

Assessment of the ecological status of lake Boyuk Ala Gol based on geographic information systems (Case study of Kalbajar District)

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Keywords

*Kalbajar, remote sensing, GIS, spectral
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ABSTRACT

High-altitude lakes (HALs) play an important role in mitigating climate impacts, regulating water resources, replenishing groundwater, and maintaining ecological stability. To prevent the degradation and disappearance of these ecosystems, it is essential to map their spatial extent and monitor changes over time. However, studies on the monitoring of high-altitude wetlands worldwide remain limited, and this topic has not received sufficient attention. In this study, Geographic Information Systems (GIS) and remote sensing techniques were employed to analyze changes in the area of Lake Böyük Ala Göl between 1990 and 2023. A Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) was used to generate slope and Topographic Wetness Index (TWI) maps. Landsat 4–5 TM and Landsat 8 satellite imagery were used to calculate the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI), as well as to perform supervised classification for different years. Over the past 33 years, 2.45% of the total lake area has been lost, corresponding to an annual decrease of 3.1 km². The results demonstrate that GIS and remote sensing techniques are effective methods for delineating, mapping, and assessing the dynamics of lakes and wetlands.

INTRODUCTION

Lakes constitute one of the components of the global hydrological cycle. Azerbaijan is located along the coast of the Caspian Sea, the world's largest lake. The formation of a lake requires a depression, which is referred to as a lake basin or lake depression. Water accumulates in such depressions, resulting in the formation of lakes.

Natural lakes are rapidly declining worldwide. Between 1970 and 2015, the area of inland and coastal lakes decreased by approximately 25%. This decline is three times greater than the rate of forest-cover loss [1]. As a consequence, important ecosystem services, including water and air purification, biodiversity conservation, groundwater recharge, and the provision of habitats supporting food security, are also being lost [1–2].

High-altitude wetlands (HAWs) are defined as “natural or artificial, permanent or temporary, stagnant or flowing wetlands, reed beds, meadows, peatlands, and water bodies containing fresh, saline, or brackish water located at elevations above 3000 m” (Chatterjee et al., 2010). These fragile ecosystems are critically important for ensuring environmental and economic security for mountain communities and large populations living in lowland areas. They regulate water flow, conserve biodiversity, function as carbon sinks that help mitigate the effects of climate change, and provide essential ecosystem services [2–3]. Nevertheless, high-altitude wetlands are under considerable threat from watershed degradation, alterations in hydrological regimes, anthropogenic pressures, and climate change. Their

important ecosystem services have also not yet been adequately assessed.

Geographic Information Systems (GIS) and remote sensing technologies based on Landsat satellite data have been widely applied for lake monitoring in different regions of the world [3]. These technologies are considered effective tools for monitoring lake distribution because they enable large-scale, repeated observations and comprehensive analyses of spatiotemporal dynamics.

The main objective of this study is to map lakes, particularly Lake Boyuk Ala Gol, and detect changes using Geographic Information Systems and remote sensing techniques, while generating scientific findings that may contribute to future strategies for the conservation of wetland ecosystems.

MATERIALS AND METHODS

The study area is a freshwater lake located in the Kelbajar District on the Karabakh volcanic plateau. It belongs to the lakes of the Lesser Caucasus and is bordered by Armenia to the west. The study area is located between 40°00' N and 45°44' E and covers an area of approximately 480 km². The lake is situated at an elevation of 2,729 m above sea level. Its maximum length is 3.7 km, while its maximum width exceeds 9 m, and its volume is 24.3 million m³. The area surrounding the lake consists of valuable alpine meadows.

The Qurbagalıchay River, originating on the northwestern slope of the Sarchalidagh Range and flowing into Lake Small Ala Gol, probably merged with the Azadchay, Dikpilekenchay, and other rivers

that previously flowed into Lake Boyuk Alagol before volcanic eruptions occurred in the region, eventually draining into Lake Lake Goycha. However, volcanic eruptions altered the relief, thereby disrupting the connection of these areas with Lake Goycha and resulting in the formation of individual lakes and wetland areas within natural depressions.

At present, there are six wetland areas within the Lake Boyuk Ala Gol region, with a combined area of 3.5 km², accounting for 2.7% of the basin. In the recent past, these wetland areas constituted an interconnected system of lakes.

The surface of Lake Boyuk Ala Gol is covered by ice from early November to the end of April and, in some colder years, until mid-May. The ice thickness reaches 0.8–1.0 m. During June–August, water temperature ranges from 14 to 16 °C. Water transparency varies between 0.8 and 1.4 m. The lake water is hydrocarbonate in composition, with a total ion concentration ranging from 53 to 59 mg/L. The water can be used for various economic purposes.

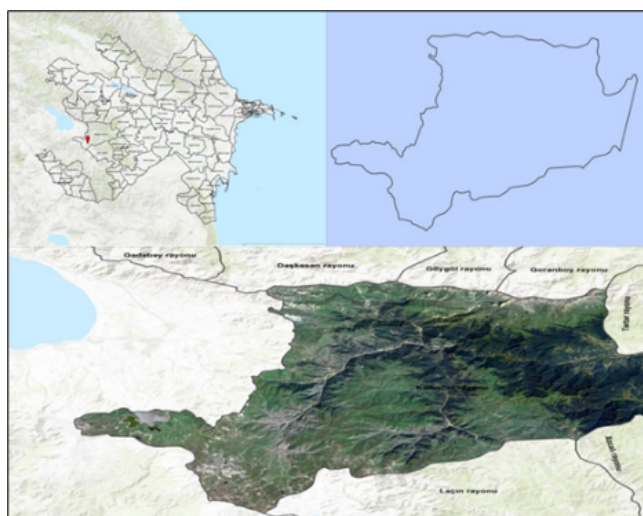


Figure 1. Study area

2.2. Satellite Imagery Data

Landsat TM and OLI (Thematic Mapper and Operational Land Imager) imagery, as well as the SRTM digital elevation model (DEM) with a spatial resolution of 30 m for the study area, were obtained from the data portal of the United States Geological Survey (USGS). Landsat OLI imagery consists of 11 spectral bands, with a spatial resolution of 30 m for Bands 1–9. Panchromatic Band 8 has a spatial resolution of 15 m. According to [4], Landsat imagery with a spatial resolution of 30 m provides sufficient accuracy for mapping at a scale of 1:100,000. Detailed information on the satellite imagery used in this study is presented in Table 1.

Table 1. Landsat images used in the study

Satellite images	Filming duration	Spatial resolution
Landsat 4-5 TM	1990	30 m
Landsat 8-9 OLI	2020	30 m

2.3. Research Methods

Prior to the mapping of wetland areas, all multitemporal Landsat images were preprocessed using ArcGIS (version 10.8). These preprocessing steps included the removal of cyclic errors, radiometric correction, and atmospheric correction. In addition, TWI, NDVI, and NDWI indices were calculated for the study area, followed by supervised classification and accuracy assessment.

2.4. Index-Based Classification (NDVI, NDWI, TWI, Slope)

Numerous studies have demonstrated the significant practical value of these indices for wetland mapping and change analysis. The incorporation of NDWI (Normalized Difference Water Index) and NDVI (Normalized Difference Vegetation Index) into the classification process improves the accuracy of the results and enables clearer discrimination of wetland classes. Therefore, these indices are widely used to delineate wetland boundaries [4–5].

2.5. Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is one of the most widely used indices for assessing the condition and density of vegetation (Tucker, 1979). This index is based on the red (0.63–0.69 μm) and near-infrared (0.76–0.90 μm) spectral bands. NDVI is frequently used for monitoring changes in lakes. For the analysis of Landsat 5 TM satellite imagery, NDVI values were calculated for each year using Band 3 (red) and Band 4 (NIR) (Figure 2). The calculation formula is as follows:

$$NDV = \frac{X_{NIR} - X_{RED}}{X_{NIR} + X_{RED}} \quad (1)$$

NDVI values generally range from –1 to +1. Positive values indicate dense vegetation, whereas negative or near-zero values indicate areas without vegetation or water surfaces.

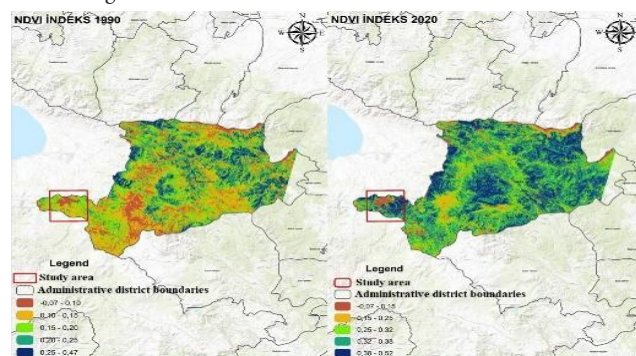


Figure 2. NDVI map of the study area for 1990–2020

2.6. Normalized Difference Water Index (NDWI)

The Normalized Difference Water Index (NDWI) is used to identify open-water surfaces and enhance their visibility in satellite imagery [6]. It also enables the accurate separation of water bodies by reducing the influence of soil and vegetation features (Figure 3). The NDWI is calculated using the green (0.52–0.60 μm) and near-infrared (0.76–0.90 μm) spectral bands. The calculation formula is as follows:

$$NDWI = \frac{(X_{Green} - X_{NIR})}{(X_{Green} + X_{NIR})} \quad (2)$$

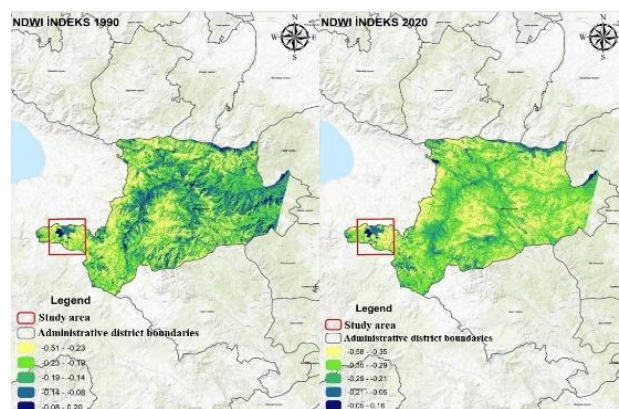


Figure 3. NDWI map of the study area for 1990–2020

An analysis of land-cover changes during 1990–2023 indicates that these changes were influenced by anthropogenic factors, resulting in

deterioration and fragmentation of landscape characteristics, as well as changes in the area, density, and temperature indicators of the territory. Analysis of water bodies identified using the NDWI shows that the water-surface area of Lake Boyuk Ala Gol has decreased considerably. This may indicate a potential risk of water scarcity in the near future. Therefore, the management of wetland areas and reassessment of land-use practices are considered essential measures for preventing these emerging problems (Figure 4). The changes in lake area are presented in Table 2.

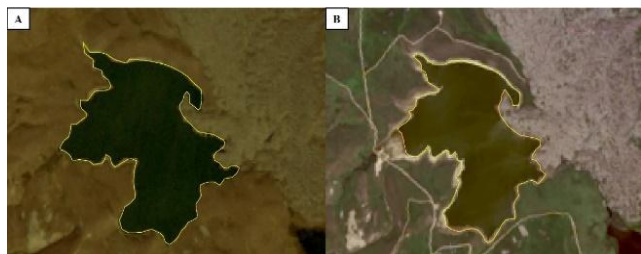


Figure 4. Changes in the area of the study site between 1990 (a) and 2023 (b)

Table 2. Area change of the study area

Filming duration	Area, in km ²
1990	5.3
2020	3.1

2.7. Topographic Wetness Index (TWI)

In wetland delineation, topographic position is also used as an additional indicator of wetland occurrence rather than relying solely on NDWI and NDVI. This approach is widely applied in wetland detection and mapping [7]. The Topographic Wetness Index (TWI) was first introduced by Beven and Kirkby (1979) within the TOPMODEL runoff model. TWI is calculated for each pixel using factors such as contributing area and slope. TWI is expressed by the following equation:

$$\ln \frac{a}{\tan b} \quad (3)$$

This index indicates the relationship between soil moisture and topographic conditions and plays an important role in predicting the spatial distribution of wetland areas. Figure 5 presents the TWI map of the study area.

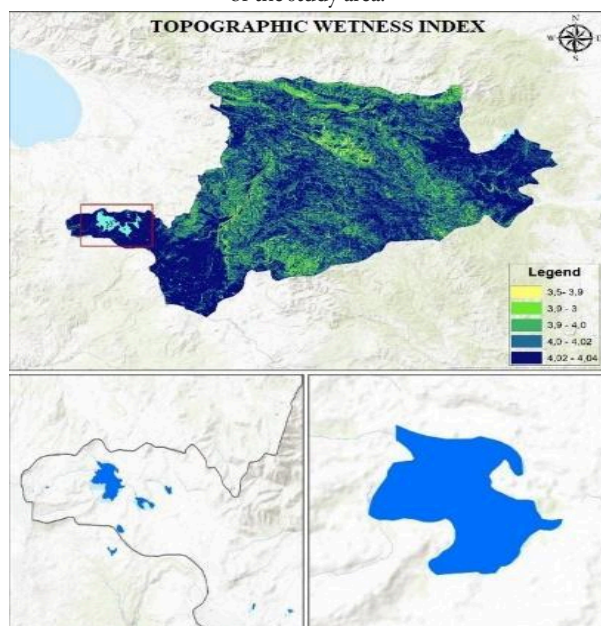


Figure 5. Topographic Wetness Index (TWI) map of the study area

The potential lake zone was identified as an area with a higher potential for water accumulation. The TWI evaluates the tendency of each grid cell to receive and retain water, with higher TWI values indicating a greater potential for water accumulation within the corresponding pixel [8].

2.8. Slope

Figure 6 presents the slope map of the study area. Areas with slopes of less than 5% were considered potential wetland areas, as this approach has been used in numerous studies for wetland delineation [9].

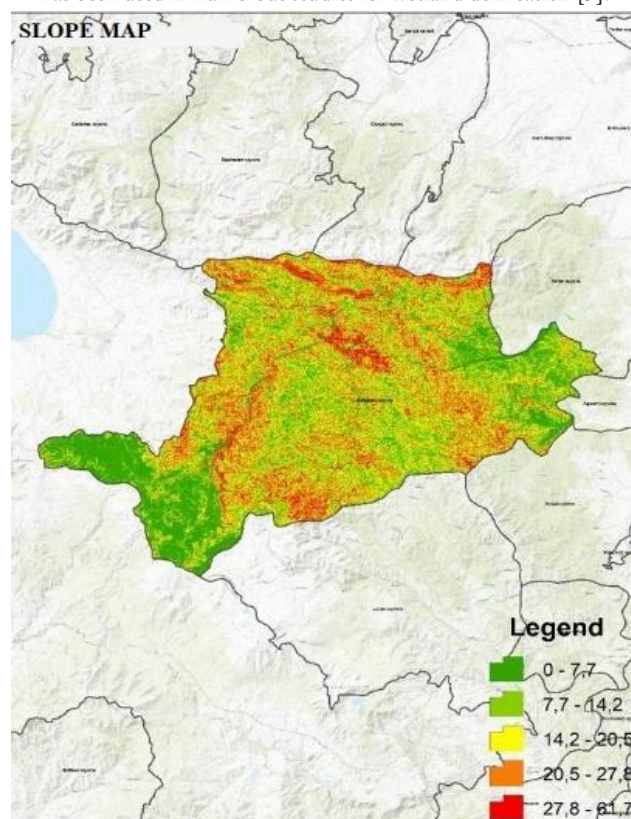


Figure 6. Slope map of the study area (%)

2.9. Supervised Classification

Among supervised classification methods applied to remote sensing data, maximum-likelihood classification is currently considered one of the most widely used approaches. Its widespread application is primarily attributed to its statistical robustness, simplicity of implementation, and ease of interpretation of the resulting outputs [9–10]. Due to these advantages, maximum-likelihood supervised classification is one of the most commonly used techniques for wetland mapping [11].

This method is a parametric supervised classification technique that assigns each pixel to a particular class based on the probability of its membership in that class. The underlying formulation assumes equal probabilities for all classes and a normal distribution of the input bands [12].

Subsequently, land cover within the study area was classified into five different classes using multitemporal Landsat satellite imagery:

- Class I: Forest cover
- Class II: Agricultural land
- Class III: Grasslands
- Class IV: Water bodies (lakes and wetlands)
- Class V: Barren land

Land-cover maps for 1990 and 2023 were prepared using ArcGIS and the methodology described above (Figure 7). The vegetation and

land-cover types within the study area include forests, grasslands, agricultural land, barren land, and wetlands. Significant changes in land-cover types were observed in the study area during 2000–2023.

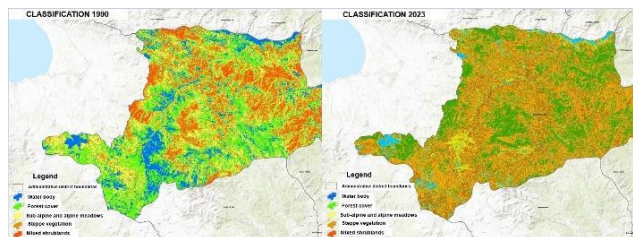


Figure 7. Classified maps of the study area for 1990 and 2023

In addition, the classification accuracy of the land-cover maps derived from Landsat satellite imagery was assessed. The results indicate that both the overall accuracy and classification accuracy exceeded 80% across all maps.

RESULTS AND DISCUSSION

The study found a substantial decrease in lake and wetland areas within the study area over the past 33 years. In 1990, the lake covered 5.3 km², whereas in 2023 its area had decreased to 3.1 km². This represents an approximate reduction of 40%.

The analysis based on Landsat satellite imagery indicates that, in addition to climatic factors such as increasing temperature and evaporation, changes in precipitation patterns, surface drought, and declining vegetation cover, anthropogenic impacts contributed to an overall 40% reduction in the area of the study site between 1990 and 2023, reducing it to approximately 3.1 km². The principal causes of lake-area degradation are both natural and anthropogenic.

CONCLUSIONS

The present study employed remote sensing and GIS technologies together with multispectral Landsat satellite imagery to map and analyze changes occurring in Lake Boyuk Ala Gol using modern approaches. Changes within the study area were identified using the NDVI and NDWI spectral indices for different years, TWI, slope derived from DEM models, and supervised classification methods applied to imagery from different years. Over the past 33 years, 2.45% of the total lake area has been lost, while the annual rate of loss is reported as 3.1 km².

The overall classification accuracy for 1990 and 2023 exceeded 85%. This level of accuracy demonstrates the reliability of remote sensing and GIS methods for lake mapping and monitoring. The results of this study are of considerable importance for the conservation of lakes and wetlands and the protection of their ecological status in high-altitude areas. The ecosystem functions of these areas include water and air purification, provision of habitats for endangered species, flood protection, biodiversity conservation, prevention of shoreline erosion, and water storage. Based on the obtained results,

the need to protect the study area from further degradation should be emphasized, particularly in view of the rapid decline observed in the area.

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