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Remote Sensing-Based Evaluation of Lake Area Dynamics: A Quantitative Assessment for Environmental Management in Turkey

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ABSTRACT

This research employs remote sensing techniques and advanced image processing algorithms to analyze lake level changes. The study focuses on two major lakes in Turkey, Burdur and Salda, using satellite imagery from 2000 to 2024. The primary objective is to investigate spatial and temporal surface area changes over a one-year period. A key step in the process involves identifying water pixels in infrared band images through binarization and image processing, enabling accurate measurements of lake sizes and shapes. The results were evaluated using three criteria: R^2, RMSE, and MAPE. Findings showed that Burdur Lake experienced a 1.47% decrease, while Salda Lake had a smaller decline of 0.307% in 2024, attributed to drought and water resource availability.

1. Introduction

Lakes are also essential bio-physical environments hosting a diverse number of organisms particularly fish, birds, amphibians as well as various aquatic taxa. Lakes as the elements of the hydrologic cycle are regulators and reservoirs of water with the concurrent processing and attenuation of anthropogenic and natural pollutions [1]. Lakes constitute about 70 % of the world supply of freshwater used in irrigation and this figure highlights the roles played by lake in agricultural productivity and other ecological sustainability [2].

This means that the management of the lake area should be made effective. Monitoring of these surface-area variations is essential to the improvement of governance of water-resources especially with the impact of changes in climates. Flood threats can be alleviated through strategic water-management interventions that include calibration of water flows when integrated with the surface-areas surveillance. It is also possible to sustain lake-surface-area monitoring to help gain sub-substantial understanding concerning hydrologic processes, ecological dynamics, and climatic

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variations [3-5]. The spatial continuity, supported by the temporal resolution through satellite imagery and remote-sensing methods, provides an ideal platform of documenting such changes to decadal levels [6]. Today, the achievements of remote sensing in the field of monitoring the surface area of lakes have progressed and provide views with more details [7]. The advancement of remote sensing technology has completely revamped the way we monitor the surface area of lakes, giving us access to invaluable resources and cutting-edge techniques for collecting data efficiently [8-10].

Many studies have been done so far to control and evaluate the lake's surface area. Al-lami *et al.,* [11] to evaluate the changes in the area of Razzaz Lake, used satellite images and NDVI, NDMI, NDWI, and WI indices to extract the water area. Wu *et al.,* [12] for geospatial quantitative analysis volume and area of Aral Lake used satellite images between 1987-2018 and the NDWI index. Chipman [13] for monitoring the trend of area, volume, and water level of the Toshka Lake in Egypt used NDLI and ELI indices to identify water areas. Albarqouni *et al.,* [14] used satellite images to investigate the relationship between temporal-spatial changes and water temperature (LSWT) Burdur, Egirdir, and Beysehiri Lakes surface in Turkey.

Managing the expanse of lakes in dry locations like Turkey is crucial for conserving water, strengthening resistance to drought, averting salinization, and sustaining harmony within the ecosystem. The primary goal of this research was to identify and examine the fluctuations in water surface size and shape alterations of Lake Burdur and Salda in Turkey, within the Lakes Region, utilizing Landsat imagery on the Mathematica software. Also, in this study, by examining the shape of the lake and the extent of its changes from different directions, the greatest or least regional changes are estimated. It should be mentioned that no such study has been done on selected lakes.

2. Methodology

2.1 Study areas

For this research, we selected Lakes Burder and Salda in Turkey (Figure 1). We selected these lakes based on the ease of access to data and the absence of active control over the surface area of the lake, and most importantly, the changes that have occurred in recent years. A summary of the characteristics of the lakes used is given in Table 1.

Lake Burdur is a tectonic salty lake in the southwest of Turkey, covering Burdur and Isparta provinces and is located near the center of the Turkish Lakes Region. It is approximately 250 square kilometers in area and of an average of 50-110 meters in depth thus making it one of the largest and deepest lakes in Turkey [15]. It has alkaline and salty waters and never freezes in the winter and is about 845 meters largely above the waves, with a pH of approximately 9.5, providing birds with a crucial habitat, giving many birds species that winter there much-needed sanctuary.

Lake Salda is another crater lake smaller than others, located in Yeşilova, Burdur Province. It covers about 43.7 to 45 square kilometers and is situated at an elevation of approximately 1139 to 1316 meters above sea level. It is one of Turkey's deepest lakes, with a maximum depth ranging from 184 to 196 meters, making it the third deepest in the country. The lake is highly alkaline, with a pH between 8 and 10, and is rich in magnesium. Its shores are covered with white sandy beaches composed of hydromagnesite mineral, which is rare and has drawn scientific interest due to its similarity to minerals found on Mars' Jezero crater.

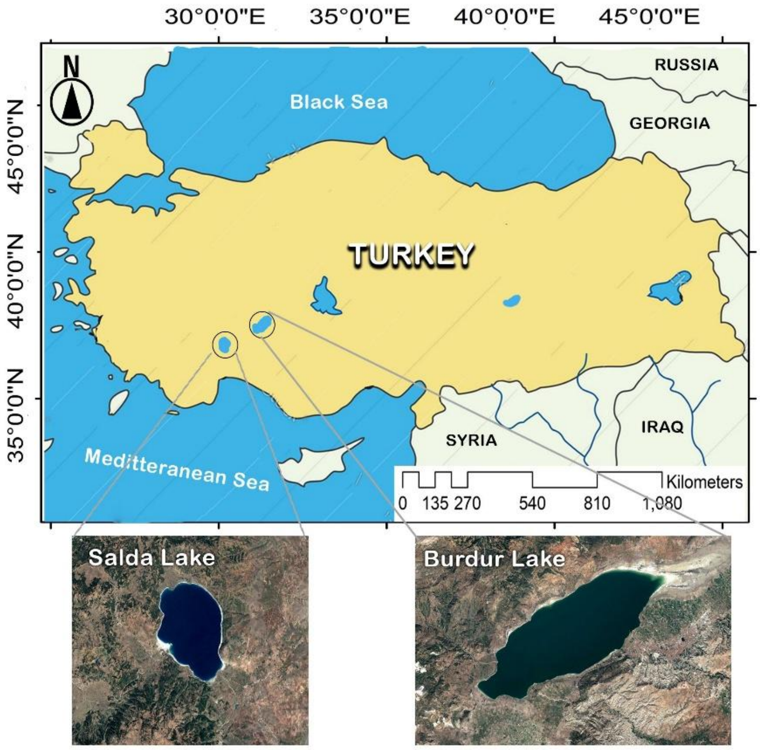

Fig. 1. The Lakes distribution (1) Burdur, and (2) Salda in Turkey

Table 1
Specifications for two selected lakes

Lake	Maximum Area (km2)	Type	Maximum Depth (m)	Surface Elevation (m)	Purpose of Use
Burdur	156.66	Saline	110	845	Tourism, surrounding agricultural lands
Salda	44.767	Highly Alkaline	196	1193	Tourism, fishing, drinking water

2.2 Data description

Our investigation into transformations within the study area spanning from 2000 to 2024 involved acquiring diverse scenes from the US Geological Survey (USGS) Global Visualization Viewer utilizing data from the Landsat dataset, employing a total of infrared 48 Landsat images for evaluation and mapping purposes. we used the Landsat look under the supervision of USGS to obtain the images (https://landsatlook.usgs.gov/explore).

2.3 Water body detection

In the first step, infrared satellite images with high resolution and minimum cloudiness were extracted. Image scaling plays an important role in estimating lake area changes in this study. On the other hand, all the tasks related to image processing and calculations were done using Mathematica software.

In this study, the key approach and method to detect the water body of the lake is the binarization of images. This process consists of dividing the pixels into white and black groups. In the binarization method, a threshold limit is specified, and the pixels within that range are assigned the number one (white), and the pixels outside that range are assigned the number zero (black) [16]. This segmentation improves the analysis of features in the image. At this stage, the pixels that are related to the lake are marked in white and the pixels that are areas other than the lake are marked in black.

Then, the areas where the lake water has increased or decreased are identified by comparing graphically and overlaying historical images.

2.4 Estimation of surface area

After processing the images and determining the water body of the lake, the area of each pixel is calculated based on the determined scale and in square kilometres. To complete this procedure, it was necessary to determine the Euclidean distance between two specific points on the scale.

$$ED = \sqrt{\text{Abs}[a-x]^2 + \text{Abs}[b-y]^2} \tag{1}$$

$$Scale\ Factor = \frac{ED}{Sc} \tag{2}$$

Sc denotes the true scale of the image, measured in kilometers squared. Following this, the size of every individual pixel was determined based on the equation:

$$Pixel\ Area = \frac{1}{Scale\ Factor^2} \tag{3}$$

After determining the area of each pixel, the total number of white pixels corresponding to the lake is counted. By multiplying the area of each pixel by the number of white pixels, the total area of the lake is determined in square kilometers for each lake. The flowchart of the steps carried out in this research to determine the surface area and its changes is shown in Figure 2.

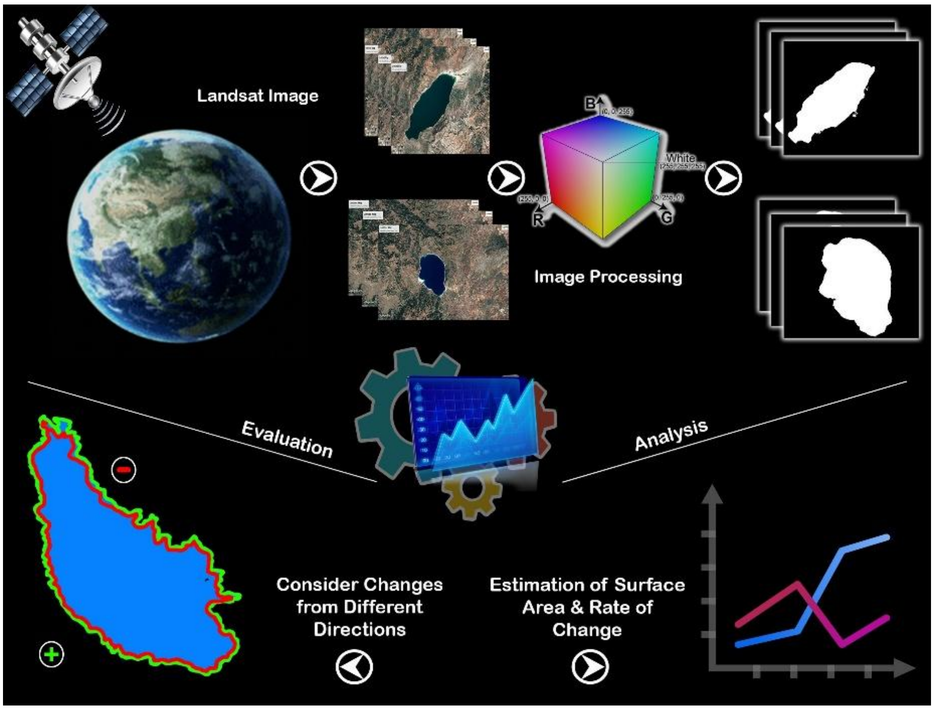

Fig. 2. Flowchart of the steps performed in this research

3. Results

3.1 Statistical and regression analysis

This article gauged the accuracy of the estimated water surface areas from 2000 to 2024 by juxtaposing data derived from Landsat images against outcomes produced by the binarization process. Also, to check and evaluate the areas estimated by the binary method, Root Mean Squared Error (RMSE), coefficient of determination (R2), and mean absolute percentage error (MAPE) criteria were used. The information in Table 2 provides a condensed overview of the results, highlighting the range of lake area values observed during the research timeframe.

Table 2
Resulting accuracy evaluation of the calculated surface area

Lale	Minimum area (km²)	Maximum area (km²)	RMSE (km2)	R2	MAPE
Burder	122.23	156.85	5.573	0.806	3.307
Salda	43.17	44.76	1.152	0.872	0.809

According to Table 2, it is clear that the proposed method in this study has worked better for Salda Lake with RMSE=1.152, R2=0.872, and MAPE=0.809 than Burder Lake with RMSE=5.573, R2=0.806, and MAPE=3.307. Figure 4 shows the scatter plots and evaluation criteria of two lakes. By inferring from the scatter diagram of Salda Lake in Figure 3, it can be seen that the points are less scattered than Burder Lake.

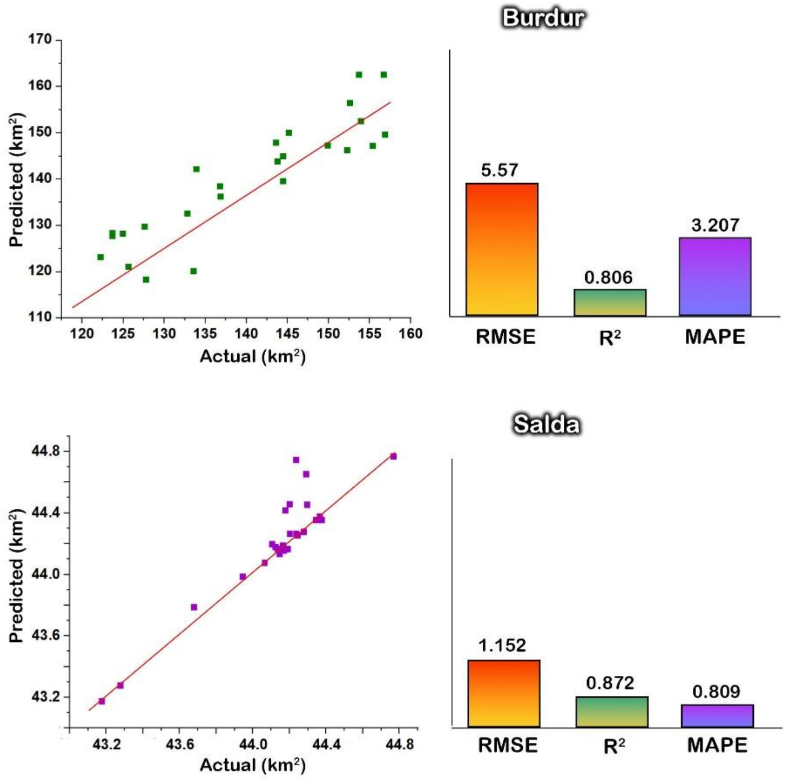

Fig. 3. Scatter plots and evaluation criteria of two selected lakes

Figure 4 shows a box plot between actual and estimated values for two important Turkey lakes. According to the box plot of Salda Lake, the minimum, average, and maximum values for both the actual and estimated values are equal to Min=(43.87, 43.95), Mean=(44.16, 44.28)and Max=(44.76, 44.78). Also, for Burdur Lake Min=(122.23,119.45), Mean=(144.46,144.13) and Max=(156.85,163.89). By comparing the statistical and visual results to estimate the surface area of two lakes, it can be concluded that in general, the method used in this study has performed well for both lakes.

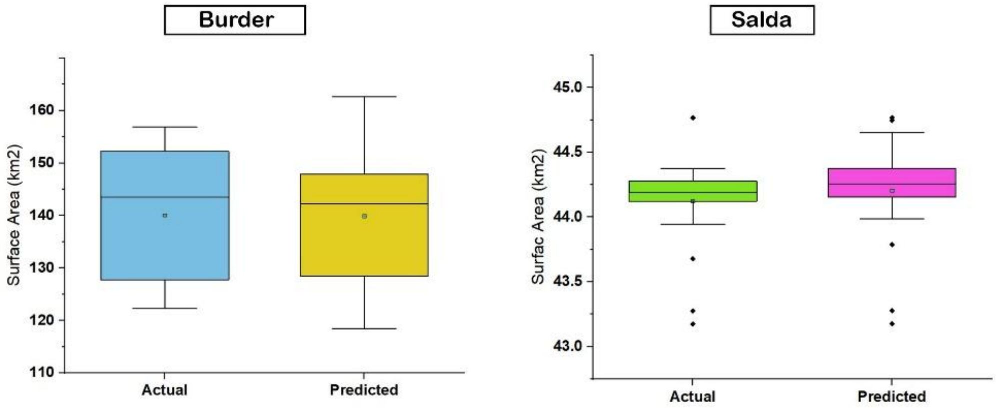

Fig. 4. Box plots and evaluation criteria of two selected lakes

4. Discussion

The primary focus of this study was on utilizing satellite imagery to examine the ever-changing surface water regions of lakes. Compared to traditional in-situ monitoring programs, satellite remote sensing offers a more comprehensive way to collect geographically and temporally dense data for estimating lake surface area. Efficient processing of satellite images within Mathematica software enabled detailed analysis of spatiotemporal changes occurring in the lakes. Most of the studies that have been conducted in the field of monitoring lake surface area with satellite images have used the usual indicators to extract the water area of lakes [1, 14, 17, 18]. There have been limited studies thus far on assessing the size and outline of Turkey lakes. Research has been scarce specifically on surface area monitoring of Lake Burdur and Salda in Turkey. The results from previous research are strikingly similar to those obtained through the binarization-oriented methodology [19].

The Landsat series data stands out with its sophisticated sensors, tailored spectral bands for diverse uses, fluctuating spatial resolutions, and a track record of ongoing advancements in satellite technology for observing Earth [20]. By applying remote sensing technology, which is a useful technique with high capabilities, helps decision-makers and officials by providing significant insight into water level fluctuations over time, at a lower cost and with exceptional performance.

5. Conclusion

The present study discovers useful information about the changes in the surface of two lakes of different dimensions in Turkey by processing satellite images of the past years. As one of the findings of this research, it is possible to mention the decrease in the surface area of Burdur Lake from 133.54 km2 in 2023 to 127.76 km2 in 2024. Also, Salda Lake has reached from 44.23 km2 to 44.103 km2.

Future research can focus on automatic monitoring and early warning systems for fluctuations of lake surface area and investigation of other related parameters such as discharge rate and nutrition, precipitation, and evapotranspiration. Also, the prediction of the lake surface area for the following years can have good effects on future decisions to preserve lakes and properly manage water resources.

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Conflicts of Interest
The authors declare no conflicts of interest.

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