Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi
Afyon Kocatepe University – Journal of Science and Engineering
https://dergipark.org.tr/tr/pub/akufemubid

Araştırma Makalesi / Research Article
e-ISSN: 2149-3367
DOI: https://doi.org/10.35414/akufemubid.1579340
AKÜ FEMÜBİD **25** (2025) 045801 (946-955)
AKU J. Sci. Eng. **25** (2025) 045801 (946-955)

Assessing Boundary Shifts at Gölcük Lake (Kütahya) with Google Earth Images

Makale Bilgisi / Article Info
Alındı/Received: 04.10.2024
Kabul/Accepted: 28.02.2025
Yayımlandı/Published: 04.08.2025

Google Earth Görüntüleri ile Gölcük Gölü (Kütahya) Sınır Değişimlerinin Değerlendirilmesi

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Abstract
Climate change is one of the most pressing issues facing the world today, with far-reaching impacts on ecosystems, human health, and global economies. It is characterized by significant alterations in temperature, precipitation patterns, and the frequency of extreme weather events, largely driven by human activities such as deforestation, industrial emissions, and the intense use of fossil fuels. United Nations has introduced a collective approach through the Sustainable Development Goals (SDGs), a set of 17 global goals adopted in 2015 as part of the 2030 Agenda for Sustainable Development. For this purpose, the boundary shifts of Gölcük Lake in Simav, Kütahya, Türkiye, were examined using high-resolution Google Earth images from 2013 and 2023. Supervised classification techniques in ArcGIS Pro were applied to analyze changes in the lake's area over a decade marked by significant climate variability. The use of spatial data and geographic information system (GIS) methods allowed for precise measurement and visualization of these changes, proving highly useful for assessing the extent and impact of lake shrinkage. The findings reveal a 22.7% reduction in lake area, equating to approximately 32,279 m², indicating a notable shrinkage likely influenced by environmental factors. Temperature and precipitation data, obtained from the Ministry of Environment, Urbanization and Climate and the Turkish State Meteorological Service, were also assessed. The data showed an increase in average temperature from 11.5°C to 13°C and a slight decrease in precipitation over the period, suggesting potential contributions from climate change to the lake's shrinkage. These results underscore the importance of ongoing monitoring and sustainable management to mitigate the adverse impacts of climate change on freshwater resources.

Keywords *Boundary Shift, Climate Change, Gölcük Lake, Kütahya, Geographic Information System*

Öz
İklim değişikliği, bugün dünyanın karşı karşıya olduğu en acil sorunlardan biri olup, ekosistemler, insan sağlığı ve küresel ekonomiler üzerinde geniş kapsamlı etkiler yaratmaktadır. Bu durum, büyük ölçüde ormansızlaşma, sanayi kaynaklı emisyonlar ve fosil yakıtların yoğun kullanımı gibi insan faaliyetlerinin neden olduğu, sıcaklık, yağış düzenleri ve aşırı hava olaylarının sıklığında önemli değişimlerle tanımlanmaktadır. Birleşmiş Milletler, 2030 Sürdürülebilir Kalkınma Gündemi kapsamında 2015 yılında kabul edilen 17 küresel hedeften oluşan Sürdürülebilir Kalkınma Amaçları (SKA) ile kolektif bir yaklaşım sunmuştur. Bu amaç doğrultusunda, Türkiye'nin Kütahya iline bağlı Simav ilçesindeki Gölcük Gölü'nün sınır değişimleri, 2013 ve 2023 yıllarına ait yüksek çözünürlüklü Google Earth görüntüleri kullanılarak incelenmiştir. Göl alanındaki değişimleri analiz etmek için ArcGIS Pro'da gözetimli sınıflandırma teknikleri uygulanmıştır. Mekansal veri ve coğrafi bilgi sistemleri (CSB) yöntemlerinin kullanımı, bu değişikliklerin yüksek hassasiyetle ölçümünü ve görselleştirilmesini sağlamış ve göl küçülmesinin boyutunu ve etkisini değerlendirmede son derece yararlı olmuştur. Elde edilen sonuçlar, göl alanında %22,7'lik bir azalma olduğunu ve yaklaşık 32.279 m²'lik önemli bir küçülmeyi göstermektedir; bu küçülmenin çevresel faktörlerden etkilenmiş olabileceği düşünülmektedir. Çevre, Şehircilik ve İklim Değişikliği Bakanlığı ile Meteoroloji Genel Müdürlüğü'nden elde edilen sıcaklık ve yağış verileri de değerlendirilmiştir. Veriler, ortalama sıcaklığın 2013'te 11,5°C'den 2023'te 13°C'ye yükseldiğini ve aynı dönemde yağış miktarında hafif bir azalma olduğunu göstermektedir; bu durum, iklim değişikliğinin gölün küçülmesine potansiyel bir katkısı olabileceğini düşündürmektedir. Bu sonuçlar, tatlı su kaynakları üzerindeki iklim değişikliğinin olumsuz etkilerini azaltmak için sürekli izleme ve sürdürülebilir yönetimin önemini vurgulamaktadır.

Anahtar Kelimeler *Sınır Değişimi, Iklim Değişikliği, Gölcük Gölü, Kütahya, Coğrafi Bilgi Sistemleri*

1. Introduction

Climate change represents one of the most significant challenges currently facing humanity in the 21st century. It is defined as a major alteration in the climate patterns of the Earth, characterized by changes in temperature, precipitation and other atmospheric conditions over an extended period of time (Pachauri et al. 2014). The primary drivers of climate are human activities, particularly the burning of fossil fuels, deforestation and industrial processes (Brosch, 2021; Perrier et al. 2005; Pollack et al. 1998). Such activities result in an increase in atmospheric greenhouse gases, thereby contributing to

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global warming and a multitude of adverse environmental impacts (Jeffry et al. 2021). The effects of climate change are far-reaching and complex, impacting ecosystems, human health, and economic stability in a multitude of ways (Yang et al. 2022).

The increase in global temperatures has resulted in a rise in the frequency and severity of weather events, including hurricanes, droughts and floods. These have caused disruption to communities and widespread destruction (Marsooli and Lin, 2020). Moreover, shifts in climate patterns present a significant challenge to biodiversity, as numerous species grapple with the difficulties of adapting to swiftly evolving habitats and modified nutritional resources. Additionally, the societal and economic consequences of climate change are far-reaching and pervasive (Dietz et al. 2024). Those in vulnerable populations, particularly in developing countries, face an elevated risk to their livelihoods, food security, and access to clean water. The potential for health concerns to be exacerbated, such as the spread of infectious diseases and heat-related illnesses, is also heightened by climate change (Taconet et al. 2020). As the global community addresses these challenges, the necessity for prompt and collective action to mitigate climate change and adapt to its unavoidable effects has never been more pressing. A comprehensive understanding of the complexities of this phenomenon is essential for the development of effective policies and strategies for a sustainable future. The shrinking of lakes represents a significant environmental issue that is reflective of broader changes in climate and land use, with profound implications for both ecosystems and human communities which are directly related with climate change (Kiage and Douglas, 2020). As the size of freshwater bodies decreases, the impact extends not only with the loss of water volume but also disturbing complex ecological balances and endangers biodiversity.

Lake shrinkage is also an important issue when considering the United Nations Sustainable Development Goals (UN SDGs). The 17 SDGs aim to address global challenges and promote sustainable development, with specific goals related to water resources, climate action, and ecosystem conservation. For example, Goal 6 (clean water and sanitation) emphasizes the need to ensure the availability and sustainable management of water resources, which is directly affected by the shrinking of lakes. As lakes shrink, the quality and availability of freshwater for drinking, agriculture, and sanitation are compromised, threatening the health and livelihoods of surrounding communities. In addition, lake shrinkage is closely linked to Goal 13 (Climate Action) because it reflects the broader impacts of climate change, such as changes in precipitation patterns and increased evaporation rates. In addition, the ecological consequences of lake shrinkage, including biodiversity loss and habitat degradation, are linked to Goal 15 (Life on Land), which calls for the protection, restoration and sustainable use of terrestrial ecosystems.

Addressing lake shrinkage is critical not only to achieving these interrelated goals, but also to building resilience in communities that rely on these vital freshwater resources, ultimately contributing to a sustainable and equitable future. As computing technologies and software continue to advance, lake shrinkage studies have evolved significantly. Remote sensing, Geographic Information Systems (GIS), and high-resolution satellite imagery have provided new ways to monitor and analyze lake levels and surfaces (Bastawesy et al. 2008; Kimijima et al. 2020). As a part of these new tools to use, support vector machine (SVM) and ISO cluster classification of Landsat images provided that the Al-Razzazah Lake in Iraq experienced an 84.1% decline in surface area and a 63.4% reduction in shoreline length between 1989 and 2019 (Jumaah et al. 2022). Another study focusing on Lake Burullus in Egypt using an ISODATA classification of Landsat images between 1985 and 2020 provided an insight about the %44.8 loss of lake surface (Keshta et al. 2022). A synthesis approach known as modeling lake water changes model (LWC-model) was proposed by another study using a temporal Landsat data showed a %58.2 water surface reduction for the Lake Urmia, Iran (Emami and Zarei, 2021). In the literature, there are many tools available for analyzing changes and shifts in lake boundaries, but Google Earth and related tools are very commonly preferred by various researchers (Amani et al. 2020; Li et al. 2022; Pang et al. 2024; Yan et al. 2021; Zhao et al. 2024). These technologies have improved the ability to accurately assess the shrinkage of lake boundaries and to track changes over time. Additionally, data analysis and modeling software allows for complex simulations and scenarios to understand how climate change and human activities affect lake ecosystems. As a result, conservation strategies and management plans can be developed with more comprehensive and detailed data on lake shrinkage. These advances help both scientists and policymakers achieve sustainable water management and ecosystem protection goals.

Considering climate change and its widespread impacts, this study focuses on lake shrinkage, specifically changes at Gölcük lake, Simav, Kütahya, Türkiye (Figure-1). The aim of this research is to assess the extent of shrinkage of the lake's boundary between the years 2013 and 2023, a period that has witnessed significant climatic variations.

High-resolution Google Earth images with 30-cm spatial pixel resolution from both years, which provide detailed visual data to facilitate accurate measurements, are used to conduct this analysis. The study employs supervised learning methods, a powerful approach to machine learning that uses labeled data sets to train algorithms to detect patterns and make predictions. The results of this study will contribute to the broader discourse on the impacts of climate change and inform sustainable management practices aimed at mitigating the adverse effects of lake shrinkage.

2. Materials and Methods

2.1 Study Area

Gölcük lake, which is located about 5 km north of Simav district center of Kütahya province, is classified as a tectonic lake (Ocakoğlu et al. 2022). It is situated to the south of the Simav Plain and is influenced by the surrounding topography, including Simav Mountain to the south, Gölcük to the northeast, Akdağ to the northwest and Şaphane Mountain to the east. The streams flowing from these mountains, along with the seasonal rainfalls, contribute to the water resources of the Simav River, which are supports the hydrology and water cycle of the Gölcük lake. The drying process of Gölcük Lake, which began in 1961, took approximately 20 years to complete, and by the 1980s, the dried lakebed was being used for agriculture purposes. Administrative issues regarding the lake area emerged in the 1970s. Initially, with the decision of the Council of Ministers dated 23.09.1977 and numbered 77/13966, published in the Official Gazette dated 27.10.1977 and numbered 16607, the Simav Land and Agricultural Reform Region was declared in accordance with Law No. 1757 on Land and Agricultural Reform which was later repealed. The most significant feature of the Gölcük Lake is that agriculture has been conducted without the use of irrigation or fertilizers. For this reason, the soil of the lakebed holds great importance for the local community. Beans are the most commonly cultivated crop on the leased lakebed. Between 1960 and 1990, the lakebed was the most productive agricultural land in the region. However, since 2005, a decline in productivity has been observed due to factors such as the contamination of the area with domestic and chemical waste, problems arising from leasing, and improper farming practices. While 750–800 kg of dry beans per decare were harvested between 1970 and 1980, this value has dropped below 100 kg per decare in recent years. With this decline in productivity, beans, which were the most commonly grown crop in the region, have been replaced by corn, sunflower, wheat, sugar beet, and poppy. Most of the beans grown on the lakebed are produced by farmers for their own use (Personal Communication). No depth measurements have been recorded to monitor changes in the water level of the lake over the years. Gölcük lake and its surrounding area also serve as a recreational site, making it an important cultural and tourist center in the region.

2.2 Data Collection

In order to assess the boundary shifts of Gölcük lake over an optimal date range, Google Earth images with a 30 cm pixel resolution from 28/04/2013 and 12/09/2023 were used. The high resolution of these images enables a comprehensive assessment of changes in the land cover features of the study area. The generalized flowchart of the study is shown in Figure 2 including all steps followed in this study.

2.3 Data Processing

Image processing, spatial analysis, and similar techniques are fundamental tools for earth scientists working with aerial, spatial, and georeferenced data. ArcGIS Pro, developed by ESRI, is the most professional tool on the market for this purpose. It is used by many researchers in earth science fields such as natural hazards, environmental geology, engineering geology, and even in rock mechanics for image processing, creating distribution maps, and assessing spatial data (Acar and Özkul, 2020; Acar and Zengin, 2023; Öngen and Ergüler, 2020; Öngen and Zengin, 2025; Zengin, 2023a, 2023b; Zengin and Erguler, 2022). By default, Google Earth images are not georeferenced which prevents working with coordinated spatial dataset and satellite images. For this reason, the first step is to georeference images from both dates prior using them in ArcGIS Pro. To accomplish this, the georeferencing tool in ArcGIS Pro was used with four control points to increase the accuracy between the two images and the spatial outputs of the analysis. These control points were selected based on distinct and clearly identifiable features, such as road intersections and building corners, visible in both the satellite images and the reference maps. The accuracy of the georeferencing process was evaluated by calculating the Root Mean Square (RMS) error.

2.4 Supervised Classification

It is possible to perform both supervised and unsupervised classification with spatial analysist extension provided within the multivariate toolset. Image classification toolbar provides user-friendly hands-on environment for creating a training samples which will be used for classification of the input image along with signature files.

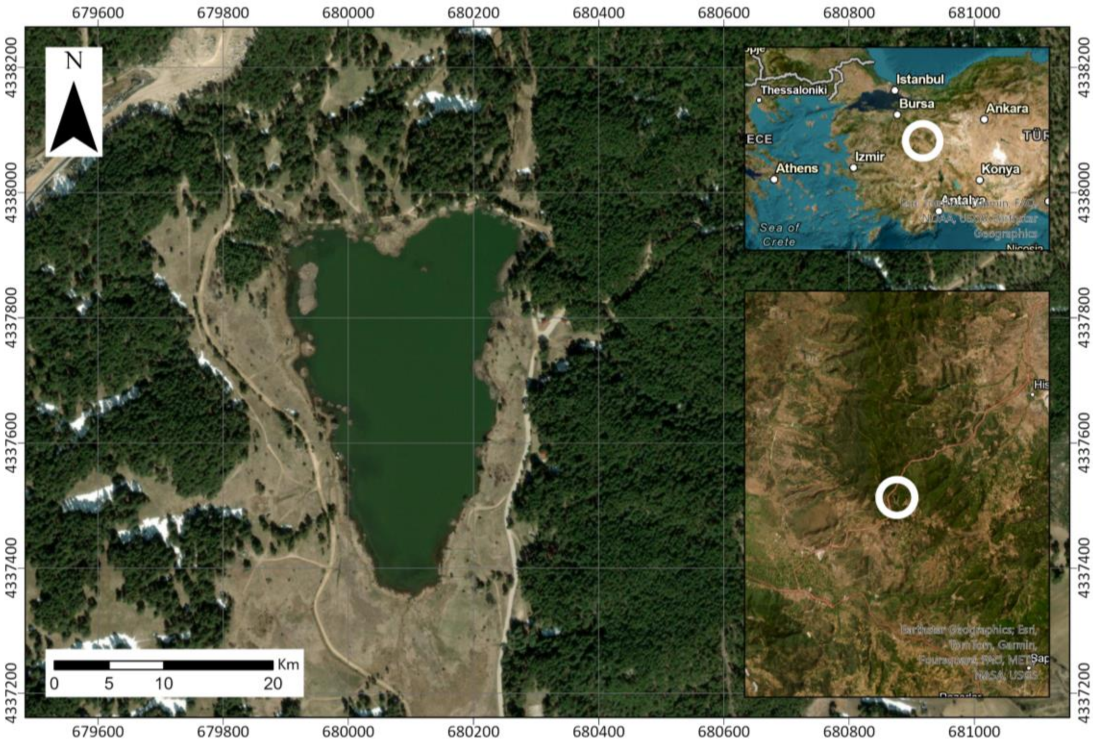

Figure 1. Aerial view of Gölcük lake and its surroundings.

In supervised classification, training samples are used to identify each class based on user-defined criteria. In this study, the National Land Cover Database 2011 (NLCD2011) was chosen to determine the land cover classes. Although NLCD2011 contains 9 classes, only 5 were used to match the land cover features in the study area:

- *Water:* Areas of open water with minimal or no vegetation.
- *Developed:* Areas primarily vegetated with some constructed materials.
- *Barren:* Regions with sparse vegetation, largely consisting of exposed rock, soil, or sand.
- Forest: Regions dominated by evergreen trees.
- *Herbaceous:* Areas covered predominantly by grass-like or herbaceous vegetation.

The image classification process involved the identification of distinct land cover classes based on their unique pixel characteristics and sample RGB values, which represent the most characteristic pixels for each class. The classes, listed in alphabetical order, are as follows: Barren (RGB: 189-193-194), Developed (RGB: 221-219-232), Evergreen (RGB: 20-32-46), Herbaceous (RGB: 119-105-104), and Water (RGB: 5-1-48). These RGB values were selected as representative samples to ensure accurate differentiation and effective classification of the land cover types within the study area.

After creating the training samples, a signature file can be generated to store the defined class zones along with their statistical information. At this stage or after classification, if necessary, the training samples can be redefined or corrected. Support Vector Machine (SVM) is a popular supervised classification algorithm used within the Image Classification toolbar to differentiate between classes in remote sensing data. SVM is effective for classifying high-dimensional data, making it suitable for complex datasets in land cover, vegetation, and urban studies (Noble, 2006; Pisner and Schnyer, 2020; Schölkopf, 1998). In ArcGIS Pro, SVM can classify multiband imagery or segmented raster inputs by creating a hyperplane that best separates data into predefined classes by the users. It is particularly advantageous for its ability to handle noisy data, correlated bands, and imbalanced training samples, requiring fewer samples than other methods like maximum likelihood classification. For segmented rasters, SVM calculates additional attributes such as converged color, mean digital number, standard deviation, compactness, and rectangularity to enhance classification accuracy. The results are output as an Esri classifier definition file (.ecd), which contains all statistical and classification details. SVM is highly suitable for applications like land cover mapping, water body extraction, and environmental monitoring, making it a preferred choice for researchers working with complex datasets in diverse geographic and environmental contexts. The effective use of SVM and its capabilities makes it ideal for working with mixed or overlapping land features, as in this study.

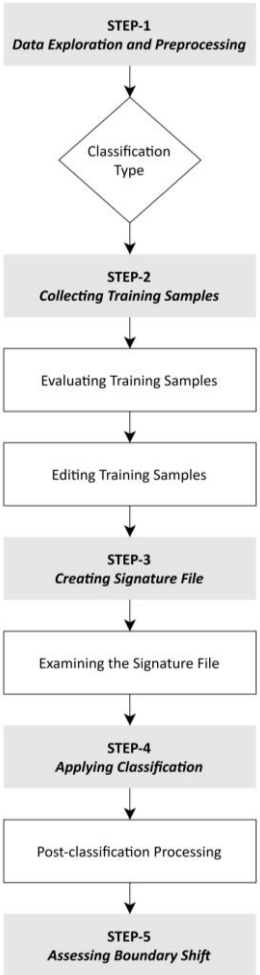

Figure 2. Flowchart illustrating the methodology used in the study, including followed steps.

2.5 Change Detection

Following classification, the lake boundaries from 2013 and 2023 were extracted and converted from raster to polygon in ArcGIS to calculate the area covered by each class. A change detection analysis was performed to quantify the shrinkage of the lake boundary by focusing only the *"water"* in the study area. The changes in area were then calculated to determine the extent of shrinkage, and a spatial overlay was conducted to visualize the differences between the two time periods.

2.6 Accuracy Analysis

The accuracy assessment of satellite-derived maps, including land use and land cover maps, from various sources such as Google Earth Pro, is a crucial step in remote sensing data processing to ensure the quality and reliability of the generated maps (Rwanga et al. 2017). As suggested by different studies, the accuracy assessment of satellite imagery involves three fundamental steps: determining the sample size and sampling method, collecting reference data, and using a confusion matrix to evaluate classification metrics (Chaaban et al. 2022). There are various sampling methods commonly used in the accuracy assessment of satellite maps, including simple random sampling, stratified random sampling (SRS), equalized stratified random sampling (ESR), stratified even sampling, cluster sampling, and systematic sampling (Dong et al. 2020). In this study, the stratified random sampling method was chosen. Stratified random sampling ensures that randomly distributed points are created within each class, with the number of points proportional to the relative area of the class. To enhance the reliability of the results, over 100 sampling points were generated, and ground truth values were subsequently added to the attribute table. Then, a confusion matrix was created to compare the reference and classified data. By implementing the confusion matrix for two separate classification results from 2013 and 2023, accuracy metrics such as user's accuracy, producer's accuracy, Kappa coefficient, and classification accuracy for each class were derived. Confusion matrix for the years 2013 and 2023 given in Table 1 and Table 2 respectively.

Table 1. Confusion matrix for the year 2013.

Class	Water	Barren	Forest	Herbaceous	Total	U_Accuracy	Kappa
Water	16	0	3	0	19	0.84	0
Barren	0	7	0	3	10	0.70	0
Forest	1	0	45	3	49	0.92	0
Herbaceous	0	0	3	25	28	0.89	0
Total	17	7	51	31	106	0	0
P_Accuracy	0.94	1	0.88	0.81	0	0.88	0
Kappa	0	0	0	0	0	0	0.82

Table 2. Confusion matrix for the year 2023.

Class	Water	Developed	Barren	Forest	Herbaceous	Total	U_Accuracy	Kappa
Water	14	0	0	1	0	15	0.93	0
Developed	0	7	0	2	1	10	0.70	0
Barren	0	0	6	0	5	11	0.55	0
Forest	0	0	0	47	2	49	0.96	0
Herbaceous	0	0	0	5	12	17	0.71	0
Total	14	7	6	55	20	102	0	0
P_Accuracy	1	1	1	0.85	0.6	0	0.84	0
Kappa	0	0	0					0.76

3. Results and Discussions

This study aimed to demonstrate the boundary shift of Gölcük Lake using high-resolution Google Earth images from 2013 and 2023 (Figure 3). A five-step flowchart was employed in this study, including *Data Exploration and Preprocessing*, *Collecting Training Samples*, *Creating Signature Files*, *Applying Classification*, and *Assessing Boundary Shifts*. The 30-cm spatial resolution of the Google Earth images used in this study has also increased detail and accuracy of the results. The analysis of Gölcük Lake's boundary changes over the past decade reveals a reduction in lake area. In 2013, the lake covered an area of 142,396 m², which decreased to 110,117 m² by 2023. This reduction represents a shrinkage of approximately 32,279 m², or 22.7%, over ten years (Figure 4). Such a considerable decrease highlights the impact and important of potential environmental and anthropogenic factors on the lake which needs to be investigated further. The use of high-resolution Google Earth images and supervised classification methods provided reliable insights into these changes, underscoring the importance of ongoing monitoring and conservation efforts for Gölcük Lake.

Table-1 presents the accuracy assessment results for the 2013 classification, highlighting the performance of four classes: Water, Barren, Forest, and Herbaceous. The overall classification accuracy is high, with user's accuracy ranging from 70% to 92% and producer's accuracy ranging from 81% to 100%. The Water class achieved a user's accuracy of 84% and a producer's accuracy of 94%, with three misclassifications into the Forest class. The Barren class exhibited the lowest user's accuracy at 70%, due to three samples being misclassified as Herbaceous, but it achieved a producer's accuracy of 100%, indicating that all Barren pixels were correctly identified. The Forest class showed a user's accuracy of 92% and a producer's accuracy of 88%, with most errors occurring in the Water and Herbaceous classes. The Herbaceous class had a user's accuracy of 89% and a producer's accuracy of 81%, with some misclassifications into the Forest and Barren classes. The overall Kappa coefficient of 0.82 indicates a high level of agreement and reliability in the classification. Table-2 provides the accuracy assessment results for the 2023 classification, which includes five classes: Water, Developed, Barren, Forest, and Herbaceous. The overall classification accuracy is high, with user's accuracy ranging from 55% to 96% and producer's accuracy ranging from 60% to 100%. The Water class demonstrated strong performance with a user's accuracy of 93% and a producer's accuracy of 100%, with only one misclassification into the Forest class. The Developed class achieved a user's accuracy of 70% and a producer's accuracy of 100%, though two samples were misclassified as Forest and one as Herbaceous.

The Barren class showed the lowest user's accuracy at 55%, due to misclassifications into the Herbaceous class, despite a producer's accuracy of 100%. The Forest class performed exceptionally well, with a user's accuracy of 96% and a producer's accuracy of 85%, with minor misclassifications into the Herbaceous class. The Herbaceous class had a user's accuracy of 71% and a producer's accuracy of 60%, with some confusion observed in the Barren and Forest classes. The overall Kappa coefficient of 0.76 indicates substantial agreement and reliable classification results. However, noticeable errors between overlapping classes, such as Barren and Herbaceous, and Developed and Forest, could be addressed by incorporating additional spectral bands or auxiliary data like DEMs having a higher spatial resolution similar to used in this study. Overall, the 2023 classification demonstrates robust performance, with room for improvement through enhanced training data and additional contextual information. The temperature data between 1931 to 2023 and precipitation data from 2005 to 2023 were also considered in analyzing the boundary changes of Gölcük Lake (Figure 5).

As can be seen from Figure 3, there is a meteorological station within the proximity of the study area (39°09'57.0"N 29°04'56.0"E). The data prior to the installation of this station near the lake were obtained from the station located in Simav city center (39°07'30.7"N 28°59'30.7"E). Although the time span is relatively short, the average temperature increased from 11.5°C in 2013 to 13°C in 2023 over this decade. During the same period, while there were seasonal fluctuations in precipitation amounts, the overall trend showed a slight decrease. These data, which can be seen as indicators of climate change, may also have contributed to the lake's shrinkage. The temperature and precipitation data were obtained from the Ministry of Environment, Urbanization and Climate and the Turkish State Meteorological Service. Figure 5. illustrates the long-term trends in average temperature (°C) and average precipitation (mm) in the study area. The temperature data, spanning from 1931 to 2023, shows relatively stable values with minor fluctuations until the 1990s, followed by a slight upward trend, suggesting a gradual warming over the decades. The precipitation data, available from 2005 to 2023, displays significant variability, ranging from approximately 400 mm to 700 mm, with a general increasing trend over the period.

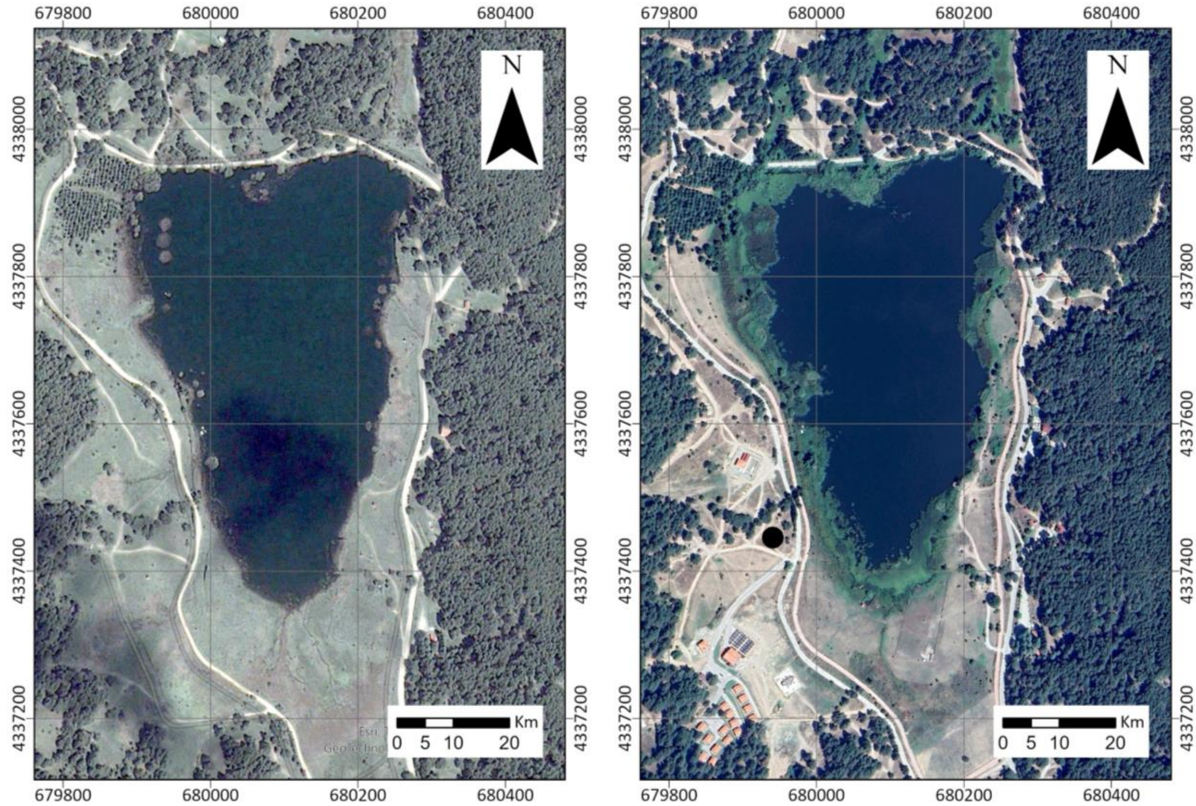

Figure 3. Google Earth images of the Gölcük Lake (Left: 2013 and Right: 2023, Black dot: Meteorological station).

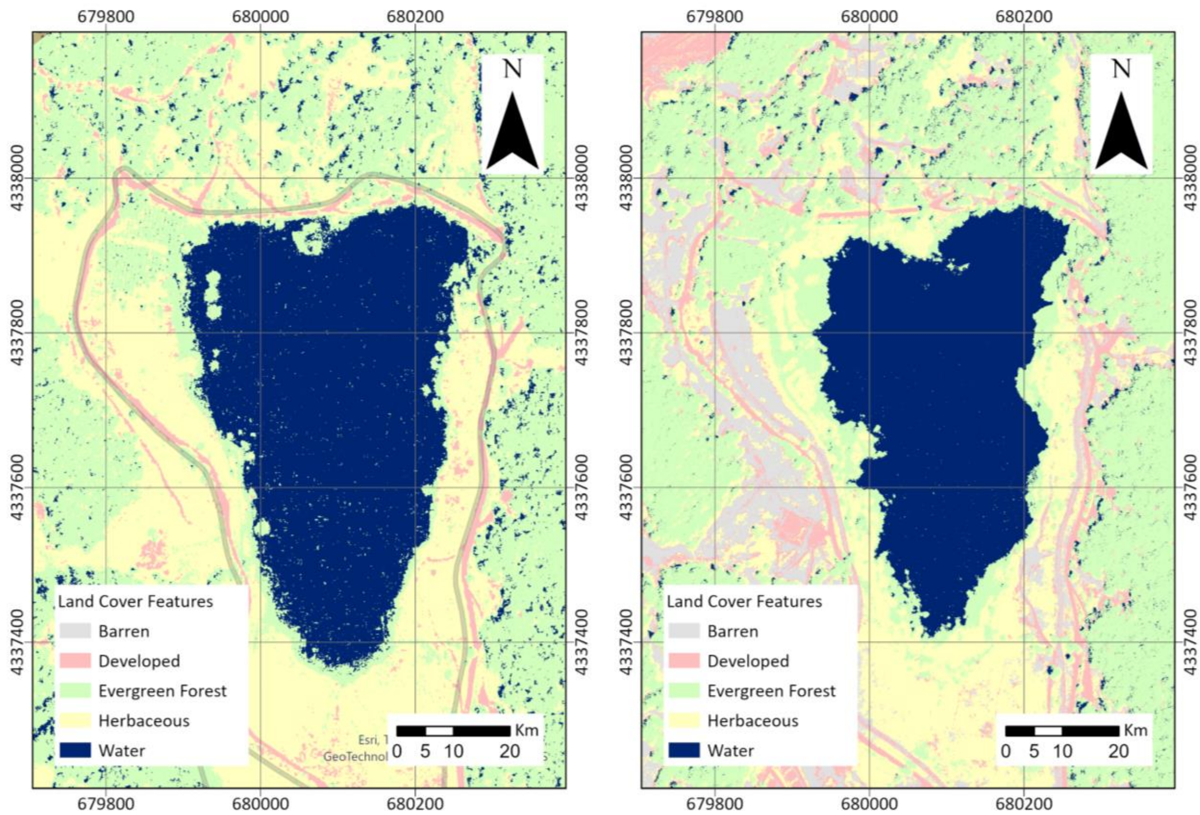

Figure 4. Boundary shifts at Gölcük Lake observed through supervised classification analysis (Left: 2013 and Right: 2023).

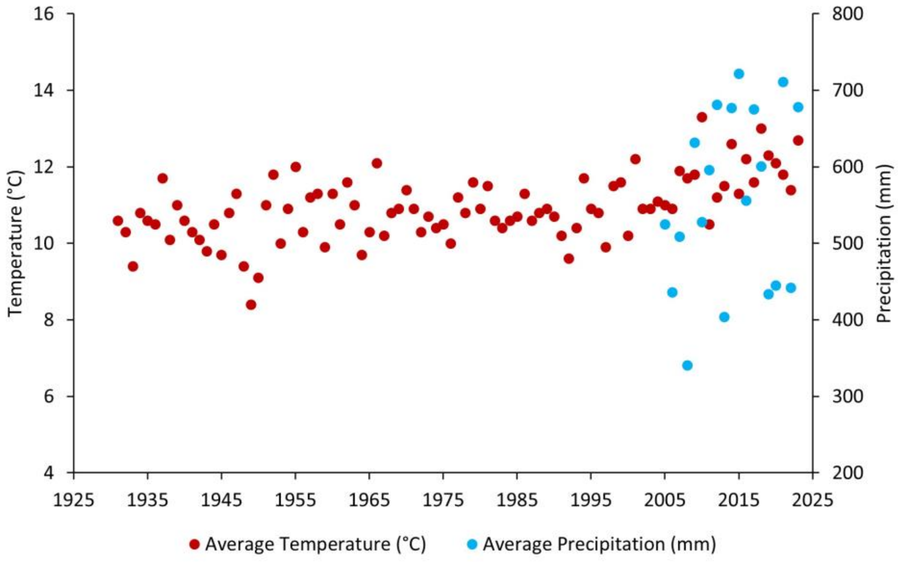

Figure 5. Annual average temperature and precipitation trends for the Gölcük Lake region from 2013 to 2023.

These trends indicate a potential correlation between rising temperatures and increased precipitation in recent years, reflecting possible impacts of climatic changes in the region. Further statistical analysis is required to confirm these observations and assess their implications considering regional rainfall, water resource status and basin regions.

4. Conclusions

In conclusion, this study successfully assessed the boundary shifts of Gölcük Lake over the period from 2013 to 2023 using high-resolution Google Earth images and advanced supervised classification techniques in ArcGIS Pro. The results indicate a significant reduction in lake area, amounting to approximately 32,279 m² or 22.7% shrinkage, highlighting the impact of potential environmental changes. In studies where a similar approach to the one used in this study was applied, high coefficients were achieved, particularly in identifying lake surfaces (Yang et al. 2012). Google Earth images are also utilized for semi-automatic mapping of temporal changes in lake boundaries with high resolution. The successful results achieved, particularly in glacial lakes, make this approach a widely preferred option in areas lacking high-resolution sources such as Landsat and Sentinel (Beck et al. 2013). Drone images in RGB format with similar resolution to Google Earth images have also been used in boundary delineation and analysis studies related to lakes (Buchsteiner et al. 2023). In this study, the usability of RGB-format Google Earth images as an alternative to multispectral satellite images for detecting changes in lake boundaries studied. The images were found to be particularly successful in distinguishing the boundaries of wetlands; however, due to the RGB format of the data source, some limitations were observed in separating barren, developed, and herbaceous areas. Additionally, the analysis considered temperature and precipitation trends, with findings suggesting that rising temperatures and decreasing precipitation may have contributed to this shrinkage, potentially influenced by climate change. This study emphasizes the importance of continued monitoring and conservation efforts for Gölcük lake, serving as a case study for understanding the broader implications of climate change on freshwater resources. By integrating remote sensing and GIS tools, this research provides a reliable methodology for lake boundary monitoring, supporting the development of sustainable management practices in response to ongoing environmental changes.

Declaration of Ethical Standards

The authors declare that they have complied with all ethical standards.

Credit Authorship Contribution Statement

Author-1: Conceptualization, Methodology, Data curation, Software, Validation, Writing – Original Draft, Writing – Review & Editing, Visualization.

Author-2: Conceptualization, Methodology, Validation, Writing – Original Draft.

Author-3: Conceptualization, Methodology, Validation, Writing – Original Draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

Data will be made available upon reasonable request.

Acknowledgement

The authors would like to express their gratitude to the reviewers for their constructive comments and valuable suggestions, which have significantly contributed to improving the quality of this manuscript. Additionally, the authors thank Kütahya Dumlupınar University for providing licensed access to the ArcGIS Pro software through the BAP project, funded by the Kütahya Dumlupınar University Scientific Research Projects Coordination Office under grant number #2024-01.

5. References

Acar, R.U. and Özkul, C., 2020. Investigation of heavy metal pollution in roadside soils and road dusts along the Kütahya–Eskişehir Highway. *Arabian Journal of Geosciences*, **13**, 216. https://doi.org/10.1007/s12517-020-5206-2

Acar, R.U. and Zengin, E., 2023. Performance Assessment of Landsat 8 and Sentinel-2 Satellite Images for the Production of Time Series Land Use/Land Cover (LULC) Maps. *Journal of Scientific Reports-A*, **53** 1–15. https://doi.org/10.59313/jsr-a.1213548

Amani, M., Ghorbanian, A., Ahmadi, S.A., Kakooei, M., Moghimi, A., Mirmazloumi, S.M., Moghaddam, S.H.A., Mahdavi, S., Ghahremanloo, M., Parsian, S., Wu, Q. and Brisco, B., 2020. Google Earth Engine Cloud Computing Platform for Remote Sensing Big Data Applications: A Comprehensive Review. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, **13**, 5326–5350. https://doi.org/10.1109/JSTARS.2020.3021052

Bastawesy, M.A., Khalaf, F.I. and Arafat, S.M., 2008. The use of remote sensing and GIS for the estimation of water loss from Tushka lakes, southwestern desert, Egypt. *Journal of African Earth Sciences*, **52**, 73–80. https://doi.org/10.1016/j.jafrearsci.2008.03.006

Beck, M.W., Vondracek, B., Hatch, L.K. and Vinje, J., 2013. Semi-automated analysis of high-resolution aerial images to quantify docks in glacial lakes. *ISPRS Journal of Photogrammetry and Remote Sensing,* **81**,60–69. https://doi.org/10.1016/J.ISPRSJPRS.2013.04.006

Brosch, T., 2021. Affect and emotions as drivers of climate change perception and action: a review. *Current Opinion in Behavioral Sciences*, **42**, 15–21. https://doi.org/10.1016/J.COBEHA.2021.02.001

Buchsteiner, C., Baur, P.A. and Glatzel, S., 2023. Spatial Analysis of Intra-Annual Reed Ecosystem Dynamics at Lake Neusiedl Using RGB Drone Imagery and Deep Learning. *Remote Sensing*, **15**, Page 3961 15, 3961. https://doi.org/10.3390/RS15163961

Chaaban, F., El Khattabi, J. and Darwishe, H., 2022. Accuracy Assessment of ESA WorldCover 2020 and ESRI 2020 Land Cover Maps for a Region in Syria. *Journal of Geovisualization and Spatial Analysis*, **6**, 1–23. https://doi.org/10.1007/s41651-022-00126-w

Dietz, T., Shwom, R.L., Whitley, C.T., 2024. Climate Change and Society. *Annual Review of Sociology*, **46**, 15. https://doi.org/10.1146/annurev-soc-121919

Dong, S., Chen, Z., Gao, B., Guo, H., Sun, D. and Pan, Y., 2020. Stratified even sampling method for accuracy assessment of land use/land cover classification: a case study of Beijing, China. *International Journal of Remote Sensing*, **41**, 6427–6443. https://doi.org/10.1080/01431161.2020.1739349

Emami, H. and, Zarei, A., 2021. Modelling lake water's surface changes using environmental and remote sensing data: A case study of lake Urmia. Remote Sensing Applications, **23**, 100594. https://doi.org/10.1016/J.RSASE.2021.100594

Jeffry, L., Ong, M.Y., Nomanbhay, S., Mofijur, M., Mubashir, M. and Show, P.L., 2021. Greenhouse gases utilization: A review. *Fuel,* **301**. https://doi.org/10.1016/j.fuel.2021.121017

Jumaah, H.J., Ameen, M.H., Mohamed, G.H. and Ajaj, Q.M., 2022. Monitoring and evaluation Al-Razzaza lake changes in Iraq using GIS and remote sensing technology. *The Egyptian Journal of Remote Sensing and Space Science*, **25**, 313–321. https://doi.org/10.1016/J.EJRS.2022.01.013

Keshta, A.E., Riter, J.C.A., Shaltout, K.H., Baldwin, A.H., Kearney, M., El-Din, A.S. and Eid, E.M., 2022. Loss of Coastal Wetlands in Lake Burullus, Egypt: A GIS and Remote-Sensing Study. *Sustainability (Switzerland)* **14**,4980. https://doi.org/10.3390/SU14094980/S1

Kiage, L.M. and Douglas, P., 2020. 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*, **709**. https://doi.org/10.1016/j.scitotenv.2019.136022

Kimijima, S., Sakakibara, M., Amin, A.K.M.A., Nagai, M. And Arifin, Y.I., 2020. Mechanism of the rapid shrinkage of limboto lake in Gorontalo, Indonesia. *Sustainability (Switzerland)*, **12**, 1–14. https://doi.org/10.3390/su12229598

Li, K., Wang, J., Cheng, W., Wang, Y., Zhou, Y., Altansukh, O., 2022. Deep learning empowers the Google Earth Engine for automated water extraction in the Lake Baikal Basin. *International Journal of Applied Earth Observation and Geoinformation*,**112**, 102928. https://doi.org/10.1016/J.JAG.2022.102928

Marsooli, R. and Lin, N., 2020. Impacts of climate change on hurricane flood hazards in Jamaica Bay, New York. *Climate Change*, **163**, 2153–2171. https://doi.org/10.1007/s10584-020-02932-x

Noble, W.S., 2006. What is a support vector machine? *Nature Biotechnology*, **24**, 1565–1567. https://doi.org/10.1038/nbt1206-1565

Ocakoğlu, F., Kuzucuoğlu, C., Akbulut, A. and, Çilingiroğlu, Ç., 2022. Lake level changes and paleo-precipitation estimations based on colluvial stratigraphy of Holocene sediments in West Anatolia (Simav Graben). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **597**. https://doi.org/10.1016/j.palaeo.2022.111001

Öngen, A.S. and Ergüler, Z.A., 2020. The effect of urban heat island on groundwater located in shallow aquifers of Kutahya city center and shallow geothermal energy potential of the region. *Bulletin Of The Mineral Research and Exploration,* **165**, 1–24. https://doi.org/10.19111/bulletinofmre.820395

Öngen, A.S. and Zengin, E., 2025. Spatial assessment of urban heat island (UHI) in Kütahya using Landsat-8 satellite data. *Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi*, **14**, 122–131. https://doi.org/10.28948/NGUMUH.1527341

Pachauri, R.K., Meyer, L., Hallegatte France, S., Bank, W., Hegerl, G., Brinkman, S., van Kesteren, L., Leprince-Ringuet, N. and van Boxmeer, F., 2014. *Climate Change 2014 Synthesis Report*, Kristin Seyboth (USA). Gian-Kasper Plattner.

Pang, Y., Yu, J., Xi, L., Ge, D., Zhou, P., Hou, C., He, P. and Zhao, L., 2024. Remote Sensing Extraction of Lakes on the Tibetan Plateau Based on the Google Earth Engine and Deep Learning. *Remote Sensing*, **16**, 583. https://doi.org/10.3390/RS16030583

Perrier, F., Le Mouël, J.-L., Poirier, J.-P. and Shnirman, M.G., 2005. Long-term climate change and surface versus underground temperature measurements in Paris. *International Journal of Climatology*, **25**, 1619–1631. https://doi.org/10.1002/joc.1211

Pisner, D.A. and Schnyer, D.M., 2020. Support vector machine. Machine Learning: Methods and Applications to Brain Disorders, **2020**, 101–121. https://doi.org/10.1016/B978-0-12-815739-8.00006-7

Pollack, H.N., Huang, S., Shen, P.-Y., 1998. Climate Change Record in Subsurface Temperatures: A Global Perspective. *Science*, **282**, 279–281. https://doi.org/10.1126/science.282.5387.279

Rwanga, S.S., Ndambuki, J.M., Rwanga, S.S., Ndambuki, J.M., 2017. Accuracy Assessment of Land Use/Land Cover Classification Using Remote Sensing and GIS. *International Journal of Geosciences*, **8**, 611–622. https://doi.org/10.4236/IJG.2017.84033

Schölkopf, B., 1998. SVMs - A practical consequence of learning theory. *IEEE Intelligent Systems and Their Applications*, **13**, 18–21. https://doi.org/10.1109/5254.708428

Taconet, N., Méjean, A., Guivarch, C., 2020. Influence of climate change impacts and mitigation costs on inequality between countries. *Climatic Change*, **160**, 15–34. https://doi.org/10.1007/s10584-019-02637-w

Yan, Y., Zhuang, Q., Zan, C., Ren, J., Yang, L., Wen, Y., Zeng, S., Zhang, Q., Kong, L., 2021. Using the Google Earth Engine to rapidly monitor impacts of geohazards on ecological quality in highly susceptible areas. *Ecological Indicators* ,**132**, 108258. https://doi.org/10.1016/J.ECOLIND.2021.108258

Yang, M., Chen, L., Wang, J., Msigwa, G., Osman, A.I., Fawzy, S., Rooney, D.W., Yap, P.S., 2022. Circular economy strategies for combating climate change and other environmental issues. *Environmental Chemistry Letters*, **21**, 55–80. https://doi.org/10.1007/S10311-022-01499-6

Yang, X., Jiang, G.M., Luo, X., Zheng, Z., 2012. Preliminary mapping of high-resolution rural population distribution based on imagery from Google Earth: A case study in the Lake Tai basin, eastern China. *Applied Geography*, **32**, 221–227. https://doi.org/10.1016/J.APGEOG.2011.05.008

Zengin, E., 2023a. Inundation risk assessment of Eastern Mediterranean Coastal archaeological and historical sites of Türkiye and Greece. *Environmental Monitoring Assessment*, **195**. https://doi.org/10.1007/s10661-023-11549-3

Zengin, E., 2023b. A Combined Assessment of Sea Level Rise (SLR) Effect on Antalya Gulf (Türkiye) and Future Predictions on Land Loss. *Journal of the Indian Society of Remote Sensing*, **51**, 1121-1133. https://doi.org/10.1007/s12524-023-01694-0

Zengin, E., Erguler, Z.A., 2022. Experimental investigation of pore-fracture relationship on failure behaviour of porous rock materials. *Bulletin of Engineering Geology and the Environment,* **81**, 351. https://doi.org/10.1007/s10064-022-02857-y

Zhao, Z., Islam, F., Waseem, L.A., Tariq, A., Nawaz, M., Islam, I.U., Bibi, T., Rehman, N.U., Ahmad, W., Aslam, R.W., Raza, D., Hatamleh, W.A., 2024. Comparison of Three Machine Learning Algorithms Using Google Earth Engine for Land Use Land Cover Classification. *Rangeland Ecology & Management*, **92**, 129–137. https://doi.org/10.1016/J.RAMA.2023.10.007