Akdeniz Mühendislik Dergisi
Akdeniz Journal of Engineering
(AKUJE)
2025, 3(1), pp. 11-19
Araştırma Makalesi Research Article

MONITORING WETLAND TRANSFORMATIONS IN LAKE EBER OVER A DECADE USING REMOTE SENSING

UZAKTAN ALGILAMA KULLANILARAK EBER GÖLÜ'NDEKİ SULAK ALAN DÖNÜŞÜMLERİNİN ON YIL SÜRE İLE İZLENMESİ

Recep Uğur ACAR[*1] **Enes ZENGİN**[2]

[1] Geological Engineering, Kütahya Dumlupınar University, Kütahya, Türkiye.

[2] Urban and Regional Planning, Kütahya Dumlupınar University, Kütahya, Türkiye.

ABSTRACT

Eber Lake, an important wetland located in the Akarçay closed basin in the Central Anatolia Region, has experienced significant drought-induced shrinkage. This study monitored and quantified the changes in wetland areas of Lake Eber from 2015 to 2024 using high-resolution Sentinel 2-A satellite imagery and the Modified Normalized Difference Water Index (MNDWI). MNDWI was selected due to its superior performance in accurately characterizing wetland properties compared to alternative indices. An iterative analysis was conducted to determine the most appropriate threshold to distinguish between water and non-water areas, and the threshold values were validated using ground-based data. Our results reveal a striking contraction in the spatial extent of wetlands; the area decreased from 7,748 ha in 2015 to only 327 ha in 2024, indicating a decrease of approximately 96%. This significant loss highlights the profound impact of environmental factors such as prolonged droughts, increasing temperatures and changing precipitation patterns, and likely anthropogenic pressures. The integration of remote sensing and robust GIS methodologies in this study provides a detailed, temporally continuous record of wetland transformations, providing new insights into regional hydrological dynamics. The findings not only improve our understanding of the ongoing environmental changes in Lake Eber but also highlight the urgent need for sustainable management practices and conservation strategies to mitigate further degradation of this vital ecosystem.

Keywords: Lake Shrinkage, Modified Normalized Difference Water Index, Remote Sensing, Sentinel 2-A.

ÖZET

Orta Anadolu Bölgesi'ndeki Akarçay kapalı havzasında bulunan önemli bir sulak alan olan Eber Gölü, kuraklık kaynaklı önemli bir küçülme yaşamıştır. Bu çalışmada, 2015-2024 yılları arasında Eber Gölü'nün sulak alan alanlarındaki değişiklikler yüksek çözünürlüklü Sentinel 2-A uydu görüntüleri ve Değiştirilmiş Normalleştirilmiş Fark Su Endeksi (MNDWI) kullanılarak izlenmiş ve niceliksel olarak belirlenmiştir. MNDWI, alternatif endekslere kıyasla sulak alan özelliklerini doğru bir şekilde karakterize etmedeki üstün performansı nedeniyle seçilmiştir. Su ve su dışı alanlar arasında ayrım yapmak ve en uygun eşik değerini belirlemek amacıyla aşamalı bir analiz yürütülmüş ve eşik değerleri yer tabanlı veriler kullanılarak doğrulanmıştır. Sonuçlarımız, sulak alanların mekansal kapsamında çarpıcı bir daralma olduğunu ortaya koymaktadır; alan 2015'teki 7.748 hektardan 2024'te sadece 327 hektara düşmüştür; bu da yaklaşık %96'lık bir azalmayı göstermektedir. Bu önemli kayıp, uzun süreli kuraklıklar, artan sıcaklıklar ve değişen yağış düzenleri ve muhtemel antropojenik baskılar gibi çevresel faktörlerin derin etkisini vurgulamaktadır. Bu çalışmada uzaktan algılama ve sağlam GIS metodolojilerinin entegrasyonu, sulak alan dönüşümlerinin ayrıntılı, zamansal olarak sürekli bir kaydını sunarak bölgesel hidrolojik dinamiklere dair yeni bulgular sağlar. Bulgular, yalnızca Eber Gölü'ndeki devam eden çevresel değişikliklere ilişkin anlayışımızı geliştirmekle kalmaz, aynı zamanda bu hayati ekosistemin daha fazla bozulmasını azaltmak için sürdürülebilir yönetim uygulamalarına ve koruma stratejilerine olan acil ihtiyacı da vurgular.

Anahtar Kelimeler: Değiştirilmiş Normalleştirilmiş Fark Su Endeksi, Göl Küçülmesi, Sentinel 2-A, Uzaktan Algılama.

*Corresponding Author (Sorumlu Yazar), e-mail: ugur.acar@dpu.edu.tr

Submission Date Başvuru Tarihi	Revision Date Revizyon Tarihi	Accepted Date Kabul Tarihi	Published Date Yayım Tarihi
03.02.2025	12.02.2025	21.02.2025	01.06.2025

1. INTRODUCTION

Water is essential for all living organisms to exist, function and survive [1], [2]. Lakes, defined in the surface water category, are one of the most critical water resources. In addition to their function as a vital water source, lakes are also of significant ecological value due to their high biodiversity [3], [4]. The phenomenon of global warming, in conjunction with the effects of human activity, such as the intensification of agricultural practices, which are subject to a perpetual rise in consequence of climate change, is exerting an ever-increasing degree of pressure on lakes and all other water resources throughout the world [5], [6], [7], [8]. Recently, the number of water resources facing various challenges, including drying up, shrinking, or even disappearing, has been increasing. These issues are attributable to climatic changes, rising water demand, and the impact of human activities in arid-semi-arid regions [9]. In many areas, the diminution or total loss of wetlands has resulted in biodiversity loss, economic difficulties and social problems [10]. The preservation of these resources and their transference to subsequent generations are of critical importance for the well-being of humanity. Lakes offer a variety of benefits, including the regulation of flooding and the storage of carbon. In addition to their role as a water source, they also serve numerous other functions. It is, therefore, imperative that measurements and observations are made for the sustainable management of water resources to ensure the future of our planet.

Remote sensing and geographic information systems technologies offer significant advantages in carrying out the requisite measurements and observations concerning drought and water resources [4], [11] Satellite images and other remote sensing data allow the monitoring of large areas quickly and effectively. Remote sensing methods have proven to be quite valuable tools in the literature for analysing the change of lakes and wetlands over time, assessing the status of water resources, and determining the effects of drought. These tools facilitate the expeditious, precise, and cost-effective monitoring and evaluation of water resources compared to alternative land-based studies [12], [13], [14], [15].

Several remote sensing methodologies have been developed to detect water bodies. Among these, image classification and water indices and water indices are the most effective [12], [13], [16], [17]. Water indices are considered efficacious and accessible methods of detecting water bodies through remote sensing. Water indices consist of simple algorithms, including the normalised difference water index (NDWI) [12] and the modified normalised difference water index (MNDWI) [18], which are executed with spectral bands that consider the spectral characteristics of water with high reflectance in the visible region and low reflectance in the infrared region. Water indices, despite their primitive configuration and operating principles, can produce information with greater agility and precision compared to alternative methodologies [17]

Lake Eber is a vital wetland in the Central Anatolia Region of Türkiye. It is evident that the presence of the habitat in question significantly enriches the region's biodiversity. Moreover, the area provides numerous benefits to the local community, including the assurance of a reliable water supply, agricultural irrigation, and facilitating recreational activities. However, significant changes have been observed in the water level and wetland area of the lake due to climate change and human activities in recent years. These alterations have precipitated a state of imminent extinction for the lake, thereby jeopardising the local ecological equilibrium and the sustainability of the region's water resources. This study evaluates the change in the wetland area of Lake Eber over 10 years between 2015 and 2024. The methodology employed analysed Sentinel 2-A satellite imagery and Modified Normalised Difference Water Index (MNDWI) data. Sentinel 2-A satellites provide high-resolution, multi-spectral imagery, allowing precise mapping of wetlands. MNDWI is a reliable technique for differentiating water bodies from other surfaces by utilising the spectral characteristics of water. Utilising the data and methodology, the alterations in the wetland area of Lake Eber will be subject to continuous monitoring and analysis. The findings obtained will provide valuable information for understanding the dimensional change of the lake from past to present.

2. MATERIALS AND METHODS

2.1. Study Area

Lake Eber is a tectonic lake located in the Akarçay Closed Basin, approximately 70 km away from Afyonkarahisar province, and is categorised as a semi-circular lake according to Reeves (1968) (Figure 1) [18, 19]. The Akarçay Closed Basin is located at the intersection of Western Anatolia and Central Anatolia and is bounded by mountains in the south-eastern to north-western direction [19].

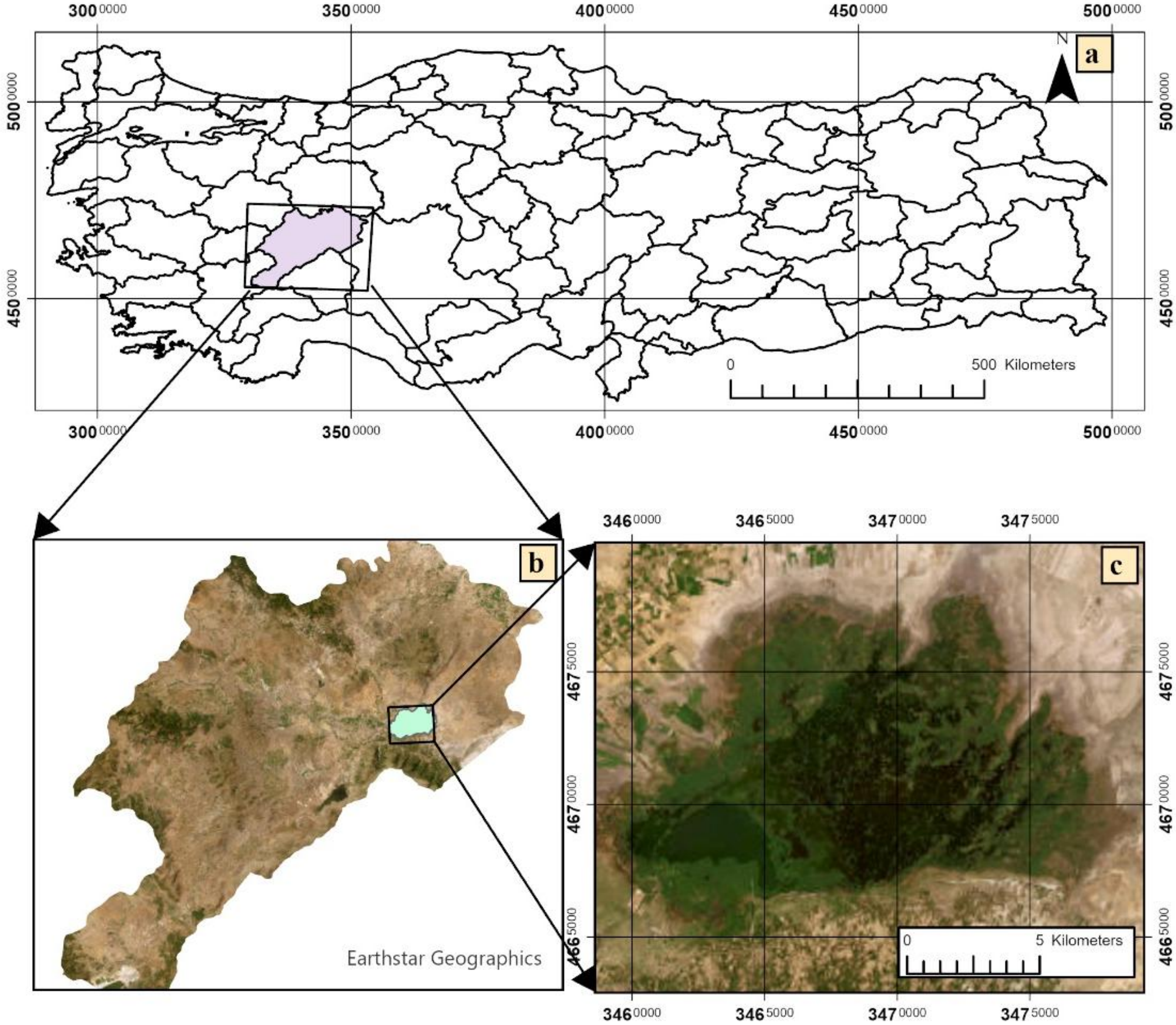

Figure 1. Location of the study area a) Türkiye and Afyonkarahisar, b) Afyonkarahisar and Lake Eber Location, c) Lake Eber Satellite Image.

2.2. Data Acquisition and Preprocessing

In this study, the temporal change of the wetlands of Lake Eber was examined using Sentinel 2-A satellite data from the Copernicus Open Access Centre of the European Space Agency (Table 1). The data set under scrutiny encompasses a 10-year period from 2015 to 2024, specifically focusing on the months of September. The selection of September as the study period is predicated on the fact that it marks the conclusion of the summer season, and the onset of precipitation has not yet commenced. Furthermore, images with less than 5% cloud cover were selected to minimise atmospheric effects.

Table 1. Date of satellite data used for the present study

Date of Acquisition (date/month/year)
05/09/2015
09/09/2016
04/09/2017
04/09/2018
09/09/2019
03/09/2020
08/09/2021
08/09/2022
18/09/2023
27/09/2024

The methodology of the present study is summarised in Figure 2. The Sentinel 2-A data acquired for this study were subjected to pre-processing using SNAP software. Initially, radiometric corrections were applied to remove atmospheric effects and convert the pixel values to actual surface reflectance. Given the differing spatial resolutions of the various spectral bands of the Sentinel 2-A satellite (Table 2), it is necessary to harmonise pixel sizes for multispectral analyses. To this end, resampling was performed for all 13 bands. Subsequently, Lake Eber subsetted the study area to reduce the data size and increase processing efficiency.

Table 2. Sentinel 2-A Bands and specifications

Band	Name	Spatial resolution (m)
1	Coastal Aerosol	60
2	Blue	10
3	Green	10
4	Red	10
5	Red Edge 1	20
6	Red Edge 2	20
7	Red Edge 3	20
8	Near-infrared	10
8A	Near-infrared	20
9	Water Vapour	60
10	Cirrus	60
11	Shortwave infrared	20
12	Shortwave infrared	20

The pre-processed images were transferred to ArcGIS Pro software in a format suitable for MNDWI calculations. Within the ArcGIS Pro framework, the delineation of lake wetlands was accomplished by calculating the MNDWI values for each year, followed by performing area calculations. This approach enabled the determination of the changes in the wetlands of Lake Eber over 10 years.

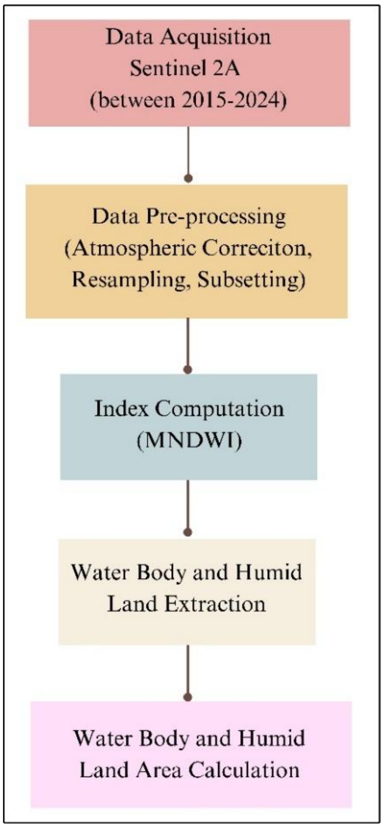

Figure 2. The following flowchart illustrates the general methodology employed in this study.

2.3. Modified Normalized Difference Water Index (MNDWI)

One of the standard methods used for determining water bodies in remote sensing is water indices produced from spectral bands. These indices can be easily calculated with simple algorithms. The Modified Normalised Difference Water Index is a vital water index developed based on the difference between the high reflectance properties of water in the green region and the low reflectance properties of water in the shortwave infrared region (Equation 1) [18].

$$MNDWI = \left(\frac{Green - SWIR}{Green + SWIR}\right) \tag{1}$$

Here, 'Green' is used to denote the reflectance value of the green band, while 'SWIR' is employed to represent the reflectance value of the shortwave infrared band. MNDWI values range from -1 to +1, with positive values indicating water bodies. MNDWI values greater than 0 indicate wetlands or humid regions, while values closer to 1 are a stronger indicator of the presence of water. By contrast, other surfaces (e.g. vegetation, soil, buildings) exhibit negative or near-zero MNDWI values (Table 3). This attribute renders MNDWI a valuable instrument in diverse fields, including identifying and observing water bodies, wetland cartography, lake and reservoir surveillance, water resources management, flood and drought observation, and water quality evaluation.

Table 3. MNDWI Values and Interpretation

Ranges of Values	Meaning
0,2 - 1	Water bodies, streams and flood areas
0 - 0,2	Humid lands
0,3 - 0	Moderate drought and dry lands
-1 – 0,3	Drought and dry lands

3. RESULTS AND DISCUSSION

This study aimed to monitor and quantify changes in the wetlands of Lake Eber over a decade (2015–2024) using Sentinel 2-A satellite imagery and the Modified Normalized Difference Water Index (MNDWI). The methodology consists of four key steps: Data Exploration and Preprocessing, Identification of Wetlands using MNDWI, Determination of the Optimal Threshold for Water-Land Classification, and Assessment of Boundary Shifts (Figure 3 and 4). MNDWI was chosen due to its proven superiority over other indices (e.g., NDWI) in accurately characterizing water properties, especially in heterogeneous and urban landscapes [18–22]. Moreover, its capacity to provide comprehensive open water data and detect temporal changes in water quality reinforces its suitability for this study. A critical component of our approach was to determine the optimal threshold value to distinguish water from non-water areas. To achieve this, we performed an iterative analysis of the histogram distribution of MNDWI values. We conducted these processes by testing a range of potential threshold values and then selecting the threshold value that minimized misclassification errors by validating these values with real data to assess the accuracy of our classification. This rigorous sensitivity analysis not only ensured the reliability of our water delimitation process but also provided an important methodological contribution by providing a replicable framework for similar studies in other regions. Our results show a significant decrease in the geographical extent of the wetlands of Lake Eber during the study period. In particular, the wetland area decreased from 7748 ha in 2015 to only 327 ha in 2024, representing a contraction of approximately 96% (Table 4). Although a small increase was observed in 2019 compared to 2018, the overall trend remains a persistent decline. This significant loss highlights the serious impact of both environmental and anthropogenic factors on the lake's ecosystem. This study is one of the first to apply such an integrated approach to Lake Eber by combining high-resolution Sentinel 2-A data with a robust application of the MNDWI method, providing a detailed, temporally continuous record of wetland transformations.

Table 4. Changes in the Eber Lake area over the years (hectare(ha)).

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Wetland (ha)	7748	5464	4767	3615	3735	1644	399	707	843	327

Multiple factors are likely contributing to the observed shrinkage of Lake Eber. Climatic influences such as prolonged drought and increasing temperatures may accelerate water evaporation, thereby reducing the area of the lake. In parallel, anthropogenic activities are further straining the lake’s water resources. These environmental changes not only threaten biodiversity by reducing habitat availability and altering water quality but also disrupt local food chains and may impact migratory bird populations that rely on the lake as a critical refuge. From a socio-economic perspective, the dramatic shrinkage of Lake Eber could have profound consequences for sectors such as agriculture and tourism. The findings highlight the urgent need for an integrated water management strategy that combines efficient water use, conservation efforts and pollution control measures. To address these challenges, a comprehensive analysis integrating hydrological, meteorological and ecological data is essential. Regular monitoring of groundwater levels, water use patterns and land use changes will be important to better elucidate the driving forces behind lake shrinkage.

4. CONCLUSION

In conclusion, this study comprehensively investigated the annual changes in Lake Eber, a major wetland in the Akarçay Basin of Türkiye, during the period 2015-2024. By integrating high-resolution Sentinel 2-A satellite data with Geographic Information System (GIS) tools and using the Modified Normalized Difference Water Index (MNDWI), we developed a robust methodological framework to monitor changes in the lake's wetland boundaries. The process included detailed data exploration and preprocessing, precise water-land classification via iterative threshold determination (validated with real data), and subsequent assessment of boundary shifts.

Our findings reveal a striking decrease in the geographic extent of Lake Eber's wetlands, from 7748 hectares in 2015 to only 327 hectares in 2024, representing a decline of approximately 96% in a decade.

Although a slight increase was observed in 2019, the overall trend indicates a persistent and significant loss of wetlands. This decline highlights the serious impact of both environmental and anthropogenic factors on the lake ecosystem.

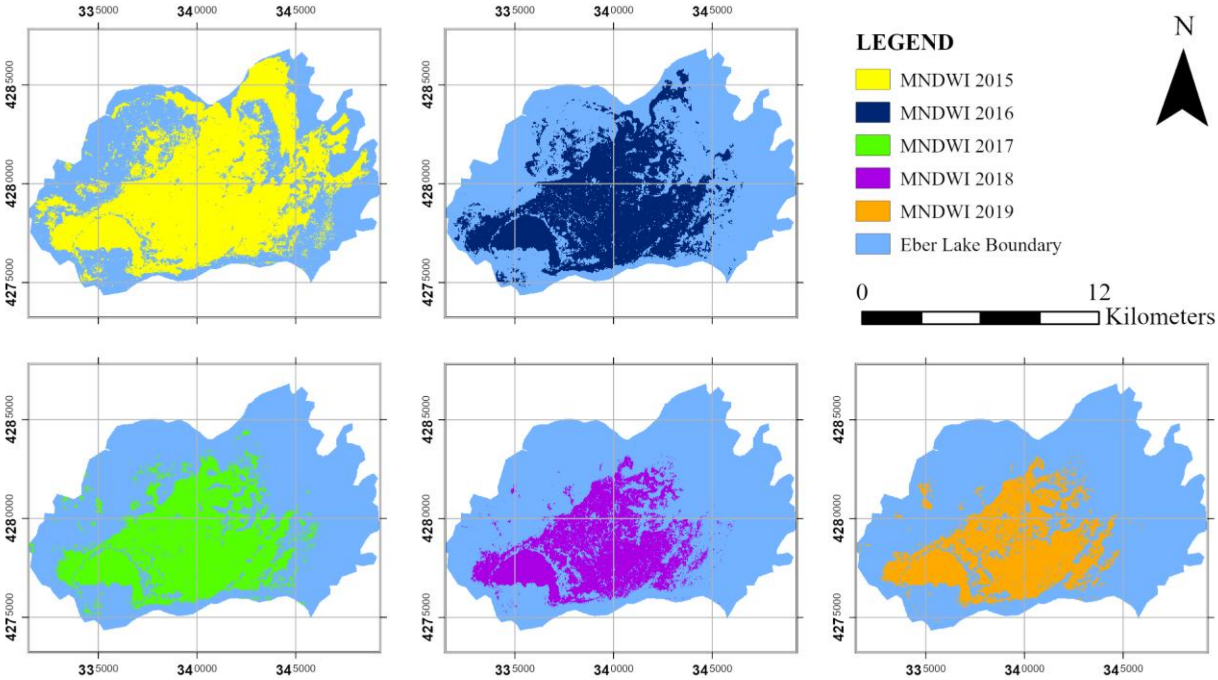

Figure 3. Distribution of wetland boundaries obtained using MNDWI (2015-2019)

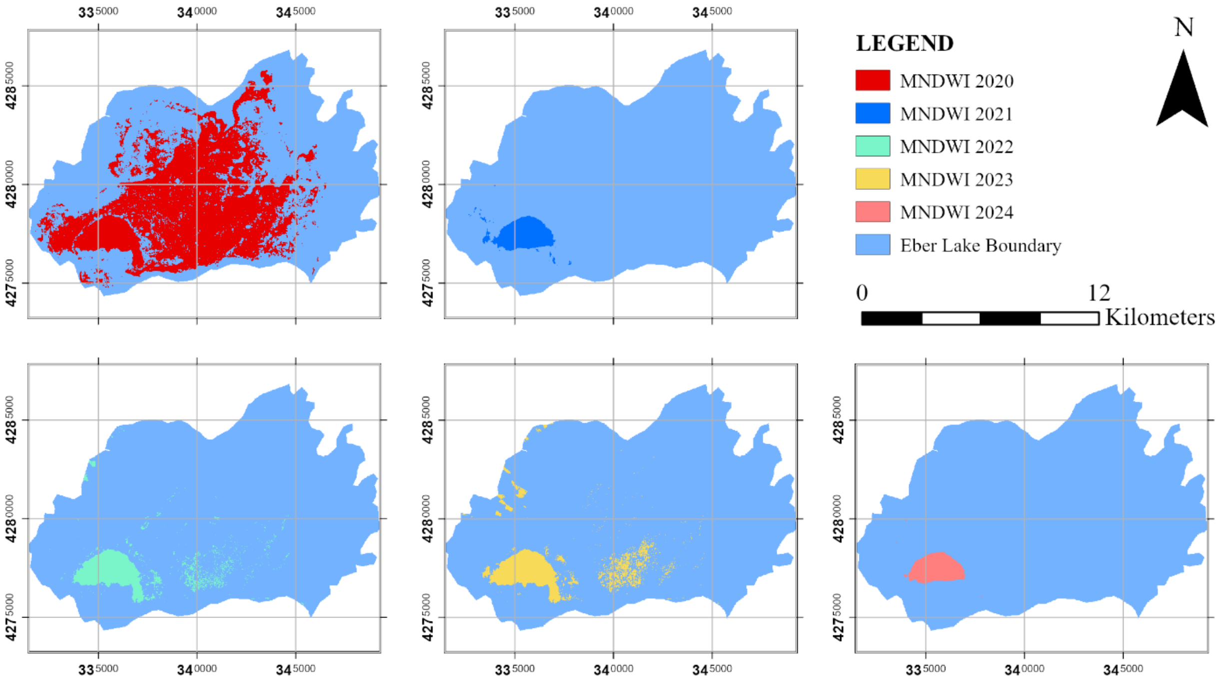

Figure 4. Distribution of wetland boundaries obtained using MNDWI (2020-2024).

Several important factors are likely contributing to this shrinkage. Climatic impacts such as prolonged droughts, rising temperatures and accelerated evaporation have undoubtedly played a significant role. In addition, erosion through human activities such as agricultural irrigation may have further accelerated the decline in water resources. These changes not only threaten biodiversity (through habitat loss and disruption of migratory bird patterns) but also create serious socioeconomic challenges for local communities dependent on agriculture, tourism and fisheries.

The study demonstrates the effectiveness of remote sensing and GIS tools as cost-effective and rapid methods for environmental monitoring. The innovative integration of high-resolution satellite imagery with a rigorous thresholding process using MNDWI provides a reproducible framework for future investigations of wetland dynamics. Moreover, this approach provides critical insights that can support the development of sustainable management practices and integrated water management strategies. As a result, the deep decline observed in Lake Eber serves as a striking reminder of the urgent need for comprehensive monitoring and conservation efforts. By combining hydrological, meteorological and ecological data, the drivers of wetland degradation can be better understood and reduced, ensuring the long-term protection of these vital ecosystems.

REFERENCES

[1] K. Demirel and Y. Kavdır, “Effect of Soil Water Retention Barriers On Turfgrass Growth and Soil Water Content,” Irrig Sci, Vol. 31, No. 4, Pp. 689–700, 201.

[2] E. Özelkan, “Comparison of Remote Sensing Classification Techniques for Water Body Detection: A Case Study in Atikhisar Dam Lake (Çanakkale),” Cumhuriyet Science Journal, Vol. 40, No. 3, Pp. 650–661, 2019.

[3] J. T. A. Verhoeven, B. Beltman, R. Bobbink, And D. F. Whigham, Eds., Wetlands and Natural Resource Management, Vol. 190. Berlin, Heidelberg: Springer Berlin Heidelberg, 2006.

[4] Ü. Özaslan and E. Erdoğan Yüksel, “Determination of Land Change in the Susurluk Basin Kocaçay Delta Wetland Using Remote Sensing and Geographic Information Systems,” Journal of Bartin Faculty of Forestry, 2024.

[5] M. Akif Erdoğan, F. Sönmez and S. Berberoğlu, "Baraj Göllerinde Su Seviyelerinin Uzaktan Algılama ve CBS ile Tahmini ve İzlenmesi: Adana Seyhan Baraj Gölü Örneği," 5. Uzaktan Algılama-CBS Sempozyumu (UZAL-CBS 2014), İstanbul, Turkey, 2014.

[6] M. E. Sönmez and M. Somuncu, “Evaluation of spatial change in the Sultan Marshes in sustainability,” Turkish Geographical Review, Vol. 66, 1-10, 2016.

[7] B. Chang, K.-N. He, R.-J. Li, Z.-P. Sheng, And H. Wang, “Linkage of Climatic Factors and Human Activities with Water Level Fluctuations in Qinghai Lake in The Northeastern Tibetan Plateau, China,” Water (Basel), Vol. 9, No. 7, P. 552, Jul. 2017.

[8] İ. Dursun and A. A. Babalık, “Determining the Amount Of Soil Lost By Erosion By Using Geotextile In Different Land Use Types: A Case Study Of Karam Creek Sub-Basin,” Turkish Journal of Forest Science, Vol. 7, No. 2, Pp. 138–154, 2023.

[9] L. M. Kiage and P. Douglas, “Linkages Between Land Cover Change, Lake Shrinkage, And Sublacustrine Influence Determined from Remote Sensing of Select Rift Valley Lakes in Kenya,” Science of The Total Environment, Vol. 709, P. 136022, 2020.

[10] B. M. Jones, G. Grosse, L. M. Farquharson, P. Roy-Léveillée, A. Veremeeva, M. Z. Kanevskiy, B. V. Gaglioti, A. L. Breen, A. D. Parsekian, M. Ulrich and K. M. Hinkel, “Lake and Drained Lake Basin Systems in Lowland Permafrost Regions,” Nat Rev Earth Environ, Vol. 3, No. 1, Pp. 85–98, 2022.

[11] Y. Bao and X. Zhang, “The Study of Lakes Dynamic Change Based on Rs and Gis –Take Dalinuoer Lake as An Example,” Procedia Environ Sci, Vol. 10, Pp—2376–2384, 2011.

[12] S. K. Mcfeeters, “The Use of The Normalized Difference Water Index (Ndwi) In the Delineation of Open Water Features,” Int J Remote Sens, Vol. 17, No. 7, Pp. 1425–1432, 1996.

[13] H. Xu, “Modification of Normalised Difference Water Index (Ndwi) To Enhance Open Water Features in Remotely Sensed Imagery,” Int J Remote Sens, Vol. 27, No. 14, Pp. 3025–3033, 2006.

[14] M. Karaman, E. Özelkan, And S. Taşdelen, “Influence of Basin Hydrogeology in the Detectability of Narrow Rivers by Sentinel2-A Satellite Images: A Case Study in Karamenderes (Çanakkale),” Journal of Natural Hazards and Environment, Vol. 4, No. 2, Pp. 140–155, 2018.

[15] S. Kale and D. Acarlı, "Spatial and Temporal Change Monitoring in Water Surface Area Of Atikhisar Reservoir (Çanakkale, Turkey) By Using Remote Sensing And Geographic Information System Techniques," Alinteri Journal of Agriculture Science, Vol. 34, No. 1, Pp. 47–56, 2019.

[16] L. Ji, L. Zhang, And B. Wylie, "Analysis of Dynamic Thresholds for The Normalized Difference Water Index," Photogramm Eng Remote Sensing, Vol. 75, No. 11, Pp. 1307–1317, 2009.

[17] Y. Du, L. Linglin, T. Liqiao, L. Feng, W. Hailei, G. Yuanmiao, S. Zhongmin. "Analysis of Landsat-8 Oli Imagery for Land Surface Water Mapping," Remote Sensing Letters, Vol. 5, No. 7, Pp. 672–681, 2014.

[18] W. T. Edmondson, "Reeves, C. C., Jr. 1968. Introduction To Paleolimnology. Developments In Sedimentology No. 11. American Elsevier, New York. 228 P. $18.00.," Limnol Oceanogr, Vol. 14, No. 4, Pp. 650–651, 1969.

[19] M. M. Köle, M. Ataol, and T. Erkal, "Spatial Changes of Eber and Akşehir Lakes Between 1990 And 2016," In International Geography Symposium, Ankara: Tücaum, 2016.

[20] M. Ichsan Ali, G. Darma Dirawan, A. Hafid Hasim, And M. Rais Abidin, "Detection of Changes in Surface Water Bodies Urban Area with Ndwi and Mndwi Methods," Vol. 9, No. 3, 2019.

[21] H. Dibs, "Comparison of Derived Indices and Unsupervised Classification for Al-Razaza Lake Dehydration Extent Using Multi-Temporal Satellite Data and Remote Sensing Analysis," Journal of Engineering and Applied Sciences, Vol. 13, Pp. 1–8, 2018.

[22] S. Szabó, Z. Gácsi, And B. Balázs, "Specific Features of Ndvi, Ndwi and Mndwi as Reflected in Land Cover Categories," Landscape & Environment, Vol. 10, No. 3–4, Pp. 194–202, 2016.