al., 2020). Whether climate change is framed in terms of anthropogenic forcing, shifting climatic zones, or increasing aridity, its most profound impacts on terrestrial systems are often manifested through the degradation of water resources (Şen, 2022). Consequently, investigating the mechanisms underlying lake surface-water contraction dynamics has become a central research priority in contemporary Earth sciences.

Global-scale research provides robust evidence that lake surface water temperatures (LSWT) have risen markedly, with shallow basins in arid and semi-arid regions experiencing rapid surface-area contraction (Wang et al., 2021; Woolway et al., 2020). In the Mediterranean, a growing body of evidence highlights intensifying desertification pressures on high-altitude mountain lakes, leading to progressive shrinkage and, in some cases, complete disappearance (Alevkayalı et al., 2023; Yayla et al., 2025; Yıldız, 2025). While warming trends and declining precipitation are primary drivers, the degradation of lake ecosystems cannot be attributed solely to climatic factors; intensive anthropogenic activities, such as uncontrolled agricultural irrigation and dam construction on inflowing streams, influence water-balance dynamics to a degree comparable to climate change (Altan Aydın and Doğu, 2018).

At the core of these dynamics are the physical properties of water bodies, which provide critical thermal buffering through their high specific heat and deep penetration of solar radiation. This stabilizing effect is governed by the surface energy balance, in which the low surface albedo of water moderates heat absorption relative to surrounding terrestrial surfaces (Zhang et al., 2022; Yücer, 2023). However, as hydrological recession occurs, the replacement of cooling water surfaces with heat-absorbent materials, a process often examined through the urban heat island framework (Mamizadeh and Aslan, 2019; Orhan, 2021; Özcanlı and Yılmaz, 2024; Pashaei and Aksoy, 2022), is suggested to disrupt the local energy budget (Karadoğan and Kavak, 2017). In the Lakes District, the desiccation of lake surfaces is hypothesized to alter energy partitioning; as latent heat flux associated with evaporation declines, more energy is partitioned into sensible heat (Zhou et al., 2022). This transition from aquatic to terrestrial surfaces may not only alter albedo but also initiate a positive hydro-climatic feedback that amplifies regional warming (Albarqouni et al., 2022; Liu et al., 2020; Du et al., 2023; Kumar et al., 2023).

A bibliographic assessment of lake-level fluctuations across Türkiye found that nearly all lakes have experienced reductions in surface extent (Kahraman and Öztürk, 2025). While some, like Lake Salda, are prominent for their ecological and tourism value (Temurçin, Atayeter, and Tozkoparan, 2019), others, such as Lakes Eğirdir and Beyşehir, are critical resources for irrigation and potable water and are now facing severe availability challenges (Karabacak and Pınar, 2018; Tuygun et al., 2023). Although substantial alterations in surface temperature patterns have been noted across the region (Baydoğan and Sarp, 2016; Albarqouni et al., 2022), a more in-depth analysis of remote sensing (RS)-based surface temperature trends is required to better understand these system dynamics beyond simple shoreline monitoring (Aksoy, Sarı, and Çabuk, 2019).

Numerous studies in the region have examined thermal changes using LSWT for aquatic surfaces (Wan et al., 2017; Yu et al., 2023) and Land Surface Temperature (LST) for terrestrial environments

(Küçükönder, 2021; Sarp et al., 2018; Şener, 2016). LSWT is a robust indicator of climatic stress (Guo, 2022), while the Modified Normalized Difference Water Index (MNDWI) remains a predominant RS approach for characterizing shoreline dynamics (Sarp and Özçelik, 2017). Nevertheless, the coupling between long-term lake-extent changes and spatial temperature dynamics has not been systematically examined. This study aims to investigate how decadal-scale changes in lake boundaries may influence LSWT and LST patterns in lake systems and their surrounding environments using remote sensing data. In particular, it examines whether newly exposed lake basin surfaces exhibit distinct thermal responses and evaluates the potential for hydro-climatic feedback mechanisms over the period 1990–2025.

2. Materials and Methods

The methodological framework of the study consists of sequential stages, commencing with the processing of satellite imagery and followed by the construction of the relevant analytical datasets (Figure 1). Subsequently, the lake boundaries for the years 1990 and 2025 were delineated using the MDNWI. Trend analyses of LSWT were performed within the 1990 lake boundaries, while LST measurements were conducted spatially within the defined boundaries.

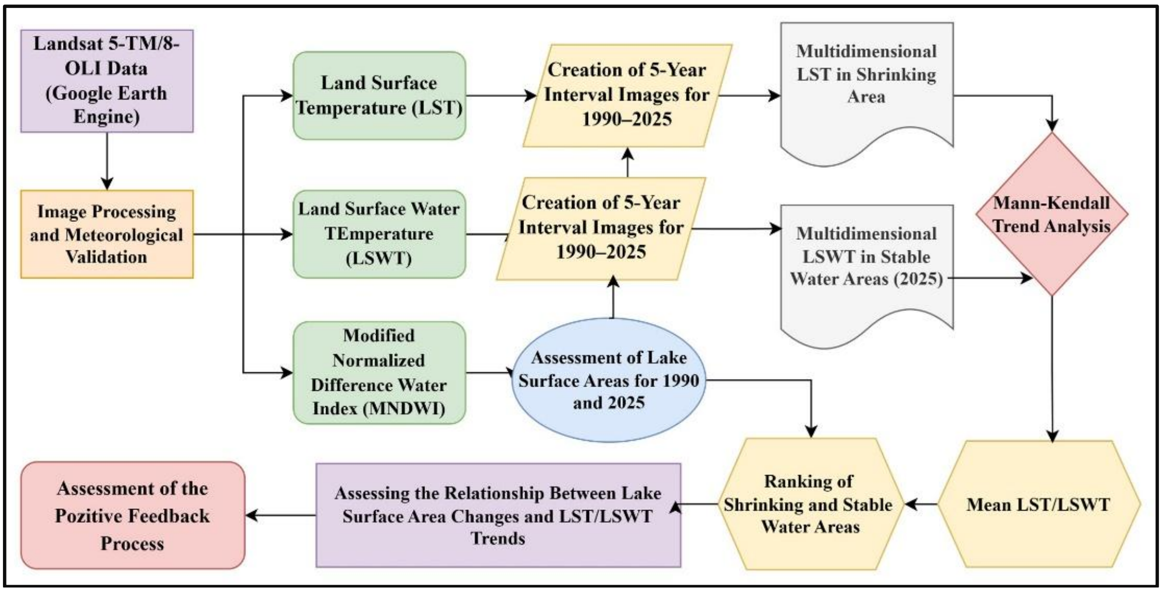

Figure 1. Flowchart of the methodology for assessing hydrological contraction and surface temperature dynamics using multi-temporal satellite data.

2.1. Research Area

The designation of the "Lakes District" (Göller Yöresi) was officially established during the First Geography Congress (Tuncel, 2011). The study area is located in southwestern Türkiye, approximately between 37.0°– 38.5° N latitudes and 29.30°–32.0° E longitudes. Characterized by intricate topography with elevations ranging from ~820 m to over 3000 m, the region hosts numerous lakes, including Acıgöl, Akgöl, Akşehir, Beyşehir, Burdur, Eber, Eğirdir, Gölhisar, Ilgın, Işıklı, Karataş, Kovada, Salda, Suğla, Yarışlı, and Yazır (Figure 2). Geomorphologically, the region is shaped by neotectonic processes associated with the Isparta Angle, where extensional tectonics superimposed on paleo-tectonic structures created multiple fault-controlled depressions that host current lake basins (Karaman, 2010; Şengör, 1984). The morphology of basins and active faulting significantly influences the spatial distribution and persistence of these lakes (Atalay et al., 2020).

Climatically, the region serves as a transitional zone between Mediterranean and continental climate regimes, characterized by hot, dry summers and cooler, wetter winters. The mean annual temperatures range between 10–15 °C, and precipitation varies between approximately 400–800 mm. Although long-term precipitation trends lack statistical significance, rising temperatures and decreasing discharge levels indicate increasing hydroclimatic stress (Coşkun, 2020).

Hydrologically, the region comprises both endorheic and exorheic systems, resulting in diverse water balance dynamics. Lakes with closed basins, such as Burdur, Acıgöl, and Salda, are primarily controlled by the balance between precipitation and evaporation. Conversely, lakes such as Beyşehir and Eğirdir exhibit more complex inflow–outflow interactions. Furthermore, certain systems have been significantly modified by anthropogenic interventions. Lakes such as Suğla and Kovada are regulated by artificial channels, while soda extraction in Acıgöl and dam construction at Ilgın considerably alter natural hydrological processes.

Consequently, these lakes were excluded to ensure the consistency of the hydro-climatic analysis. The Lakes District presents an appropriate case study owing to its combined exposure to climatic variability, tectonically controlled basin morphology, and increasing anthropogenic pressures. The presence of observable changes in the lake surface, alongside documented temperature increases, provides a robust framework for exploring potential hydroclimatic feedback mechanisms.

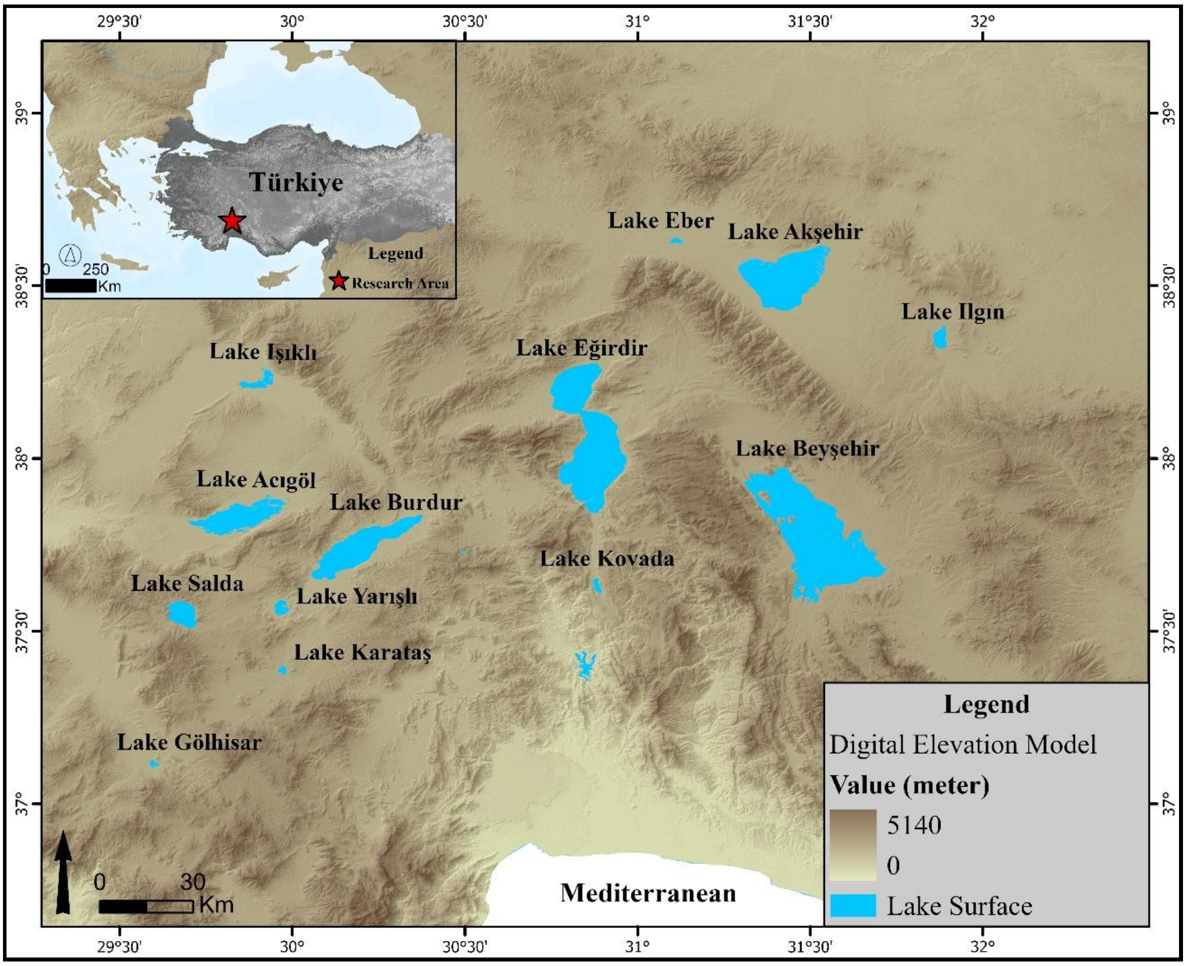

Figure 2. Location map of the study area and the spatial distribution of the lakes.

2.2. Data

This study employed the Google Earth Engine (GEE) platform to analyze surface temperature and land-cover dynamics in the Lakes District between 1990 and 2025 (Gorelick et al., 2017). The primary data source was the Landsat Collection 2 Level 2 archive, which provides atmospherically corrected surface reflectance and LST products, ensuring high-quality data and cross-sensor temporal consistency.

To establish a robust long-term record, Landsat 5 Thematic Mapper (TM) imagery was employed for the 1990–2010 period, followed by Landsat 8 OLI/TIRS data for the 2015–2025 timeframe. These sensors, characterized by their 30 m spatial resolution, were selected for their established reliability in mapping aquatic boundaries and extracting thermal signatures (EROS, 2020a, 2020b). To reduce the influence of seasonal variability and cloud interference, a strict cloud-cover threshold of <10% was enforced, and median-composite algorithms were applied to generate representative annual images. This systematic approach to data selection and pre-processing pipeline provided a high-fidelity time series, thereby enabling a reliable derivation of long-term hydro-thermal trends.

2.3. Method

Boundary analyses were conducted to assess spatial hydrological changes in the lakes and their associated LST impacts on the surrounding terrestrial ecosystems. For each lake, boundaries were delineated separately for 1990 and 2025, and the corresponding changes in surface area were calculated. Lake surface extents were extracted using the MNDWI. This index was used to identify water surfaces for

1990 and 2025 (Equation 1):

$$\text{MNDWI} = \frac{Green - SWIR1}{Green + SWIR1} \tag{1}$$

In this equation, Green denotes the surface reflectance of the green spectral band, whereas SWIR1 pertains to the short-wave infrared reflectance (Band 5 for Landsat 5 TM and Band 6 for Landsat 8 OLI). Following the methodology proposed by Xu (2006), pixels with MNDWI values ≥ 0 were classified as water surfaces. This thresholding approach allows for the effective separation of aquatic bodies from terrestrial features by leveraging the distinct spectral signatures of water in the green and SWIR regions.

Land Surface Temperature and Lake Surface Water Temperature (LST/LSWT): LST (Şener, 2016) and LSWT (Wan et al., 2017) values were derived from Landsat thermal bands using a standardized radiometric conversion process. The calculation of LST was performed through a sequential transformation of thermal band data from Radiance to Top-of-Atmosphere (TOA) radiance (Sarp et al., 2021), and subsequently to Surface Temperature (Equation 2). For radiance computation, the Landsat thermal bands were first converted into TOA radiance values.

$$L_\lambda = M_L \cdot Q_{cal} + A_L \tag{2}$$

- L_λ= TAO radiance (W/m²·sr·μm)
- M_L= Radiance multiplicative scaling factor for the specific band
- A_L= Radiance additive scaling factor
- Q_{cal}= Quantized and calibrated standard product pixel value

Using the TOA radiance, Brightness Temperature is then calculated in Kelvin units (Equation 3):

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \tag{3}$$

- T_B= Brightness Temperature
- K_1, K_2= Thermal conversion constants specific to the Landsat thermal bands

LST is derived from brightness temperature by incorporating surface emissivity (ε) and applying atmospheric correction procedures (Equation 4):

$$LST = \frac{T_B}{1 + \left(\frac{\lambda \cdot T_B}{\rho}\right) \ln \varepsilon} \tag{4}$$

- LST= land surface temperature (Kelvin)
- λ= average wavelength of the thermal band (m)
- $\rho = \frac{h \cdot c}{\sigma} = 1.438 \times 10^{-2}$ m*K (h: Planck's constant, c: speed of light, σ: Boltzmann constant)
- ε= Surface emissivity (typically 0.95 for terrestrial surfaces)

For lake surfaces, LSWT is calculated using a formulation like that applied for LST; however, the emissivity coefficient is adjusted to values appropriate for water surfaces (Equation 5):

$$LWST = \frac{T_B}{1 + \left(\frac{\lambda \cdot T_B}{\rho}\right) \ln \varepsilon_{water}} \tag{5}$$

- $LWST$= Lake Surface Water Temperature (Kelvin)
- ε_{water}= Surface emissivity coefficient of water =0,98)

All temperature data were converted from Kelvin to degrees Celsius.

Mann-Kendall (MK) Trend Test: This nonparametric method was used to assess monotonic trends in the LST and LSWT time series (Mann, 1945; Kendall and Gibbons, 1975). The MK test is particularly robust because it does not require the data to follow a specific distribution, making it well-suited for environmental time-series analysis. The test statistic (S) is calculated based on the following equations (Equations 6 and 7):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \tag{6}$$

Here:

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} +1, & x_j - x_i > 0 \\ 0, & x_j - x_i = 0 \\ -1, & x_j - x_i < 0 \end{cases} \tag{7}$$

x_i and x_j= The number of observations in the time series (n = total number of data points) is first determined, after which the Z-score is computed.

For the variance and Z-score computation, when n > 10, the S statistic is assumed to follow a normal distribution, and the Z-score is calculated accordingly (Equation 8):

$$Z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{Var}(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{\operatorname{Var}(S)}}, & S < 0 \end{cases} \tag{8}$$

$\operatorname{Var}(S)$= The variance of the S statistics is calculated by accounting for tied ranks and repeated values in the dataset.

The statistical significance of trends is determined based on the Z-score, where Z > 0 indicates a positive (increasing) trend, Z < 0 indicates a negative (decreasing) trend, and |Z| > $Z_{(}1−α/2_{)}$ signifies that the trend is statistically significant (for α = 0.05, the critical value is 1.96).

3. Results

3.1. Assessment of the Shoreline and Surface Area Changes of Lakes (1990–2025)

Analyses based on the MNDWI indicate a consistent, ongoing reduction in lake surface areas throughout the Lakes District. All lakes included in this study showed decreases in surface area, albeit to varying degrees. The spatial distribution of these reductions varied according to the unique hydrological characteristics of each lake. Detailed quantitative data concerning these changes are provided in Table 1.

Table 1. Changes in surface areas of the studied lakes between 1990 and 2025

Lakes	1990 Area (km²)	2025 Area (km²)	Area Change (km²)	Reduction Rate (%)
Lake Akşehir	283.98	0.00	283.98	100
Lake Beyşehir	641.85	614.51	27.34	4
Lake Burdur	192.39	115.48	76.91	40
Lake Eber	22.87	4.60	22.27	80
Lake Eğirdir	456.67	409.10	56.57	10
Lake Gölhisar	4.34	3.08	1.26	29
Lake Karataş	3.99	0.00	3.99	100
Lake Salda	45.57	42.91	2.66	6
Lake Yarışlı	12,52	0,00	12,52	100

Based on the analysis of surface area contraction, Lakes Akşehir, Karataş, and Yarışlı were classified as completely desiccated, particularly in reference to summer imagery. Variations in surface area reduction were observed across most of the lakes in the Lakes District (Figure 3). These results indicate a substantial decline in seasonal water retention capacity and suggest a disruption of hydrographic continuity within the basin.

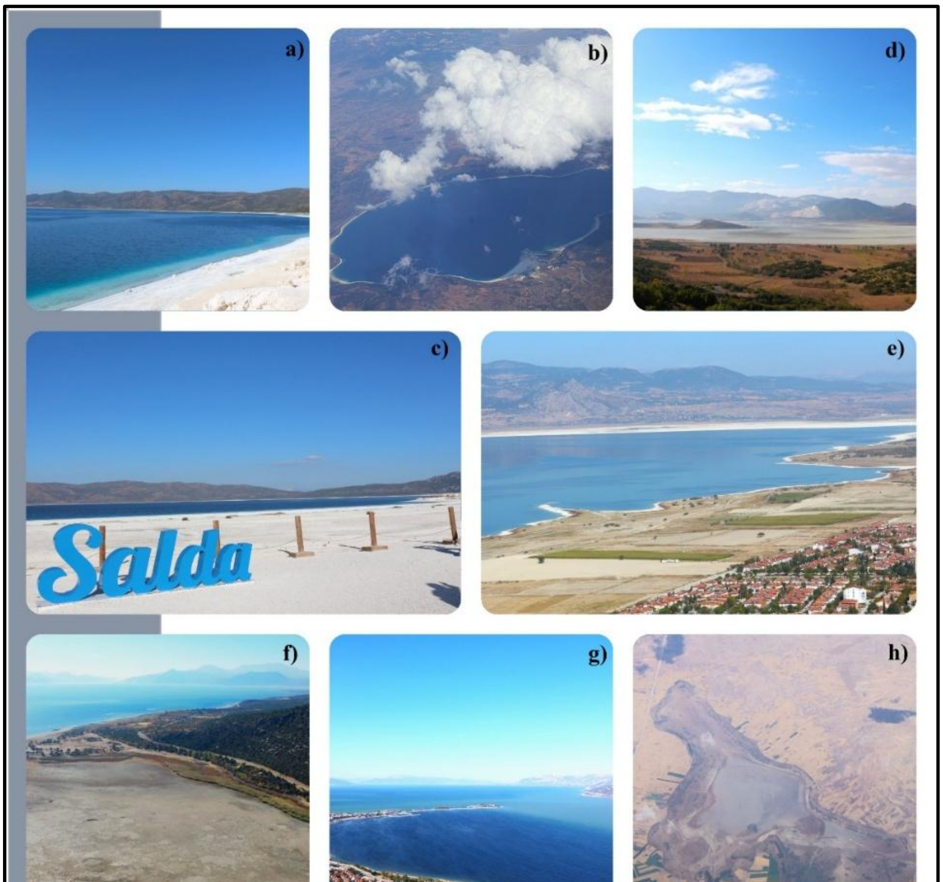

Figure 3. Current views of selected lakes in the Lakes District exhibiting varying degrees of contraction and desiccation: (a–c) Lake Salda, (d) Lake Yarışlı, (e) Burdur, (f–g) Lake Eğirdir, (h) Lake Karataş.

In long-term spatial analyses, Lakes Eber and Burdur stand out as water bodies that exhibit considerable horizontal recession. Although their initial surface extents differ considerably, both have experienced significant contraction (Table 1), with Lake Eber undergoing a more pronounced reduction since 1990. Given that both are situated within endorheic (closed) basins, these contractions serve as a critical indicator of intensifying regional hydro- climatic stress.

Conversely, Lakes Eğirdir and Beyşehir have maintained a relatively larger proportion of their surface areas; however, due to their extensive initial dimensions, their absolute area losses (km²) remain quantitatively and hydrologically consequential (Table 1). As Türkiye's largest freshwater ecosystems, these instances exemplify how even modest proportional reductions can lead to considerable volumetric water losses, with significant ecological and hydrological consequences.

Lakes Salda and Gölhisar have avoided dramatic desiccation, yet both display observable shoreline retreat. The relative stability of Lake Salda's boundaries may be attributed to its deep-basin morphology and substantial groundwater recharge capacity, whereas the resilience observed in Lake Gölhisar likely stems from sustained hydrological inputs that maintain its water balance.

Crucially, changes in lake surface extent are attributable not only to shoreline shifts but also to temporal variations in surface energy balance and thermal regimes, particularly within land–water ecotones. Unlike the relatively stable basins of Salda and Gölhisar, Lakes Akşehir, Burdur, Eber, Karataş, and Yarışlı have experienced severe contraction and, in some instances, total desiccation. Accordingly, the subsequent section evaluates LST trends over terrestrial surfaces and LSWT trends over aquatic surfaces to ascertain whether a positive feedback mechanism has emerged between lake shrinkage and regional temperature dynamics.

3.2. Spatiotemporal Trends of LST and LSWT

Lake Akşehir

Lake Akşehir exemplifies a system that has surpassed a critical thermal threshold, as evidenced by the complete summer desiccation of its surface. The disappearance of the water body eliminates evaporative cooling, thereby disrupting the hydrologically mediated thermal buffering capacity. Consequently, the surface–atmosphere energy exchange becomes entirely controlled by terrestrial processes. In the absence of an aquatic thermal cycle, increasing surface temperatures intensify sensible heat fluxes, reinforcing a distinct positive land–atmosphere feedback mechanism (Figure 4).

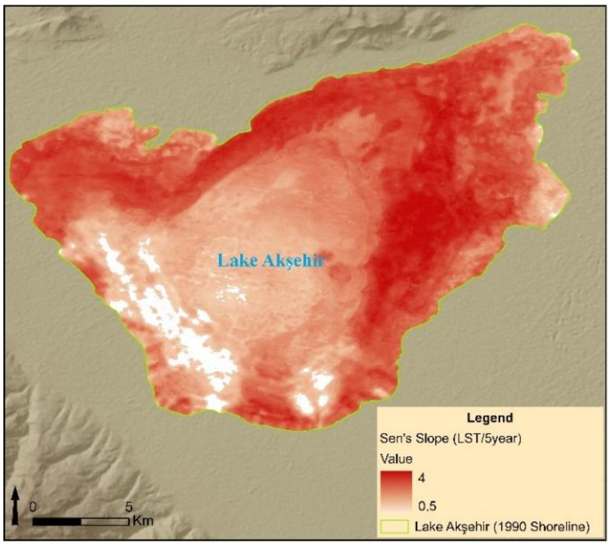

Figure 4. Surface temperature trend analysis and thermal change patterns in the Lake Akşehir basin between 1990 and 2025 (Only statistically significant pixels are shown, $p < 0.05$).

The spatial differentiation observed throughout this process is particularly striking. An analysis of 35-year LST trends over the former lake basin indicates that the Z-values for all pixels across the dried area surpass the [+1.96] threshold, thereby confirming statistically significant positive trends. Based on the Sen's Slope estimator, the magnitude of temperature increase progressively intensifies from the center toward the peripheral zones of the basin (Figure 4). This pattern can be explained by the complete depletion of soil moisture and the consequent reduction in the surface's capacity to store heat. In other words, the temperature-increasing trend is considerably more pronounced in areas of the former lake basin that have transitioned to terrestrial surfaces. The extended dry period has intensified thermal accumulation, causing surface temperatures to reach significantly more extreme levels than under historical conditions. The desiccation of Lake Akşehir illustrates that water loss signifies not merely a physical recession of the shoreline but also a fundamental transformation of the basin's surface thermal properties, effectively converting it into a stable source of positive feedback that continuously contributes to atmospheric warming.

Whereas open water absorbs a significant portion of incoming solar radiation owing to its relatively low albedo and high heat capacity, the bright salt crusts or loose sediments exposed on the dry lake basin may alter the surface reflectance characteristics. Nonetheless, the low heat capacity of these sediments leads to rapid daytime heating. With the lake's disappearance, the latent heat flux previously associated with evaporation has been replaced by sensible heat flux, which directly warms the atmosphere. This transition is further corroborated by the increasing positive trend in surface temperature observed from the basin center toward its outer margins (Figure 4).

Lake Beyşehir

Lake Beyşehir, as emphasized in previous sections, is not only one of the largest lakes in the Lakes District but also Türkiye's largest freshwater lake. Although the 300–500 m shoreline retreat observed along its margins appears spatially limited, it represents a critical transformation in the lake's thermal regime.

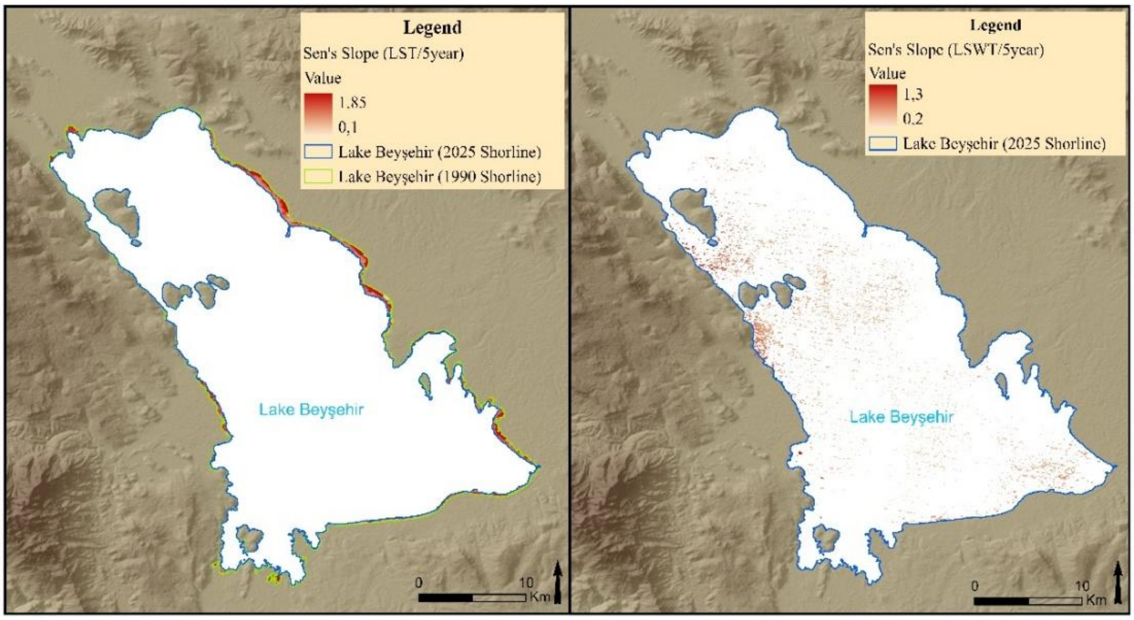

Figure 5. Lake Beyşehir, (a) LST trends associated with the contraction of the lake surface area and (b) LSWT trends between 1990 and 2025.

An analysis of LST trends in newly exposed areas shows that Z-values for all pixels exceed the +1.96 threshold, indicating statistically significant positive trends in surface temperature across these zones (Figure 5). Sen's Slope estimates show that these dried shallow zones have rapidly converted into terrestrial areas and localized thermal hotspots. Concurrently, 2025 data reveal a statistically significant increase in LSWT values across the remaining water body. This observation suggests that the lake's thermal buffering capacity is no longer confined to shoreline stability and is gradually diminishing across its entire hydrological system. Thus, water loss in Lake Beyşehir cannot be interpreted solely as a physical shoreline recession. Rather, it reflects a decline in the lake's effective heat storage capacity and hydrothermal stability, gradually transforming the lake's surface into a more persistent source of positive thermal feedback to the atmosphere. The concurrent warming of both exposed land surfaces and the remaining water bodies indicates a coupled land–water feedback mechanism that intensifies regional thermal dynamics.

Lake Burdur

Notably, the most significant changes occurred in this lake, where the surface area contracted chiefly toward the east–northeast between 1990 and 2025 (Figure 6). In the newly exposed areas, the mean LST increased by +2.5 °C, while the LSWT within the 2025 lake boundaries exhibited an additional increase of +1.2 °C. The Mann–Kendall test results demonstrate that these trends are statistically significant ($p < 0.05$), and that the warming pattern occurred gradually rather than abruptly over time.

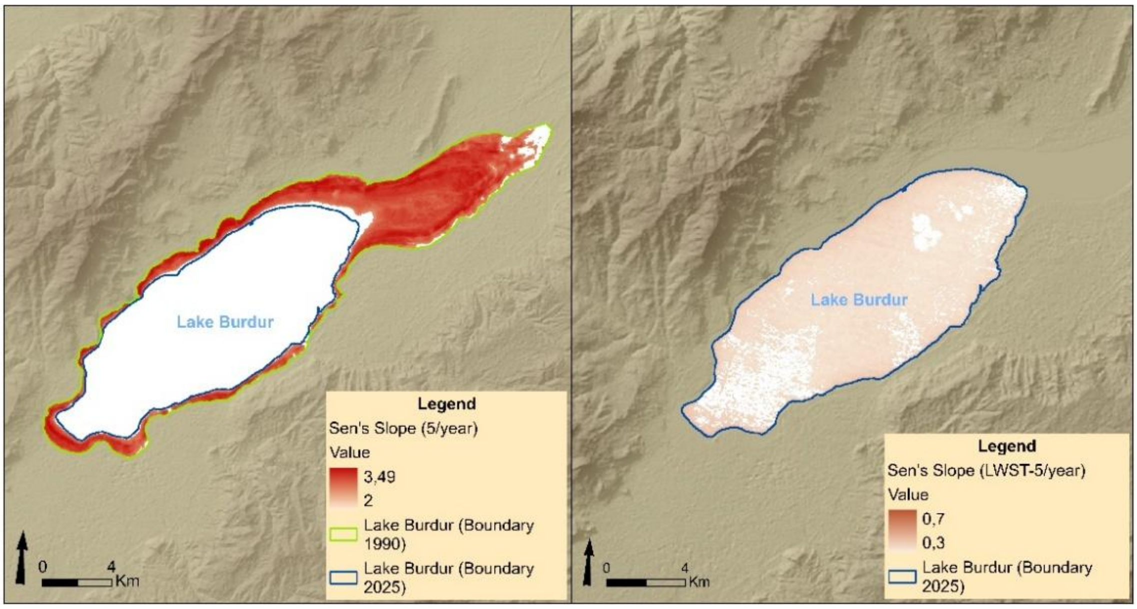

Figure 6. Spatial patterns of (a) LST trends and (b) LSWT variations associated with the shrinkage of Lake Burdur's surface extent between 1990 and 2025.

The contraction of the lake surface and the transformation of formerly submerged zones into bare terrestrial surfaces have consequently led to a pronounced, statistically robust increase in temperature. Among all the lakes studied, Lake Burdur exhibited the highest increase in surface temperature within the desiccated lake basin, underscoring the severity of thermal amplification in areas experiencing substantial water loss.

Lake Eber

Eber Lake presents a particularly intriguing case. Although it is among the lakes that have experienced the most pronounced surface contraction, long-term surface temperature trends reveal statistically significant yet relatively weak positive tendencies (Figure 7). Analysis of the 35-year LST patterns indicates that, when referenced to the 1990 shoreline, the magnitude of warming decreases progressively from east to west as it approaches the 2025 lake boundary. This spatial gradient suggests that, despite substantial shoreline retreat, the thermal amplification observed in other desiccating basins is comparatively subdued in Eber Lake. Furthermore, although a slight increase in surface temperatures was detected along the 2025 shoreline, Sen's Slope values remain below 1, indicating that the warming trend is modest in magnitude. This means that, although statistically significant ($p < 0.05$), the detected temperature increase does not indicate a pronounced thermal escalation. This finding is noteworthy because it demonstrates that extensive areal shrinkage does not necessarily correspond to strong thermal feedback intensity, implying that local hydrological conditions, residual moisture availability, or sediment characteristics may be moderating the lake's surface energy response.

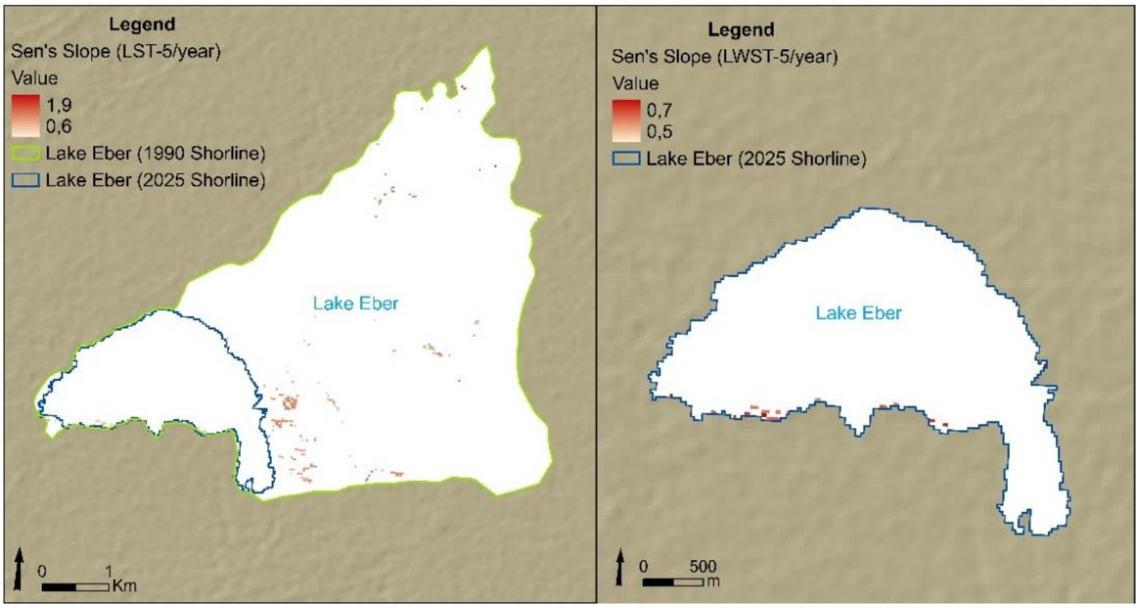

Figure 7. Spatial distribution of (a) LST trends and (b) LSWT trends associated with the contraction of Eber Lake's surface area between 1990 and 2025.

Lake Eğirdir

Analyses conducted for the 1990–2025 period in Lake Eğirdir reveal a direct interaction between morphometric contraction and thermal environmental change. The horizontal recession has reached a hydrological threshold at which the Hoyran Basin, the lake's shallow northern bathymetric section, is approaching functional separation from the main water body (Figure 8).

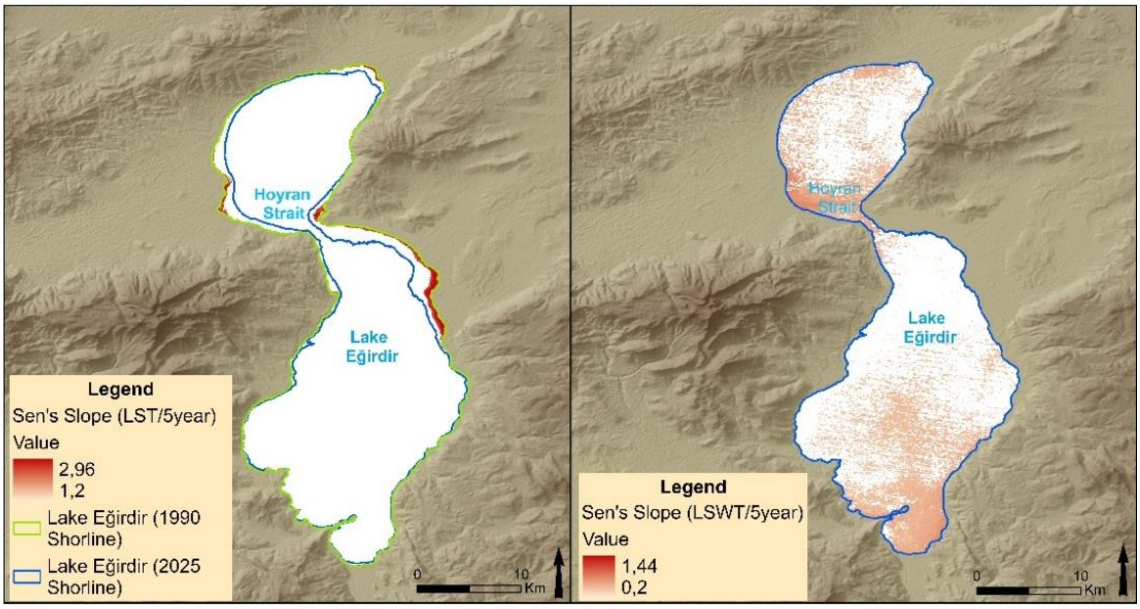

Figure 8. Spatial distribution of (a) LST and (b) LSWT trends in response to the surface area contraction of Lake Eğirdir between 1990 and 2025.

Evaluation of temporal surface temperature trends indicates that Sen's Slope values reach 1.44 for the contemporary lake surface (LSWT value) in 2025, whereas they increase markedly to 2.96 within the former lake basin areas (LST value) exposed since 1990 (Figure 8). These results demonstrate that thermal warming intensity in the desiccated zones is approximately twice that observed over the remaining water surface. Having lost the buffering influence of high specific heat capacity and evaporative cooling, these newly terrestrialized areas have become dominant microclimatic warming centers within the basin and may reinforce localized positive thermal feedback mechanisms.

The spatial distribution of surface temperatures shows that positive trends are predominantly concentrated in the southern sector and the western Hoyran sub-basin. Increasing LSWT values initiate a self-reinforcing feedback mechanism: as the lake contracts and becomes progressively shallower, its thermal inertia declines, accelerating surface warming and further intensifying evaporative water loss. In contrast, the relatively weaker warming trends observed along the eastern shoreline, despite measurable recession, indicate that riparian vegetation exerts a moderating influence by attenuating surface heat accumulation (Figure 9). The extreme Sen's Slope coefficient of 2.96 confirms that the ongoing desiccation process extends beyond hydrological shrinkage, representing the development of a pronounced basin-scale thermal anomaly.

Figure 9. Reeds remaining in the areas of Lake Eğirdir where the water surface has receded, acting as a thermal buffer to reduce surface temperatures (Source: Dr. Onur Yayla's Archive).

Lake Gölhisar

Analysis of LST and LSWT values for Lake Gölhisar indicates no statistically significant warming trends in areas affected by shoreline recession. Among all lakes examined, Lake Gölhisar exhibits the highest degree of thermal and morphometric stability, maintaining both surface area continuity and shoreline integrity.

Accordingly, it is the only lake basin in which no significant upward trend in surface water temperature was detected (Figure 10). This stability is consistent with the lake's hydrogeological configuration, including sustained groundwater recharge and a relatively sheltered topographic setting, both of which function as buffers against rapid thermal amplification observed in larger or morphologically shallow basins. A comparative assessment between the thermal stability of Lake Gölhisar and the pronounced desiccation-driven warming in basins such as Lake Akşehir and Lake Eğirdir underscores the spatial heterogeneity of regional climate responses. These findings demonstrate that warming intensity is not spatially uniform but is strongly mediated by basin-scale morphology and hydrological connectivity.

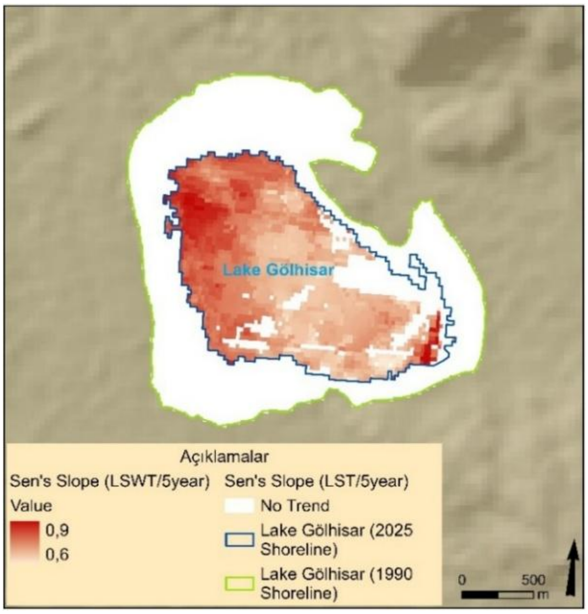

Figure 10. Spatial distribution of temporal LSWT trends in Lake Gölhisar between 1990 and 2025.

The primary reason for the absence of pronounced surface temperature increases in Lake Gölhisar is the well-developed vegetation cover that has established across the receded shoreline zones. This rapidly expanding vegetation regulates surface energy exchange by moderating albedo and enhancing latent heat flux through evapotranspiration, thereby limiting sensible heat accumulation. As a result, Lake Gölhisar is a clear case in which vegetative recovery functions as a thermal buffer, effectively suppressing microclimatic warming trends despite hydromorphological contraction.

Lake Karataş

Lake Karataş completely lost its surface area during the 1990–2025 period and became one of the lakes that had fully desiccated by the warm season of 2025. Based on the 1990 water-surface boundaries, analyses indicate that the former lake basin, now entirely terrestrialized, exhibits statistically significant, strong positive LST trends (Figure 11).

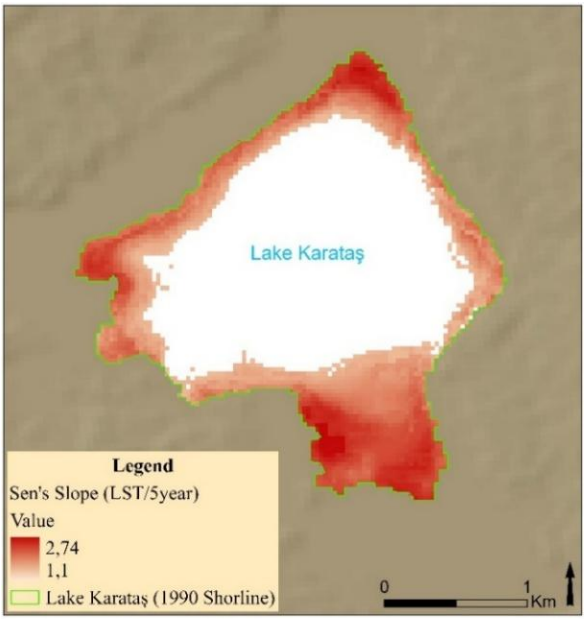

Figure 11. Spatial distribution of LST values associated with the hydrological desiccation process in Lake Karataş between 1990 and 2025.

This thermal transformation, confirmed by the statistical significance of the Mann–Kendall test results, shows that Sen's Slope reaches extreme values of up to 2.74 in the former shoreline zones, whereas no statistically significant increase has been detected in the central parts of the lake. The relatively moist conditions that still characterize the central basin—corresponding to the most recently receded portion of the former lake surface—help explain the absence of a significant trend in these areas.

The decreasing warming gradient from the shoreline toward the center may reflect the rate of lake retreat, the moisture-retention capacity of bottom sediments, or the residual thermal memory of water that persisted longer in the central basin before complete desiccation. After the water surface disappeared, a pattern like that observed in Lake Akşehir emerges, with temperature increases weakening from the periphery toward the center (Figure 11).

As in many other lakes across the region, dam construction within the basin and the presence of alluvial deposits in the depression where Lake Karataş is situated have indirectly contributed to this thermal shift. The agricultural potential of the fertile alluvial soils has intensified irrigation in the surrounding area. Ultimately, Lake Karataş represents one of the most extreme cases, demonstrating how, once the water body has entirely vanished, terrestrial surface temperatures can become the dominant microclimatic control within the basin.

Lake Salda

Lake Salda is a distinctive case in which, despite the relatively limited change in overall surface area, statistically significant thermal trends have been detected within the zones of shoreline recession (Figure 12). Analyses of LSWT within the updated 2025 water surface boundaries indicate that the warming trend remains minimal, with Sen's Slope values ranging between 0.1 and 0.9, suggesting an almost negligible increase.

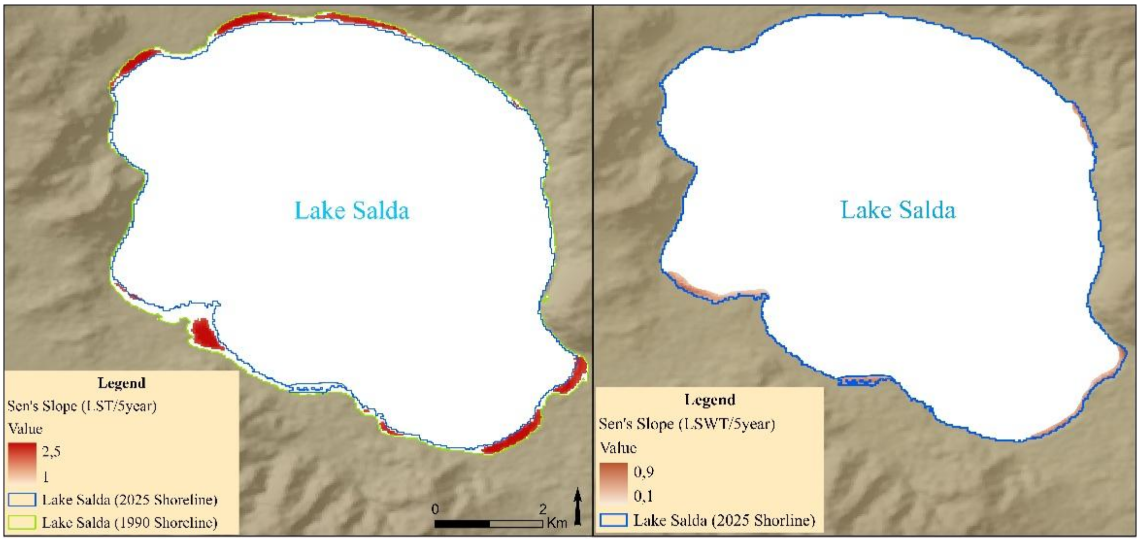

Figure 12. Spatial distribution of (a) LST trends and (b) LSWT trends identified for Lake Salda between 1990 and 2025.

This relative thermal stability can be attributed to Lake Salda's exceptional depth and correspondingly high heat capacity. As a deep-water body, it exhibits markedly greater resistance to atmospheric temperature fluctuations than shallow lakes, consistent with theoretical expectations regarding thermal inertia. In contrast, along the narrow coastal belt where the lake has retreated since 1990, LST analyses reveal a Sen's Slope of 2.50, indicating a pronounced warming trend in these newly exposed areas. Unlike the thermal stability observed over the water surface, this elevated increase coefficient in the receded zones highlights the emergence of a potential feedback mechanism affecting Salda's sensitive littoral ecosystem.

Lake Yarışlı

In the Lake Yarışlı basin, substantial water loss has led to observable temperature changes within the former lake boundaries. However, unlike lakes such as Karataş and Eğirdir, which exhibit persistent and statistically robust desiccation-driven warming trends, the temperature increases observed in Lake Yarışlı do not meet the threshold for statistical significance (Figure 13). This pattern suggests that although hydrological contraction has occurred, the associated thermal response has remained comparatively moderate and spatially heterogeneous, indicating that the basin has not yet transitioned into a pronounced microclimatic warming hotspot.

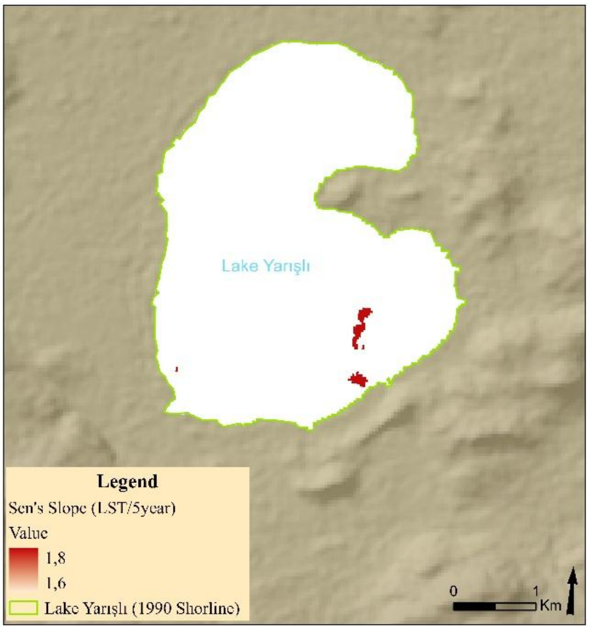

Figure 13. Spatial distribution of LST trends observed on the former lake basin of Lake Yarışlı following hydrological recession between 1990 and 2025.

These findings for the Lake Yarışlı basin can be attributed to two principal factors. First, despite overall desiccation, the lake exhibits an unstable hydrological regime, which occasionally retains temporary water storage capacity in certain years. This intermittent presence of water may moderate or disrupt the development of a consistent long-term thermal trend. Second, the areas exposed after water withdrawal are characterized by dense mineral residues—white or ice-colored crusts that resemble shallow water but contain no moisture (Figure 14). These bright mineral surfaces substantially increase the surface albedo. As such, these light-colored deposits reflect a considerable proportion of incoming solar radiation rather than absorbing it, thereby concealing the expected terrestrial warming typically associated with desiccation. Consequently, the combination of an irregular hydrological regime and high surface reflectivity likely contributes to elevated interannual temperature variability, thereby preventing the warming signal from being identified as a statistically significant monotonic trend by the Mann–Kendall test.

Figure 14. Exposed lake basin surface revealed by the retreat of the water body in Lake Yarışlı.

3.3. Relationship Between Lake Surface Contraction and Surface Temperatures

Across most lakes in the Lakes District, a decline in water surface area has coincided with increases in LST and LSWT over time. This thermal intensification reflects the sensitivity of lake ecosystems and adjacent terrestrial environments to climatic forcing. At this stage, the relationship between changes in lake surface area and thermal trends was examined statistically. To identify the lakes most severely affected by hydrological loss, a "Contraction Score" ranging from 1 to 10 was developed based on total area loss and proportional shrinkage (Table 2). Subsequently, mean temperature changes within the receded lake surfaces over the 1990–2025 period were calculated and ranked. The relationship between the two variables was analyzed using the nonparametric Spearman's Rank Correlation Coefficient at a 95% confidence level. The results demonstrate a statistically significant, strong positive relationship between the degree of lake contraction and surface temperature increases (Spearman's rho = 0.72, $p < 0.05$). These findings indicate that as lake surface area diminishes, temperatures in newly exposed zones increase significantly. In essence, greater lake shrinkage is directly associated with more intense surface temperature increases.

Table 2. Hierarchical relationship between the hydrological contraction scores of the lakes and their mean surface temperature increases during the 1990–2025 period.

Lake Name	Contraction Score	Water Surface Contraction Ranking	Mean LST/LSWT	LST/LSWT Ranking (from highest to lowest)
Lake Akşehir	10	1.	3,1	1.
Lake Yarışlı	9	2.	1,7	4.
Lake Karataş	8	3.	2,2	2.
Lake Eber	7	4.	0,7	8.
Lake Burdur	6	5.	2,1	3.
Lake Gölhisar	5	6.	0,8	7.
Lake Eğirdir	4	7.	1,2	5.
Lake Salda	3	8.	0,9	6.
Lake Beyşehir	2	9.	0,5	9.

4. Discussion

The water surface contractions observed in the Lakes District between 1990 and 2025 indicate that the region is highly sensitive hydrologically and ecologically, with many lakes at risk of disappearance (Işıldar and Ercoşkun, 2021; Özdal and Çetinkaya, 2024). Widespread global trends reporting lake area shrinkage (Alizadeh-Choobari et al., 2016; Yang, 2020; Yu et al., 2020) and increasing lake surface temperatures (Dokulil et al., 2021; Sharma et al., 2015) demonstrate that the Lakes District is not an isolated case but rather a regional manifestation of a broader global pattern (O'Reilly et al., 2015). The reduction in water surface area weakens the natural cooling capacity of lakes, leading to temperature increases both within the water bodies and across adjacent terrestrial areas (Orhan, Dadaşer Çelik, and Ekercin, 2019; Tan et al., 2020). In the Lakes District, this process has evolved into a reinforcing feedback mechanism that amplifies warming. As water retreats, the proportion of terrestrial surfaces with lower specific heat capacity increases, enhancing basin-scale heat storage and accelerating evaporation (Ptak et al., 2018). Increased evaporation, in turn, deepens water loss and further intensifies the cycle. Consistent with existing literature (Magee and Wu, 2017; Tan et al., 2020), progressive shallowing reduces the thermal buffering capacity of the water mass, rendering shallow systems increasingly vulnerable to thermal stress. Reduced thermal reflectivity in shallow zones allows solar radiation to warm the entire water column more rapidly, thereby accelerating shoreline retreat. The observed rise in LST values over newly exposed surfaces and the concurrent increase in LSWT over remaining water bodies confirm this mechanism. While climate change initiates warming at the lake surface, the subsequent terrestrial areas change of exposed areas generates additional positive feedback that further intensifies regional heating. Nevertheless, factors beyond climate forcing must also be considered to fully interpret this process.

Lake Salda exhibits a distinctly different thermal response from other lakes in the district. Its deep-basin morphology, large water volume, and relatively limited hydrological intervention provide a strong reflective and thermal buffering capacity (Woolway et al., 2020). These characteristics enhance its resistance to increases in LSWT. However, this stabilizing mechanism does not operate in the same way in many other lakes in the region.

Water losses in the district cannot be solely explained by climatic warming of lake surfaces. In hydrologically connected systems such as Lakes Eber and Akşehir, reductions in the upstream water-supplying lake are directly associated with substantial shrinkage in the downstream basin (Kale, 2018). The retreat of Lake Eber has accelerated the desiccation of Lake Akşehir. Although beyond the primary conceptual scope of this study, a significant contributing factor is the construction of dams and reservoirs in various parts of the basin, which substantially restricts surface inflow. In the Lakes District, hydraulic structures mechanically interrupt the water flows feeding the lakes, thereby accelerating shoreline contraction (Kesici and Kesici, 2006). Numerous dams and reservoirs have been constructed within the basins of Akşehir–Eber, Eğirdir, Burdur, Salda, Karataş, and Beyşehir (DSI, 2026a; 2026b). The resulting imbalance in the hydrological budget inherently contributes to increasing trends in LST and LSWT.

In addition to hydrological infrastructure, intensified agricultural activities and uncontrolled groundwater extraction of alluvial soils constitute further drivers of lake recession. The widespread cultivation of water-intensive crops such as sugar beet and maize, evaluated within Hoekstra's (2017) "Water Footprint" framework, demonstrates that agricultural productivity often incurs high ecological costs. In this context, hydrological drought transcends purely climatic origins and becomes anthropogenic, contributing to an emerging regional water crisis (Durgun Kaygısız, 2024).

Previous studies indicate that lake losses are more pronounced in smaller lakes, whereas larger lakes are more affected by irrigation and dam construction (Li et al., 2020). Conversely, the absence of statistically significant warming trends in Lake Yarışlı aligns with studies on saline and alkaline lakes (Crosman and Horel, 2009). The accumulation of light-colored mineral and salt deposits on the exposed lake basin increases surface albedo, reflecting a substantial portion of incoming solar radiation. This "mineralogical masking" effect counteracts the expected warming associated with terrestrialization, potentially rendering temperature trends statistically insignificant. Although direct studies explicitly linking salt mineralization and alkalization to suppressed LST trends are limited (Argaman, Keesstra, and Zeiliguer, 2012), evidence suggests that persistent surface mineral crusts can induce fluctuating spectral and thermal responses in RS-based temperature analyses, as observed in Lake Yarışlı.

Some studies report that high albedo conditions may enhance surface temperature trends, while afforestation or vegetation restoration may reverse this process (Xin et al., 2022). In both Lake Gölhisar and along the western shores of Lake Eğirdir south of the Hoyran Strait, vegetation colonization of exposed lake margins has been a critical factor in limiting LST increases. These findings support extensive research demonstrating the inverse relationship between NDVI and LST (Anand et al., 2025; Duan et al., 2025), confirming that vegetation growth in formerly aquatic zones can mitigate microclimatic warming. Land cover transitions toward vegetated surfaces thus directly influence the thermal regime of surrounding lake environments.

The observed correlation between water retreat and surface temperature increases in the Lakes District suggests a feedback mechanism operating through the interaction between hydrological processes and anthropogenic pressures (Zhang et al., 2018). Significant warming trends along newly formed shorelines further bolster this interpretation. These results underscore that land-lake thermal interactions function as a coupled, non-linear system in which progressive lake shrinkage may substantially weaken regional climatic buffering capacity, thereby amplifying urban thermal vulnerability under future climate and land-use scenarios (Arabacı et al., 2026). Although the intense precipitation events recorded in 2026 have facilitated temporary hydrological recovery in certain basins, this resurgence should be approached with caution, as it highlights the importance of distinguishing between short-term meteorological variability and long-term hydro-climatic trends when evaluating regional climate resilience.

5. Conclusion

Lakes in Türkiye serve not only as vital sources of life but also as strategic surface-water reservoirs supporting municipal supply, industry, agriculture, and ecosystem services. Beyond their economic significance, these lakes provide critical habitats for diverse species. This study shows that from 1990 to 2025, the majority of lakes in the Lakes District have experienced significant reductions in surface area, with some wetlands desiccating and consequently losing their ecological functions.

Analysis of LST and LSWT trends within contracting lake surfaces reveals statistically significant positive trends, confirming increasing thermal pressures across the basin. While these warming patterns are generally linked to global climate change, certain parts of the study area exhibit more pronounced, spatially heterogeneous thermal responses, likely influenced by local hydroclimatic and land-surface dynamics. Notably, the pronounced increase in LST over newly exposed lake basins indicates that lake recession is closely associated with a self-reinforcing thermal feedback mechanism, whereby increased surface heating may further accelerate water loss and exacerbate local climatic stress. Although newly exposed areas may temporarily buffer thermal increases through high albedo or localized vegetation, the overarching trend indicates a shift toward heat accumulation, compromising ecosystem stability.

These findings highlight the critical need for sustainable water management and climate adaptation strategies within the region. Urgent measures, such as water-conservation-oriented agricultural practices and basin-scale afforestation, are imperative. The thermal feedback mechanisms identified in the Lakes Region offer valuable insights into the sustainable management of shallow lacustrine systems across comparable semi-arid environments, particularly within the Mediterranean Basin.

6. Acknowledgment

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7. Compliance with Ethical Standard

a) Author Contribution

The author designed the study, drafted the manuscript, and conducted and managed the statistical analyses. The author has read and approved the final manuscript.

b) Conflict of Interest

There is no conflict of interest, according to the authors.

c) Statement on the Welfare of Animals

Not relevant,

d) Statement of Human Rights

There are no human subjects in this study.

e) Declaration of Not Using AI

The author(s) declare that they have not used any form of generative artificial intelligence in the writing of this article, nor in the creation of figures, graphs, tables, or their corresponding captions.

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8. References

Aksak, P., Öztürk, Ş. K., & Ünsal, Ö. (2023). Investigation of Urban Heat Island on Climate Parameters and Remote Sensing: The Case of Istanbul City [In Turkish]. *Aegean Geographical Journal*, *32*(1), 151-171. https://doi.org/10.51800/ecd.1266060

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).

Albarqouni, M. M., Yagmur, N., Bektas Balcik, F., & Sekertekin, A. (2022). Assessment of spatio-temporal changes in water surface extents and lake surface temperatures using Google Earth Engine for lakes region, Türkiye. *ISPRS International Journal of Geo-Information*, *11*(7), 407. https://doi.org/10.3390/ijgi11070407

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 [In Turkish]. *Turkish Geographical Review*, (82), 37-50. https://doi.org/10.17211/tcd.1287976

Alizadeh-Choobari, O., Ahmadi-Givi, F., Mirzaei, N., & Owlad, E. (2016). Climate change and anthropogenic impacts on the rapid shrinkage of Lake Urmia. *International Journal of Climatology*, *36*(13), 4276-4286. https://doi.org/10.1002/joc.4630

Altan Aydın, F., & Doğu, A. F. (2018). Level changesan d reasons in lakes: The example of Lake Van

[In Turkish]. *Yüzüncü Yıl University Journal of Social Sciences Institute*, (41), 183-208.

Anand, V., Kaur, S., Rajput, V. D., Minkina, T., Mandzhieva, S., Kumar, S., ... & Kumar, S. (2025). Analyzing the spatial relationship between land surface temperature and normalized difference vegetation index using remote sensing and GIS. *Discover Geoscience*, *3*(1), 65. https://doi.org/10.1007/s44288-025-00167-w

Arabacı, D., Kuşçu Şimşek, Ç., Ataol, M., & Eksilmez, A. F. (2026). A modelling framework for simulating 50-year thermal variation under lake drying and urban expansion: insights from Ramsar Lake Burdur, Türkiye. *Theoretical and Applied Climatology*, *157*(3), 187.

Argaman, E., Keesstra, S. D., & Zeiliguer, A. (2012). Monitoring the impact of surface albedo on a saline lake in SW Russia. *Land Degradation & Development*, *23*(4), 398-408.

Atalay, İ., Altunbaş, S., & Siler, M. (2020). The Formation and Evaluation of the Faulted Topography in the Burdur Basin, Lakes Region, SW Anatolia. *Journal of Geography* (*41*), 179-192. https://doi.org/10.26650/JGEOG2020-0016

Ayva, C., Atalay Dutucu, A., & Ustaoğlu, B. (2022). The Impact of Climate Change on Water Resources and Adaptation Proposals: Sample of Kirazdere Basin [In Turkish]. *Firat University Journal of Social Sciences*, 33(1), 47-64.

Baydoğan, E., & Sarp, G. (2016). *Spatial analysis of Lake Burdur surface temperature change between 1987-2010 [In Turkish]. World GIS Day Proceedings Book, Isparta.* https://acikerisim.sdu.edu.tr/handle/123456789/77154

Coşkun, S. (2020). Trends in Temperature, Rainfall and Flow Values in Lakes Precinct (Mediterranean Region- Turkey) [InTurkish] .*International Social Sciences Studies Journal,* (e-ISSN:2587-1587) Vol:6, Issue: 66; pp:3142-3155.

Crosman, E. T., & Horel, J. D. (2009). MODIS-derived surface temperature of the Great Salt Lake. *Remote Sensing of Environment*, *113*(1), 73-81.

Dokulil, M. T., de Eyto, E., Maberly, S. C., May, L., Weyhenmeyer, G. A., & Woolway, R. I. (2021). Increasing maximum lake surface temperature under climate change. *Climatic Change*, *165*(3), 56.

Du, J., Zhou, H., Jacinthe, P. A., & Song, K. (2023). Retrieval of lake water surface albedo from Sentinel-2 remote sensing imagery. *Journal of Hydrology*, *617*, 128904.

Duan, X., Haseeb, M., Tahir, Z., Mahmood, S. A., Tariq, A., Jamil, A.,.. & Abdullah-Al-Wadud, M. (2025). A geospatial and statistical analysis of land surface temperature in response to land use land cover changes and urban heat island dynamics. *Scientific Reports*, *15*(1), 4943.

Durgun Kaygısız, A. (2024). Eğirdir Lake Basin And The Possible Danger Of Drying [In Turkish]. *Oğuzhan Journal of Social Sciences*, 6(2), 91-99. https://doi.org/10.55580/oguzhan.1534122

Earth Resources Observation and Science (EROS) Center. (2020a). Landsat 4-5 Thematic Mapper Level-2, Collection 2 [dataset]. U.S. Geological Survey. https://doi.org/10.5066/P9IAXOVV.

Earth Resources Observation and Science (EROS) Center. (2020b). Landsat 8-9 Operational Land Imager / Thermal Infrared Sensor Level-2, Collection 2 [dataset]. U.S. Geological Survey. https://doi.org/10.5066/P9OGBGM6

General Directorate of State Hydraulic Works (DSI). (2026a). *XVIII. Regional Directorate of DSI - Information on water resources and lake levels*. https://bolge18.dsi.gov.tr/Sayfa/Detay/1030 Accessed 16 January 2026 .

General Directorate of State Hydraulic Works (DSI). (2026b). *IV. Regional Directorate of DSI - Hydrological data for the part of the Lakes Region*. https://bolge04.dsi.gov.tr/Sayfa/Detay/914 Accessed 16 January 2026 .

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote sensing of Environment*, *202*, 18-27. https://doi.org/10.1016/j.rse.2017.06.031

Guo, L., Zheng, H., Wu, Y., Fan, L., Wen, M., Li, J., ... & Zhang, B. (2022). An integrated dataset of daily lake surface water temperature over the Tibetan Plateau. *Earth System Science Data*, *14*(7), 3411-3422.

Hoekstra, A. Y. (2017). Water footprint assessment: evolvement of a new research field. *Water Resources Management*, *31*(10), 3061-3081.

Işıldar, H. T., & Ercoşkun, Ö. Y. (2021). Sustainability and resilience in the Lakes District [In Turkish]. *Journal of Management Theory and Practices Research*, *2*(2), 89-116.

Kahraman, S., & Öztürk, M. Z. (2025). The Role of Remote Sensing in Lake Studies in Türkiye: A Bibliometric Approach [In Turkish]. *Journal of Geomorphological Researches*, (15), 43-54. https://doi.org/10.46453/jader.1719133

Kale, M. M. (2018). *Historical shoreline change assessment using DSAS: A case study of Lake Akşehir, SW Turkey.* Current Debates in Sustainable Architecture, Urban Design & Environmental Studies*. IJOPEC, London*, 187-196.

Karabacak, K., & Pınar, A. (2018). Eğirdir'in fiziki coğrafya özellikleri [Egirdir's physical geographical features]. *Route Educational and Social Science Journal*, 5(5).

Karadoğan, S., & Kavak, M. T. (2017). Investigation of landforms and lithological factors affecting climate in Diyarbakır basin with MODIS satellite image data [In Turkish]. *Geological Bulletin of Turkey*, 60 (4), 557-568.

Karahan, S. (2025). Changes in Temperature, Precipitation and Depending Climate Types in Muş Under the Influence of Global Climate Change [In Turkish]. *Memba Journal of Water Sciences*, 11(1), 84-95.

Karahanlı, E., & Mutlu, C. (2025). Climate Change Impacts and the Importance of Integrated Water Management. *MEMBA Journal of Water Sciences*, 11(3), 346-360.

Karaman, M. E. (2010). The tectonic evolution of Lake Eğirdir, West Turkey. *Geologos*, *16*(4), 223-234.

Kendall, M.G. & Gibbons, J. D. (1975). *Rank Correlation Methods*. 4th Edition, Charles Griffin, London

Kesici, E., & Kesici, C. (2006). Effects of interventions to the natural structure of Lake Eğirdir (Isparta) on the ecological structure of the lake [In Turkish]. *Aegean University Journal of Fisheries*, 23, 99-103..

Kumar, B. P., Anusha, B. N., Babu, K. R., & Sree, P. P. (2023). Identification of climate change impact and thermal comfort zones in semi-arid regions of AP, India using LST and NDBI techniques. *Journal of Cleaner Production*, *407*, 137175.

Küçükönder, M. (2021). *Evaluation of the relationship between Landsat thermal images and water surface temperature in Kılavuzlu Dam Lake [In Turkish]. Turkish Journal of Remote Sensing, 3(2), 60–67. https://doi.org/10.51489/tuzal.1008741*

Legg, S. (2021). IPCC, 2021: Climate change 2021-the physical science basis. *Interaction*, *49*(4), 44-45.

Li, Z., Cao, Y., Tang, J., Wang, Y., Duan, Y., Jiang, Z., & Qu, Y. (2020). Relationships between temporal and spatial changes in lakes and climate change in the saline-alkali concentrated distribution area in the Southwest of Songnen Plain, Northeast China, from 1985 to 2015. *Water*, 12 (12), 3557.

Liu, S., Xie, Z., Liu, B., Wang, Y., Gao, J., Zeng, Y., ... & Chen, S. (2020). Global river water warming due to climate change and anthropogenic heat emission. *Global and Planetary Change*, *193*, 103289.

Magee, M. R., & Wu, C. H. (2017). Response of water temperatures and stratification to changing climate in three lakes with different morphometry. *Hydrology and Earth System Sciences*, *21*(12), 6253-6274.

Mamizadeh, S., & Aslan, Z. (2019). Surface Temperature And Albedo Modeling With Artificial Neural Networks [In Turkish]. *AURUM Journal of Engineering Systems and Architecture*, *3*(2), 227-241.

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the econometric society*, 245-259.

O'Reilly, C. M., Sharma, S., Gray, D. K., Hampton, S. E., Read, J. S., Rowley, R. J., ... & Zhang, G. (2015). Rapid and highly variable warming of lake surface waters around the globe. *Geophysical Research*

Letters, *42*(24), 10-773.

Orhan, O. (2021). Investigation of the effect of urban growth on land surface temperature in Mersin province [In Turkish]. *Geomatik*, *6*(1), 69-76. https://doi.org/10.29128/geomatik.679858

Orhan, O., Dadaser-Celik, F., & Ekercin, S. (2019). Investigating land surface temperature changes using Landsat-5 data and real-time infrared thermometer measurements at Konya closed basin in Turkey. *International Journal of Engineering and Geosciences*, *4*(1), 16-27.

Özcanlı, M., & Yilmaz, E. (2024). Determination of land cover/use changes in Türkiye and possible effects on climate change [In Turkish]. *Turkish Geographical Review*, (86), 7-24. https://doi.org/10.17211/tcd.1408186

Özdal, İ., & Çetinkaya, O. (2024). Aquatic Plant Hotspots of Türkiye: The Lakes Region Habitats, Macrophytes, Biodiversity, Usage, Threats and Problems. *Acta Aquatica Turcica*, *20*(3), 267-286. https://doi.org/10.22392/actaquatr.1424469

Pashaei, H., M. & Aksoy, T., (2022). Determining the Effects of Spatial and Temporal Land Cover Changes on Land Surface Temperature Using Remote Sensing: A Case Study of İstanbul Pendik District *GSI Journals Serie C: Advancements in Information Sciences and Technologies (AIST)*, 5(2): 1-22.

Ptak, M., Sojka, M., Choiński, A., & Nowak, B. (2018). Effect of environmental conditions and morphometric parameters on surface water temperature in Polish lakes. *Water*, *10*(5), 580.

Sharma, S., Gray, D. K., Read, J. S., O'Reilly, C. M., Schneider, P., Qudrat, A., ... & Woo, K. H. (2015). A global database of lake surface temperatures collected by in situ and satellite methods from 1985–2009. *Scientific data*, *2*(1), 1-19.

Sarp, G., Temurçin, K., & Aldırmaz, Y. (2018). Evaluation of Industrialization Effects on Urbanization and Heat Island Formation Using Remote Sensing Technologies; A Case of Istanbul Bağcılar District. *SDÜ Faculty of Arts and Sciences Journal of Social Sciences,*, (44), 1-13.

Sarp, G., Baydoğan, E., Güzel, F., & Otlukaya, T. (2021). Evaluation of the relationship between urban area and land surface temperature determined from optical satellite data: A case of Istanbul. *Advanced Remote Sensing*, *1*(1), 31-37.

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

Şen, Z. (2022). Climate change and Türkiye [In Turkish]. *Journal of Environment, Urbanization and Climate*, *1*(1), 1-19.

Şener, E. (2016). Determination of seasonal change of Lake Burdur surface water temperature using Landsat 8 satellite images [In Turkish]. *Journal of Engineering Sciences and Design*, 4(2), 67–73,. https://doi.org/10.21923/jesd.31386

Şengör, A. M. C. (1984). *The Cimmeride orogenic system and the tectonics of Eurasia*. *Geological Society of America Special Paper*, 195, 1–82.

Tagil, S., Danacioglu, S., & Yurtseven, N. (2024). Time series clustering of sea surface temperature in the Mediterranean and Black Sea Marine System. *International Journal of Climatology*, *44*(16), 6083-6099.

Tan, J., Yu, D., Li, Q., Tan, X., & Zhou, W. (2020). Spatial relationship between land-use/land-cover change and land surface temperature in the Dongting Lake area, China. *Scientific Reports*, *10*(1), 9245.

Türkeş, M., Öztaş, T., Tercan, E., Erpul, G., Karagöz, A., Dengiz, O., ... & Avcıoğlu, B. (2020). Desertification vulnerability and risk assessment for Turkey via an analytical hierarchy process model. *Land degradation & development*, *31*(2), 205-214.

Türkeş, M. (2021). Water climate of Turkey, climate change and 2019-2020 drought [In Turkish]. *EKOIQ*, 92, 90-97.

Temurçin, K., Atayeter, Y., & Tozkoparan, U. (2019). Tourism potential of Lake Salda and its surroundings and its effect on the socio-economic structure of Yeşilova district [In Turkish]. *SDÜ Faculty of Arts and Sciences Journal of Social Sciences*, (47), 40-63.

Tuncel, M. (2011). Regions of Turkey Geographical Nomenclature of the First Geography Congress (1941), and its effects on Detection Limits [In Turkish]. *Turkish Geographical Rewiev*, (57), 1-10.

Tuygun, G. T., Salgut, S., & Elçi, A. (2023). Long-term spatial-temporal monitoring of eutrophication in Lake Burdur using remote sensing data. *Water Science & Technology*, *87*(9), 2184-2194.

Vicente-Serrano, S. M., Tramblay, Y., Reig, F., González-Hidalgo, J. C., Beguería, S., Brunetti, M., ... & Potopová, V. (2025). High temporal variability not trend dominates Mediterranean precipitation. *Nature*, *639*(8055), 658-666.

Wan, W., Li, H., Xie, H., Hong, Y., Long, D., Zhao, L., ... & Yang, W. (2017). A comprehensive data set of lake surface water temperature over the Tibetan Plateau derived from MODIS LST products 2001–2015. *Scientific Data*, *4*(1), 1-10.

Wang, S., He, Y., Hu, S., Ji, F., Wang, B., Guan, X., & Piccolroaz, S. (2021). Enhanced warming in global dryland lakes and its drivers. *Remote Sensing*, *14*(1), 86.

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*(8), 388-403.

Xin, J., Yang, J., Sun, D., Han, T., Song, C., & Shi, Z. (2022). Seasonal differences in land surface temperature under different land use/land cover types from the perspective of different climate zones. *Land*, *11*(8), 1122.

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.

Yang, X., Wang, N., Chen, A. A., He, J., Hua, T., & Qie, Y. (2020). Changes in area and water volume of the Aral Sea in the arid Central Asia over the period of 1960–2018 and their causes. *Catena*, *191*, 104566.

Yayla, O., Akpınar, H., Bilgin, T., Atayeter, Y., & Korkmaz, O. (2025). An evaluation of the long-term changes in the shoreline of Lake Eğirdir in relation to climate and anthropogenic factors. *Journal of Geography*, (50), 65-78.

Yıldız, M. C. (2025). Analysis of Surface Water Area and Shoreline Changes in Lake Salda Between 1995–2025 Using Satellite Data [In Turkish]. *Turkish Journal of Technical Sciences and Innovation*, 1(1), 44-50

Yu, H., Tu, Z., Yu, G., Xu, L., Wang, H., & Yang, Y. (2020). Shrinkage and protection of inland lakes on the regional scale: A case study of Hubei Province, China. *Regional Environmental Change*, *20*(1), 4.

Yu, L., Liu, Y., Li, X., Yan, F., Lyne, V., & Liu, T. (2023). Vegetation-induced asymmetric diurnal land surface temperatures changes across global climate zones. *Science of the Total Environment*, *896*, 165255.

Yücer, E. (2023). Investigation of the Relationship between Albedo, Land Surface Temperature and NDVI Using Landsat-7 and Landsat-8 Satellite Data: The Sample of Safranbolu [In Turkish]. *KSU Journal of Engineering Sciences*, 26(1), 177-190

Zhang, F., Kung, H., Johnson, V. C., LaGrone, B. I., & Wang, J. (2018). Change detection of land surface temperature (LST) and some related parameters using Landsat image: a case study of the Ebinur lake watershed, Xinjiang, China. *Wetlands*, *38*(1), 65-80.

Zhang, X., Jiao, Z., Zhao, C., Qu, Y., Liu, Q., Zhang, H., Tong, Y., Wang, C., Li, S., Guo, J., Zhu, Z., Yin, S., & Cui, L. (2022). Review of land surface albedo: variance characteristics, climate effect and management strategy. *Remote Sensing*, *14*(6), 1382.

Zhou, X., Ray, P., Barrett, B. S., & Hsu, P. C. (2022). Systematic improvement in simulated latent and sensible heat fluxes over tropical oceans in AMIP6 models compared to AMIP5 models with the same resolutions. *Atmospheric Research*, *274*, 106214.