

Monitoring Coastline Change Using Remote Sensing and GIS Technology: A case study of Acıgöl Lake, Turkey

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Abstract. Acıgöl is a lake in Turkey's inner Aegean Region, in an endorheic basin at the junction between Denizli Province, Afyonkarahisar Province and Burdur Province. The lake is notable for its sodium sulphate reserves extensively used in the industry and Turkey's largest commercial sodium sulphate production operations are based here. Coastline changes caused by sediment erosion and accretion have important consequences for coastal ecosystems and coastal communities. Coastlines are the natural borders which separate the water and land. Change of coastline has great importance, therefore it is needed to detect this change and take precautions. In this study, for the purpose of detecting the coastline change of Acıgöl Lake, multispectral Landsat images from the years of 1985, 2000, 2015 were used. Coastline belonging to these years is drawn numerically and coastline change belonging to these years in Acıgöl Lake is provided with the help of Geographic Information Systems and Remote Sensing method and software. After the analysis of the changes, it was determined that there was a significant decline in Acıgöl lake. At the end of the study, significant coastline movements (in some parts more than 200 m) were detected for a 30-year period.

1. Introduction

A Geographic Information System (GIS) integrates hardware, software, and data for capturing, managing, analysing, and displaying all forms of geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. A geographic information system (GIS) lets us visualize, question, analyze, and interpret data to understand relationships, patterns, and trends [1]. Spatial and temporal changes in parameters supply data for GIS and other modelling tools. GIS is an important tool which can use spatial data in different disciplines [2]. While GIS outputs constitute input data during modelling studies, they are also widely applied during visualization of the results obtained from modelling [3].

Remote sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation [4]. Remote sensing systems measure the reflected or emitted energy from the earth's surface using a sensor mounted on an aircraft or a spacecraft platform. GIS is used to capture, store, retrieve, analyze, and display spatial data [5]. Remote Sensing and GIS in conjunction with field survey provide valuable spatial information to evaluate environmental changes on water



bodies and their vicinity all around the world in from local to global scales [6, 7]. Remote sensing data can be used in environmental monitoring programs where the objective is to monitor changes in surface phenomena over time [8]. Digital spatial data analysis and mapping; remote sensing and GIS are widely applied in environmental and natural resources monitoring [9].

In recent years, remote sensing and photogrammetry have been used in a widespread manner for the purpose of following the change in the coastal area management and the use of the coast. A change could be revealed as a result of assessing the photographs on these different time zones by taking old and new photographs of the region which are chosen in order to follow the change on the coast. Following the change on the coastal line with the help of photogrammetry, remote sensing is much more practical compared to topographic measurements. With these methods, developmental route of the environmental problems which experienced in the past could be observed step by step. By this means, it is possible to calculate the dimensions and effects of the change [10, 11, 12, 13]. Coastlines, which are one of the components, are recognized as unique features on the earth [14, 15]. The coastline can be defined as the line of contact between land and a body of water [16, 17]. This is a border line on a local scale representing the limit of dry land on a map [18, 19].

Knowledge of coastline is the basis for overcoming coastal problems, measuring and characterizing land and water resources such as the area of the land and the perimeter of the coastline [19]. Monitoring the evolution of the coastline is an important task in several applications such as cartography and the environmental management of the entire coastal zone [20, 11].

Changes in the coastline and water level of lakes mainly reflect changes in precipitation, evaporation, runoff and human activities integrated over the lakes and their basins. In that sense, these fluctuations constitute a sensitive indicator of past and present climate and human activity changes at a local and regional scale. Remotely sensed data acquired by operational satellites are more and more widely used for the identification, monitoring and delineation of lake mapping at regional or global scales. The availability of multiband, multitemporal and multisensor images and advances in digital processing and analysis have enabled research scientists to gather information about the spatial and temporal evolutions and sensitivities of alterations due to natural and anthropogenic events [10,21,22,23]. Although representing a relatively small percentage of Earth's water, lakes are integral features of the global hydrological system. Lakes are and always have been of great importance to humanity for water supply, as a habitat for food, as a source of power and for recreation and aesthetic value [24].

Different types of environmental sources, especially water bodies play a crucial role in human life and economy. Nowadays, the significance of water bodies, especially fresh water sources like lakes is increasing since these sources are being threatened due to global warming, drought and human needs. In addition to serving as supply for human needs such as irrigation and drinking water, a water reserve in a lake and its catchment area can also be important sources contributing to country's economy and policy like in the case of Acıgöl Lake in Turkey [25].

In this research, aerial photographs from 1985, 2000 and 2015 were used to investigate the coastal changes that took place over the last 30 years along the coastal area. The main objectives of this study are to estimate changes in the coastline and water level of lakes using derived water levels from satellite imagery, remote sensing techniques and in situ water level measurements and to investigate the impacts of climate on lake levels and water reserves.

2. Study area

Acıgöl (literally "the bitter lake" in Turkish) is a lake in Turkey's inner Aegean Region, in an endorheic basin at the junction between Denizli Province, Afyonkarahisar Province and Burdur Province (37°49' N 29°53' E). Its surface area varies greatly through the seasons, with 100 km² in spring and 35 km² in late summer. The lake's altitude is 836 m and it is fed primarily by high-sulfate springs issuing from a fault line on its south side (Figure 1).



Figure 1. Location of the study area

At SW Anatolia, Turkey, the crustal extension created several fluvio-lacustrine basins with active sedimentation in modern deep to shallow lakes [26-32]. Acıgöl Lake is considered to be one of the largest hyper saline lakes in Turkey. The lake is notable for its sodium sulfate reserves extensively used in the industry and Turkey's largest commercial sodium sulfate production operations are based here. The Acıgöl Lake is the second largest alkaline lake in the world, with active precipitation of sodium, calcium and magnesium salts and its surface varies greatly due to seasonal drought [33].

The basin with a maximum length and width of about 45 km and 14 km, respectively, has an area of about 157 km² of which only 55-60 km² are covered by the lake waters (Figure 1). Acıgöl Lake attains its maximum (163 cm) and minimum (less than 1 m) depth during December-January and August-September periods, respectively. The water depth increases from North to South (Figure 2).

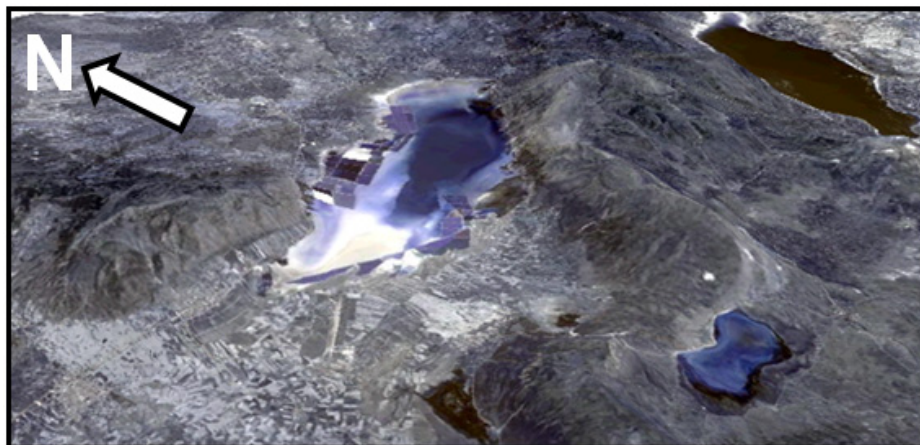


Figure 2. Acıgöl Lake

3. Data used

Remote sensing is a useful tool to detecting coastline change. It plays an important role for spatial data acquisition from an economical perspective. Digital spatial data analysis and mapping; remote sensing and GIS are widely applied in environmental and natural resources monitoring. Optical images are simple to interpret and easily obtainable. Furthermore, absorption of infrared wavelength region by water and its strong reflectance by vegetation and soil make such images an ideal combination for mapping the spatial distribution of land and water. Hence Band 4 of Landsat data in near infrared spectral range (MSS4: 0.8-0.11 μm , TM4:0.76-0.90 μm) suitable for measuring outlines of water bodies.

As high resolution data is costly, uncommon, and often entirely unavailable for a long period for the study area, Landsat satellite images were used as source material. Additionally, Landsat satellite images represent the world's longest continuously acquired collection of space-based land remote sensing data. In this context, coastline changes were analyzed using Landsat satellite images between 1985 and 2015 to determine of coastline changes in the study area. A series of satellite images from 1985, 2000 and 2015, including the study area, was provided by the U.S. Geological Survey (USGS) in Table 1. Figure 3 shows the sample images of orthophotos according to years. All the data being prepared were structured in such a way to be in the UTM projection and WGS-84 Datum.

Table 1. Basic properties of Landsat images used for water body change in the Acıgöl Lake

Dates	Satellite/sensor	Path/Row Spatial	Spatial Res. [m]	Radiometric Res. [bit]	Cloud Cover [%]
08.06.1985	LANDSAT 5	179/034	30*30	8	0
08.05.2000	Landsat ETM+	179/034	30*30	8	14
26.05.2015	Landsat ETM+	179/034	30*30	8	031

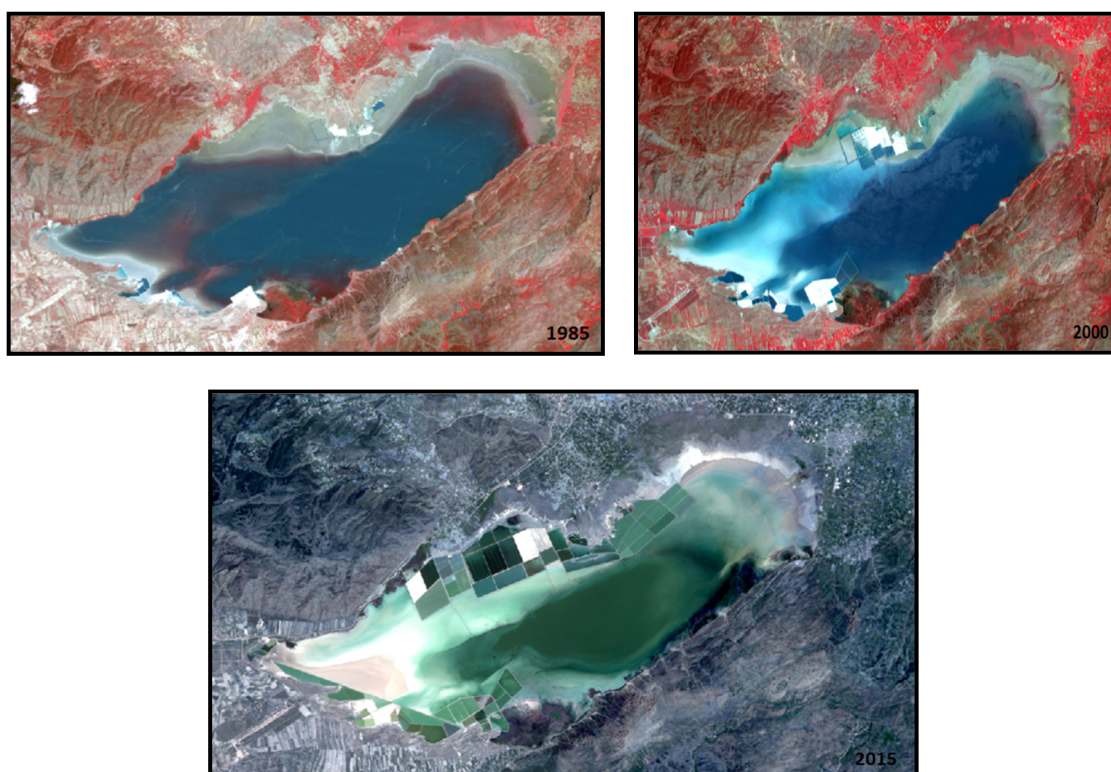


Figure 3. An overview of satellite images covering the Acıgöl Lake (1985, 2000, and 2015)

4. Results and Discussion

First of all, the changes in coastline that were digitized from the satellite image belonging to year 1985, 2000 and 2015. To examine the spatial and temporal shoreline changes of the Acıgöl Lake, water boundaries were converted into a shape file. The lakes' surface areas were then calculated using ArcGIS 10.2.2 to analyze the changes between 1985 and 2015 (Figure 4).

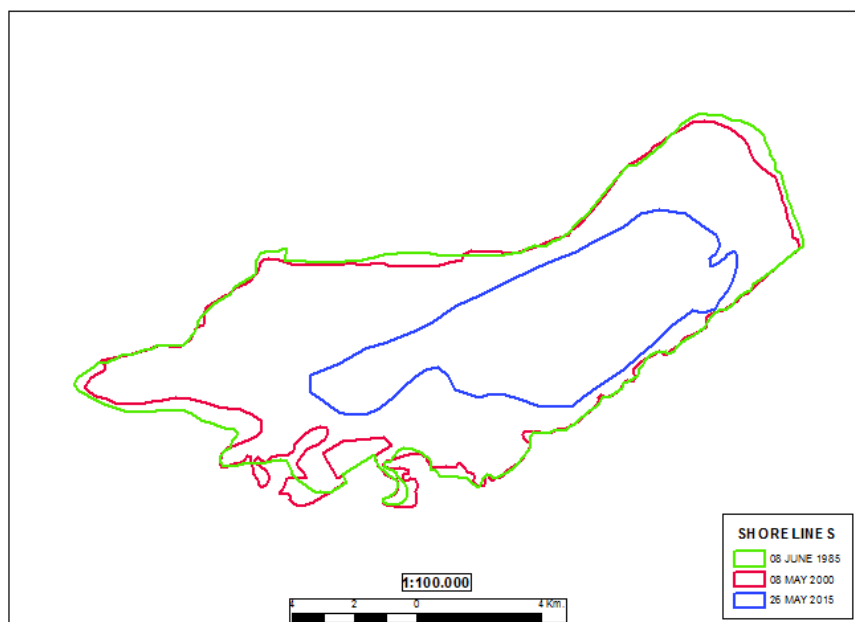


Figure 4. Coastlines changes of the Acıgöl Lake

From the results of the image analysis, the levels of the Acıgöl Lake fell dramatically and shrunk in area from 1985 to 2015. The water surface areas of the Acıgöl Lake also decreased from 129 to 42 km², a loss of 67.4% over the 30-year period, respectively (Figure 4, Table 2). Figure 4 clearly shows severe declines in the annual level of the Acıgöl Lake from 1985 to 2015. Although a study was observed between 1985 and 2000, the lake area tended to decrease over time.

Table 2. Water surface area change of the Acıgöl Lake from 1985 to 2015 (km²)

Years	Water Surfaces Area Changes		
	1985	2000	2015
Acıgöl Lake	129 (km ²)	121 (km ²)	42 (km ²)

The region receives about 400 mm of precipitation per year, whereas as much as 1000 mm of water can be lost annually through evaporation from open water bodies respectively (Figure 5, Fig 6). This annual moisture deficit is one of the major variables that help to control the characteristically high salinity of water in Acıgöl Lake.

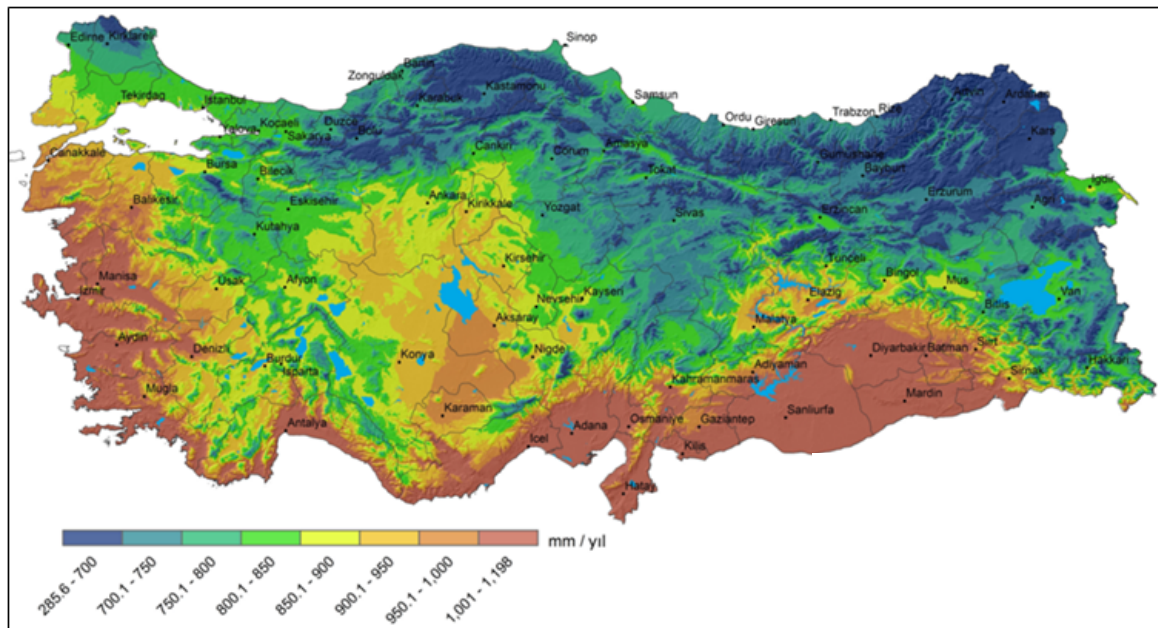


Figure 5. Turkey Annual Total Evaporation Standard Reference Map

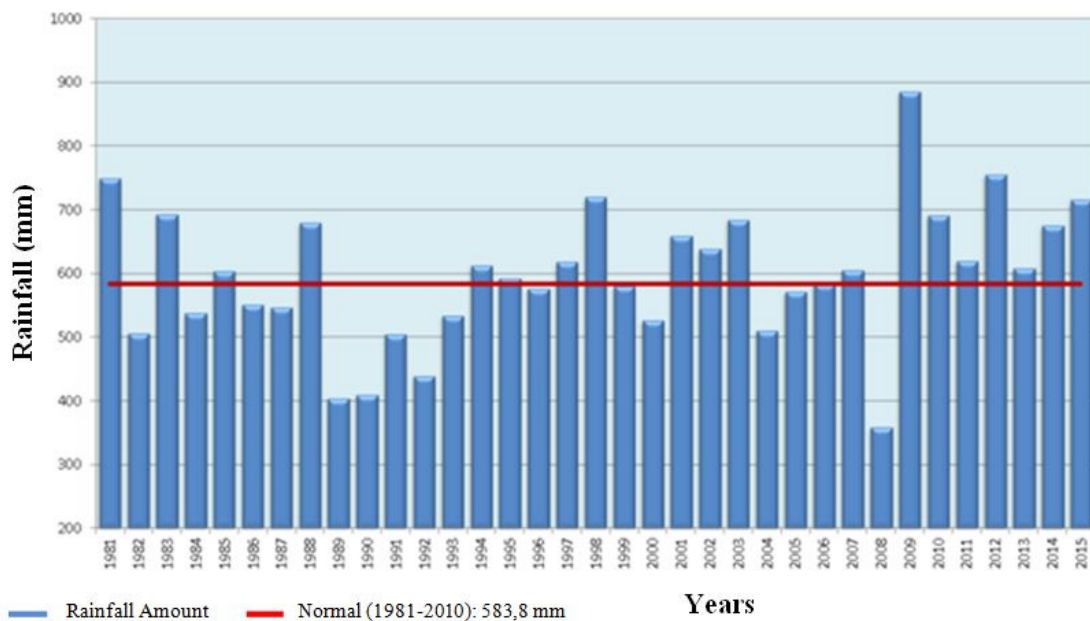


Figure 6. Denizli Annual Areal Rainfall

Acıgöl basin is in a place where semi-arid climatic conditions are dominant [34]. Vegetation is very scarce in base land. Because of the fact that Acıgöl is located in straight base of tectonic and karstic depressions, seasonal level changes are seen in a large area [35]. And the lake has started to be smaller day by day same 129 km² in the year of 1985 and about 42 km² in 2015 caused by drought and depletion of lake water. Especially, extreme temperatures and increasing evaporation, decreases in precipitation, extreme consumption of water and the use of water in farming caused desertification in the basin where

semi-arid climatic condition are dominant. Salt, salt crystal and coastal dunes appear or form in the area where the lake level decreased.

The development of industry in the basin, the transition from dry to irrigated agriculture and increase in the drinking water needs has led to greater use of water resources every day. Excessive use of sources feeding the lake has also caused a reduction in the level of the lake.

Rainfall located at the stations in the basin Çardak (368.4) mm Dazkırı (392.5) mm. As seen clearly in the monthly values during the summer severe drought shows itself. According to Thornthwaite method, the evaporation starts in April-May and continues vigorously until October. The annual amount of evaporation is about 1000 mm. During the summer it is around 1300 mm [36].

When analysing the join deviation chart for Acıgöl basin prepared by Özdemir, drought trend increasing violence has continued starting from 1984 until 1993. While the humidity increased from 1994 to 2003, it again entered a dry circuit after 2003 and drought trend continues today (Figure 7).



Figure 7. The image of Acıgöl Lake

5. Conclusions

This study investigated coastline and water level changes of lake to identify the causes for the decline in lake levels using the satellite imagery, remote sensing techniques and in situ annual temperature, precipitation and runoff data from 1985 to 2015. The results of imagery analyzes showed that the water surface areas of the Acıgöl Lake decreased from 129 to 42 km², a loss of 67.4% over the 30-year period. The lake has experienced a severe decline in water levels in recent decades. There is shallow lake, as such small changes in depth can result in great changes in spatial extent.

In particular, increasing evaporation from the lakes due to increase in warming, the reduction rainfall, excessive water consumption and agricultural water use has led to desertification in the basin dominated by semi-arid conditions. Salt, salt crystals and sand dunes are formed in large areas of the lake's retreat.

The rapid decline in the level of the lake due to the existence of global warming dealt with in a study of the relationship between climate parameters with lake level changes. They have expressed that there is a statistically significant relationship strong between lake level changes with changes in climate. They have also predicted that it will be increase in temperature and evaporation whereas a decrease in precipitation and it will continue the downward trend Acıgöl basin and its vicinity.

The use of satellite imagery and other data sources manipulated and integrated in a GIS environment provides an essential and valuable information base. Additionally, this study shows that satellite imagery provides an essential tool in determining drought impact due to the operational acquisition of satellite imagery.

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