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Changes in the Coastline and Water Level of the Akşehir and Eber Lakes Between 1975 and 2009

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Abstract The Akşehir and Eber Lakes, relatively shallow, small freshwater lakes with an area of 361 km^2 and 150 km^2 and average depth of 7 m and 2 m (1998), respectively in southwestern Turkey, have experienced a severe decline in water levels in recent decades. This study aimed to investigate coastline and water level changes of lakes and identify the causes for the decline in lake levels. Nine Landsat images from different times, monthly temperature, precipitation, discharge, lake level records and population data were used to analyze these changes. From 1975 to 2009, the water surface areas of the Akşehir and Eber Lakes decreased from 356,929 to 126,482 km^2 and from 119,882 to 85,663 km^2, a loss of 64.5% and 28.4% over the 34-year period, respectively. From 1975 to 2004, the Akşehir Lake level declined by 2.67 m from 956.02 m to 953.35 and the Eber Lake level declined by 2.03 m from 966.75 m to 964.72 m from 1975 to 2004 based on ground lake level data (in situ). The results of the temperature and precipitation analysis showed that although the annual mean climatic factors vary substantially, they show small increasing trend over the record periods. Annual discharge records on the Akarçay River and its tributaries decreased over the basin during the same period. Irrigation systems, three dams and seven pounds built in recent decades for agricultural irrigation and domestic use, made the major impact on lowering the lake levels because they derive water

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from the river for human use upstream of the lakes' catchments. Population growth, rising water consumption for agricultural and domestic purposes and building dams has led to lake levels declining. The change of lake levels might depend more on anthropogenic factors than on climatic factors.

Keywords Coastline · Lake level · Landsat image · Climate · Human activity · Lake Akşehir · Lake Eber

1 Introduction

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 (Winter 2004).

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 (Tiercelin et al. 1988). Many investigations in different parts of the world have noted a shrinkage of lakes due to anthropogenic activities such as land cover and land use change, deforestation, rising water demands for agriculture and livestock, urbanization, water abstractions upstream of lakes, dam construction and irrigation (Du et al. 2001; Yan et al. 2002; Penny and Kealhofer 2005; Legesse and Ayenew 2006; Kiage et al. 2007). In some cases, changes in climatic fluctuations, especially precipitation, are believed to be the major causes of lake shrinkages (e.g., Birkett 1995, 2000; Moln'ar et al. 2002; Mercier et al. 2002; Mendoza et al. 2006; Medina et al. 2008). In both cases, adverse effects on water availability can occur, as in the cases of Lake Chad (Birkett 2000) and Aral Sea (Heaven et al. 2002; Benduhn and Renard 2004; Micklin 2010; Oren et al. 2010).

Changes in the coastline and water level of lakes are an important task that has applications in different fields such as coastline erosion monitoring, coastal zone management, watershed definition, flood prediction and water resource evaluation. This task is difficult, time consuming and can be impossible for a huge region such as an entire country or continent, when using traditional ground survey techniques. This is because water bodies can be very large with complex shorelines, fast moving as in floods, tides and storm surges, or inaccessible (Bagli and Soille 2003).

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 imagery 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 (Chopra et al. 2001; Kalivas et al. 2003; Sidle et al. 2007; Ma et al. 2007).

A current research review shows an increasing interest in characterizing and monitoring wetlands by remote sensing (Zhang et al. 1997; Lunetta and Balogh 1999; Frazier and Page 2000; Houhoulis and Michener 2000; Munyati 2000; Chopra et al. 2001; Almeida-Filho and Shimabukuro 2002; Kalivas et al. 2003; Castaneda et al. 2005; Alexandridis et al. 2007; Sidle et al. 2007; Ma et al. 2007; Swenson and Wahr 2009). Frequently, these researches aim to detect and delineate water bodies and estimate their change. Landsat satellite images represent the world's longest continuously acquired collection of space-based land remote sensing data. For this purpose, some research has used Landsat imagery, taking advantage of the analysis potential of its spatial and temporal resolution, and the continuity of the image acquisition that began in 1972.

In Turkey, most lake monitoring studies that use remote sensing have been conducted to assess the water level because of changes in climate and human activities such as the Salt Lake (Ormeci and Ekercin 2007), Ulubat Lake (Tağıl 2007), Seyfe Lake (Reis and Yılmaz 2008) and Akşehir and Eber Lakes (Sener et al. 2009).

The Akşehir and Eber Lakes are important to the country but their dramatic changes are poorly known. Besides the scientific and ecological points of view, knowledge of the size and shape of their changes has social effects because the lakes' resources support the economy of communities settled around them. The main objectives of this study are (i) 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 (ii) to investigate the impacts of human activity and climate on lake levels and water reserves. The Akşehir and Eber Lakes are closed lakes in the Akarçay Basin and, therefore, are an ideal site to evaluate the effects of climate and human activity changes on the water resources system.

2 Study Area

The Akşehir and Eber Lakes are located in southwestern Turkey (Fig. 1). They are the area with the lowest elevation of the Akarçay Basin in the Afyonkarahisar and Konya provinces. They lie in a tectonic depression and are bound to the east by the Emirdağ Mountains and the west by the Sultan Mountains. They are separated from each other by local lowland but were connected in the past (Yıldız 1994).

The Akşehir Lake is a relatively shallow, small freshwater lake at an elevation of 952 m. a. s. l. The surface area of the lake and its catchment area are 361 km^2 and 2,376 km^2, respectively. The maximum and average depth of the lake in 1998 was 7 m and 5 m, respectively (Tezcan et al. 2002).

The Eber Lake is also a relatively shallow, small freshwater lake at an elevation of 965 m. a. s. l. The surface area of the lake and its catchment area are 150 km^2 and 4,961 km^2, respectively. The maximum and average depth of the lake in 1998 was 4 m and 2 m, respectively Table 1. Both lakes have a circular shape and their lakebeds are very flat and relatively shallow, with small fluctuations in levels that mean huge variations in sizes. Their relatively shallow depths and terminal positions make the lakes more susceptible to changes in climate and anthropogenic activities (Tezcan et al. 2002).

The Eber Lake receives water principally from the Akarçay River to the north and the four small seasonal streams from the western escarpment of the Sultan Mountains. The Akşehir Lake is fed by many small seasonal streams from the western escarpment of the Sultan Mountains. At present, there is no direct surface water connection between the two lakes. However, an aqueduct and an open channel existed until 1990. The Eber Lake provides a direct sustained outflow to the Akşehir

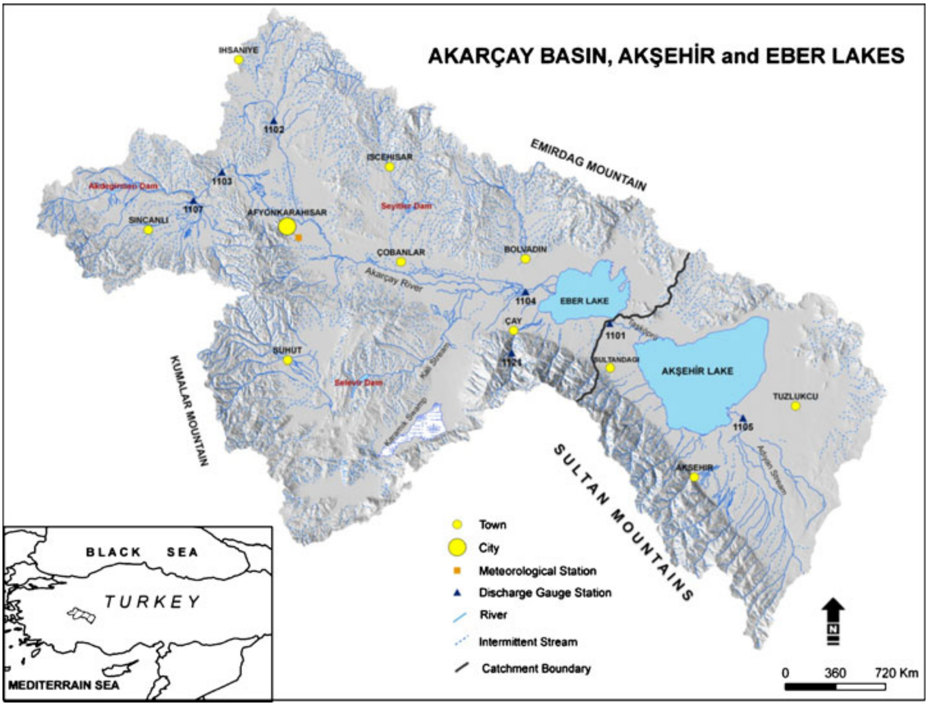

Fig. 1 Location and drainage basin map of the Akşehir and Eber Lakes

Lake through the Taşköprü channel. At present, the two lakes are topographically closed and there is no surface water outflow.

Tezcan et al. (2002) reported that groundwater plays no role on the discharge or recharge of the Eber and Akşehir Lakes based on hydrogeology and isotopic investigations. The Eber and Akşehir Lakes are closed basins within the Akarçay Basin and, therefore, the only way of water loss is though evaporation The lakes are used for different purposes such as small-scale commercial fishing, recreation and irrigation. The Akarçay Basin has many small seasonal streams. The only perennial rivers are the Akarçay and Kali. The water level variations of the Akşehir and Eber Lakes are mainly driven by hydrologic conditions over the Akarçay Basin because it contributes up to 70% of the Eber Lake water volume (Tezcan et al. 2002).

The Akarçay Basin is one of the smallest closed basins in Turkey. Its elongated shape is 250 km long and 30 km wide and covers an area of about 7,337 km^2, most of which lies along the eastern flank of the Sultan Mountains. In general, the basin has a very mild slope; Its average elevation is 1,211 m. The highest and lowest elevations in

Table 1 Properties of Akşehir and Eber Lakes

Lake	Altitude (m.a.s.l)	Lake area (km^2)	Catchment area (km^2)	Maximum depth (m)	Mean depth (m)
Akşehir	952	361	2,376	7	5
Eber	965	150	4,961	4	2

the basin are 2,625 and 955 m, respectively. The elevation in 50% of the total area is between 955 and 1,125 m. The elevation above 1,500 m is 12% of the total area. The main geomorphologic features of the basin are plain, plateau and mountain (Fig. 1).

The area is characterized by a continental climate with very cold rainy/snowy days in winter but very hot and dry weather in summer. The average annual precipitation in the basin is 434.4 mm, of which the winter and spring seasons (December to May) contribute more than 64%. The average monthly precipitation varies from 15.2 mm in July to 73.9 mm in November. The mean annual temperature is 11.1°C. The monthly mean temperature ranges from a maximum of 21.9°C in August to a minimum of 0.2°C in January. The annual average evaporation is 1,181 mm with monthly averages ranging from 20.4 mm in October to 225.5 mm in July. Figure 2 presents the long-term average climatic data recorded at the Afyonkarahisar meteorological station.

The estimated living population in the Akarçay Basin in 2000 was 650,831 inhabitants with a density of 81 inhabitants/km^2. Anthropogenic activities in the basin such as settlements, irrigation systems, livestock, agriculture, mining and forest and cattle might affect the lake water level dynamics because they affect the water cycle and lead to soils compacting. Anthropogenic factors have reduced the water absorption capacity of the basin and effective rainfall over the basin is converted easily in direct runoff instead of groundwater (Tezcan et al. 2002).

The Akşehir and Eber Lakes are two of the biggest lakes in the Akarçay Basin and their surrounding area is used for cherry growing, especially the western sides of both lakes because the microclimate affects the lakes. Cherry growing is the most important agricultural production for local people. Unfortunately, the lake has been dramatically reduced in recent years for various reasons; their size and shape has changed and cherry production has decreased as a consequence. Towns such as Akşehir, once on the lakeshore, are now located tens of kilometers from the water.

The lakes are home to many endemic birds and a wide variety of wild animals. The lakes are also on an important migration route between northern Europe and Africa for Palaearctic birds during spring and fall. Their muddy shoreline supports one of the most notable collections of bird life (flamingoes, white pelicans, etc.) in Turkey (Tezcan et al. 2002).

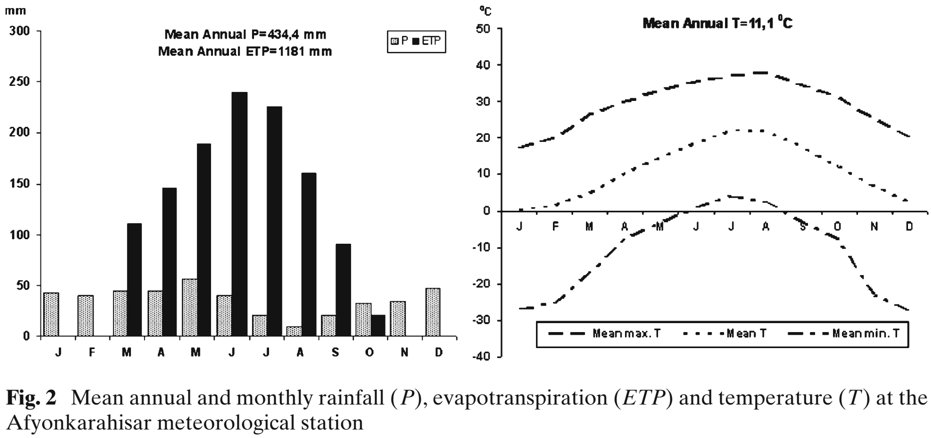

Fig. 2 Mean annual and monthly rainfall (*P*), evapotranspiration (*ETP*) and temperature (*T*) at the Afyonkarahisar meteorological station

3 Materials and Methods

It is essential to analyze the different types of data regarding changes in coastline and the water reserves of the lakes because there are many factors affecting the decline in lake levels. Different sources and types of data were used in this study. The basic data used in this study includes: (i) a Digital Elevation Model (DEM), generated from a 10 m interval contour map of the Akarçay Basin; (ii) nine Landsat images; (iii) monthly river discharge and lake level data from the General Directorate of Electrical Power Resources Survey and Development Administration (EIE) and State Hydraulic Works (DSI); (iv) monthly rainfall and temperature data from the Afyonkarahisar meteorological station; (v) population data from the Turkish Statistical Institute (TUIK) and (vi) fieldwork studies and results of other relevant studies.

In this study, nine multitemporal and multisensor images were collected between 1975 and 2009 (Table 2). All image data were acquired by the Landsat satellites. One image was obtained by the Landsat MSS onboard Landsat 1, five images were obtained by the Landsat TM onboard Landsat 5 and three images were obtained by the Landsat ETM+ onboard Landsat 7. Landsat MSS has 192/033 and the others have the same paths and rows (178/033). Cloud influence is minimal on water body extraction in this study. There were small amounts of cloud on six of the images, but less than 2% of the surface area of each. Nine Landsat images, each covering almost entirely the Akşehir and Eber Lakes, were selected between May and June to map the high water level periods.

The Landsat 7 ETM+ sub-scene covering the study site acquired on 13 May 2007 was converted to the UTM coordinate system (Zone 36) using a total of 25 control points extracted from 1: 25,000-scale topographic maps. A first order polynomial transformation method was performed to create the output images with 30 m ground resolution. The 2007 scene was used as a reference to register images acquired in the remaining eight images (image-to-image registration). The root mean square error of the polynomial transformation was less than half a pixel for the entire dataset. Checkpoints were measured on the geometrically corrected image set and compared with the topographic sheets to evaluate the quality of the geometric correction (Jensen 1996; Ormeci and Ekercin 2007).

Table 2 Basic properties of Landsat images used for water body change in the Akşehir and Eber Lakes

Dates	Satellite/sensor	Path/row	Resolution			
			Spatial (m)	Revisit (days)	Radiometric (bit)	Spectral (band)
16/06/1975	Landsat MSS	192/033	80 × 80	16	7	4
30/06/1984	Landsat TM	178/033	30 × 30	16	8	7
11/05/1989	Landsat TM	178/033	30 × 30	16	8	7
25/05/1994	Landsat TM	178/033	30 × 30	16	8	7
09/05/2000	Landsat ETM+	178/033	30 × 30	16	8	8
16/06/2002	Landsat TM	178/033	30 × 30	16	8	7
19/06/2006	Landsat ETM+	178/033	30 × 30	16	8	8
13/05/2007	Landsat ETM+	178/033	30 × 30	16	8	8
13/05/2009	Landsat TM	178/033	30 × 30	16	8	7

The delineation and extraction of the coastlines of lakes were mapped using optical and radar imagery in several ways. Classification, visual interpretation and density slicing approaches were used for water body identification in wetland areas with multiband, multitemporal and multisensor imagery (Frazier and Page 2000; Munyati 2000; Chopra et al. 2001; Toyra et al. 2001; Dechka et al. 2002; Parmuchi et al. 2002; Wang et al. 2002; Jain et al. 2005; Hung et al. 2008). A water body can be distinguished by these methods to determine its extent and flooding over large areas, although there are obvious disadvantages, such as individual pixel misclassification, mixed pixels, high turbidity or shallow depth and confusion of a dark shadow (Hui and Wu 2005).

Density slicing is an easy and valid method for identifying water bodies. It has been suggested that density slicing approaches and simple thresholds in bands 4, 5 and 7 of Landsat data give good estimations of water body but might include several non-water pixels compared with aerial photography and results derived from DEMs (Frazier and Page 2000; Jain et al. 2005; Knight et al. 2009). Density slicing approaches were used in this study for the delineation and extraction of the Akşehir and Eber Lakes. Erdas Imagine 8.7 image processing software was used for the remote sensing techniques and density slicing approaches.

To examine the spatial and temporal coastline changes of the Akşehir and Eber Lakes, we converted water boundaries into a shape file. The lakes' surface areas were then calculated using ArcGIS 9.3 to analyze changes between 1975 and 2009.

4 Analysis of the Spatial and Temporal Change of Water Bodies

From the results of the image analysis, the levels of the Akşehir and Eber Lakes fell dramatically and shrunk in area from 1975 to 2009. The water surface areas of the Akşehir and Eber Lakes also decreased from 356,929 to 126,482 km^2 and from 119,882 to 85,663 km^2, a loss of 64.5% and 28.4% over the 34-year period, respectively (Fig. 3).The area of the Akşehir Lake shrunk from 356,929 km^2 in 1975 to 370,228 km^2 in 1984, 342,437 km^2in 1989, 267,520 km^2 in 1994, 236,562 km^2 in 2000, 205,133 km^2 in 2002, 110,760 km^2 in 2006, 123,560 km^2 in 2007 and 126,482 km^2 in 2009. Over the same period, the Eber Lake also shrunk from 119,882 km^2 in 1975 to 165,201 km^2 in 1984, 119,975 km^2in 1989, 66,140 km^2 in 1994, 145,163 km^2 in 2000, 126,318 km^2 in 2002, 86,212 km^2 in 2006, 68,807 km^2 in 2007 and 85,663 km^2 in 2009 (Fig. 3; Table 3).

The identified water body change by Landsat images correlated with the change of water level in the Akşehir and Eber Lakes gauged by the DSI. The results showed a good agreement between both Landsat images and in situ datasets. From the image analysis, for example, in 1994 the in situ lake surface area was 290.79 km^2 and the lake surface as determined from satellite images was 267.520 km^2, a difference of less than 9%. In 2000, the in situ lake surface area was 247.99 $km^2$and the lake surface as determined from satellite images was 236.562 km^2, a difference of below 5% for Akşehir Lake.

Monthly lake level data are taken from two stations by the DSI (Fig. 1). Figure 4 clearly shows severe declines in the annual lake level of the Akşehir Lake from 1975 to 2004. The highest lake level was 956.02 m in 1985 and the lowest lake level was 953.35 m in 2004. Over the 29 years, the Akşehir Lake level declined by 2.67 m.

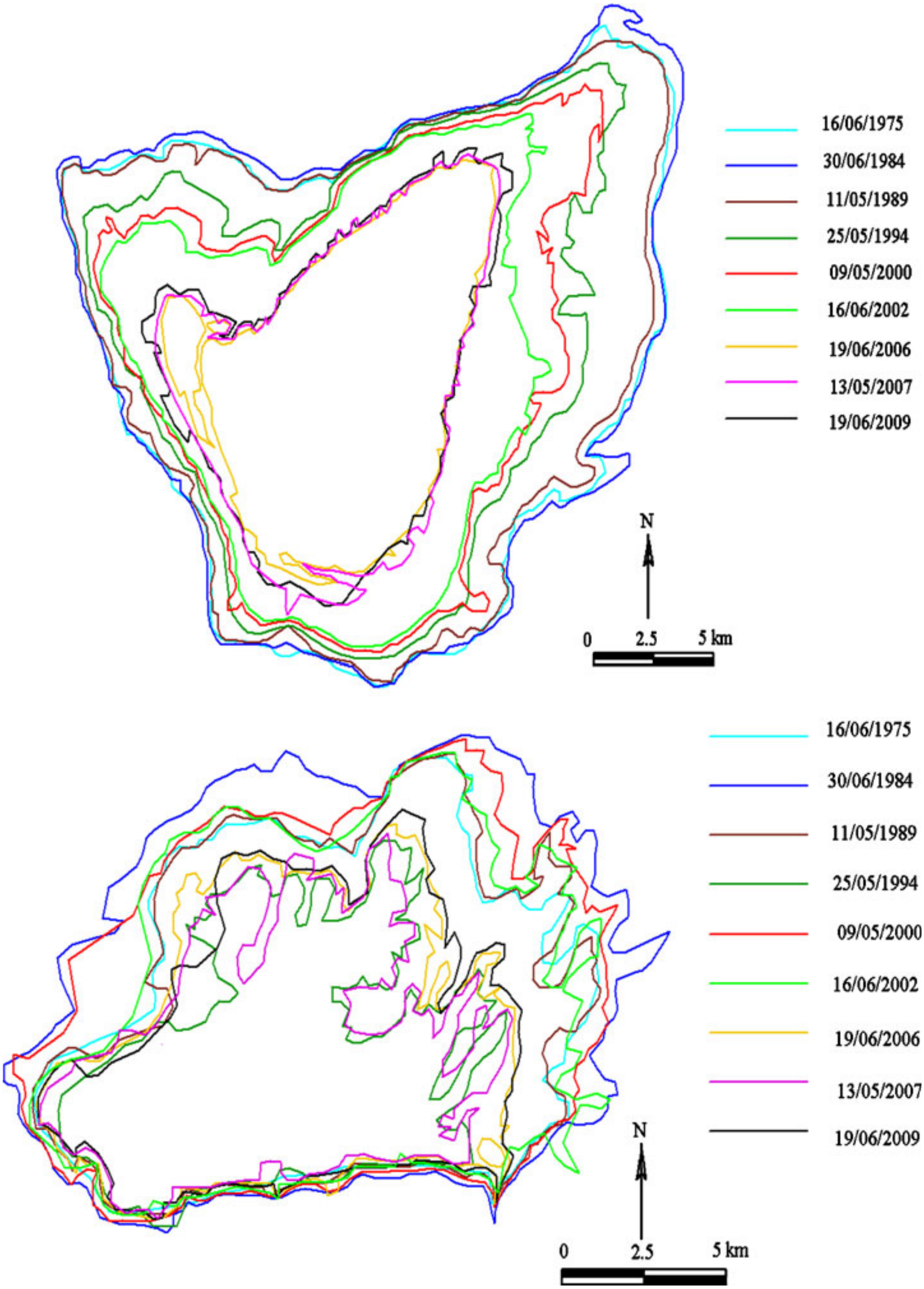

Fig. 3 Shorelines changes of the Akşehir (*top*) and Eber (*bottom*) Lakes

After 2004, there were no lake level records because the lake level was lower than the lake level gauge station. Although a rise was observed between 1975 and 1985, the lake level tended to decrease over time. The lake level continuously declined

Table 3 Water surface area changes from 1975 to 2009 of the Akşehir and Eber Lakes (in km^2)

Lake	1975	1984	1989	1994	2000	2002	2006	2007	2009
Akşehir	356,929	370,228	342,437	267,520	236,562	205,133	110,760	123,560	126,482
Eber	119,882	165,201	119,975	66,140	145,163	126,318	86,212	68,807	85,663

between 1985 and 2004 before finally dropping below the lake level gauge station (Fig. 4).

Between January and May, precipitation is concentrated over catchment of the Akşehir Lake, The lake fills up much like a bathtub, covering all its bottom

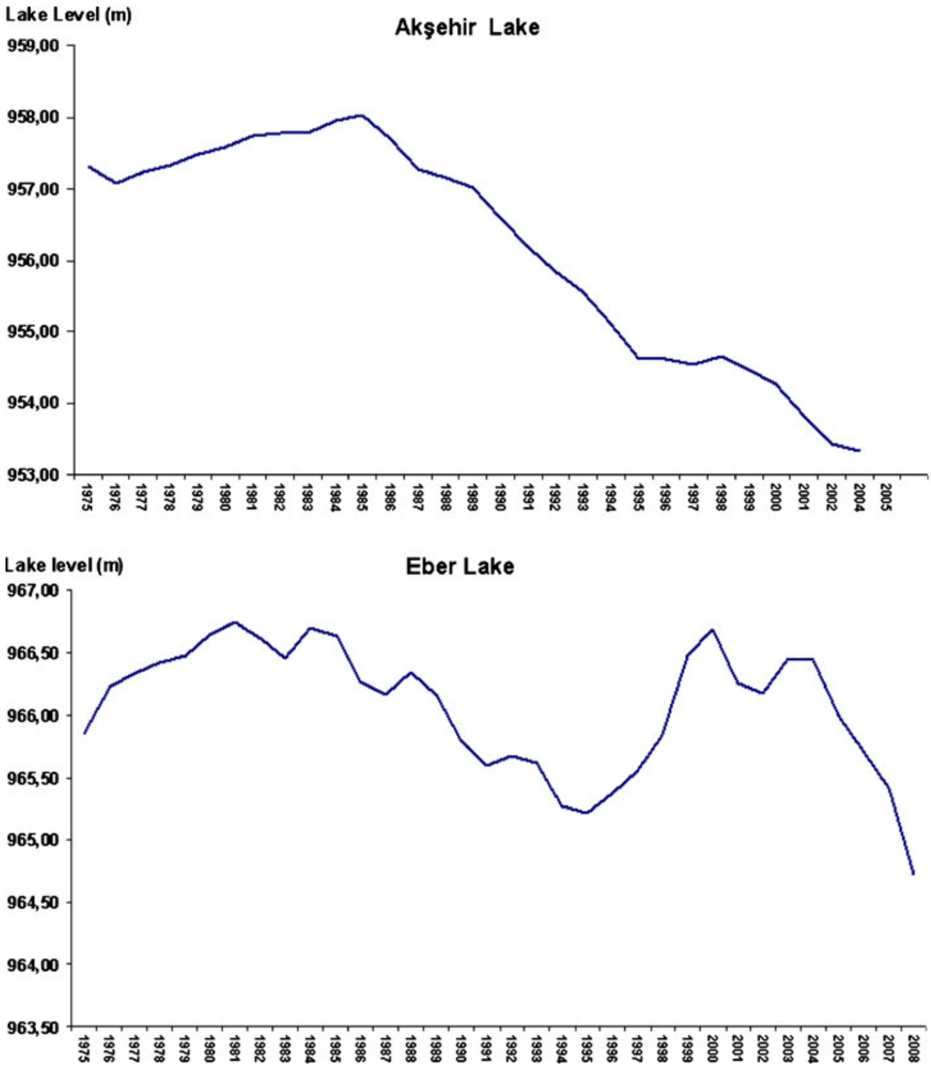

Fig. 4 Annual mean water levels of the Akşehir (*top*) and Eber (*bottom*) Lakes

marshlands with water from the feeder streams. Between May and June, the water levels in the lake reach a peak. In July and November, the water surface of the Akşehir Lake subsides. Vast tracts of flat grass-covered marshlands come out of the water. The lake has lost as much as 90% of its water in some years. However, in recent years, the lake has dried up completely in summer and fall.

There are two main reasons for this declining water level of the Akşehir Lake. First, before 1990, the Akşehir and Eber Lakes were connected via the Taşköprü channel. The Eber Lake provided a direct sustained outflow to the Akşehir Lake through this channel. The largest inflows occurred at the north of the Akşehir Lake. Figure 8 shows that the outlet of the Eber Lake provided more than 500 m^3/year water annually to the Akşehir Lake. Later, this situation changed because of the lowering level of the Eber Lake. A regulator, which was constructed on an outlet of the Eber Lake in 1990 by the DSI, is used to control the lake water outflows and thereby the lake level. The flow to the Akşehir Lake has now stopped.

Second, there are many cherry gardens in alluvial fans on the western side of the Akşehir Lake. A number of wells were also opened by local people to irrigate the cherry gardens especially in growing season. This situation hampered the groundwater flow of the alluvial fans to the Akşehir Lake.

Figure 4 shows the annual lake level of the Eber Lake from 1975 to 2008. Although fluctuations were observed, the lake level generally tended to decrease over time. The highest lake level was 966.75 m in 1981 and the lowest lake level was 964.72 m in 2008. Over these 33 years, the Eber Lake level declined by 2.03 m. A small rise was observed between 1975 and 1982 but it again decreased between 1982 and 1995. It again increased between 1995 and 2004, but dramatically declined after 2004 (Fig. 3).

5 Bathymetric Data

Bathymetric information (depth contours) is vital for lake water management. Bathymetric data were used to characterize the lake bottoms. The bathymetric data of the lakes used in this study were obtained from the DSI. Available data included depth measurement from 1,818 points and 1,888 points for the Eber Lake and Akşehir Lake, respectively. For the first time, a detailed bathymetric map of the two lakes was established. Figure 5 shows the present day bathymetric maps and depth–area relationship. The bathymetric maps clearly indicate that the lakebeds of both lakes are very flat and relatively shallow. The deepest parts of both lakes are located in the northwestern parts. Over 56% of the Eber Lake area has a depth greater than 1.4 m depth and more than 73% of the Akşehir Lake area has a depth greater than 6.6 m. The detailed representations of the lake bottoms were used to calculate the lake surface area (loss of water) and water volume (water storage) at any given level of water. Finally, a set of possible water volumes was calculated to estimate the water storage capacity of the Akşehir and Eber Lakes (Figs. 5 and 6).

6 Runoff

Monthly mean discharge records compiled by the EIE and DSI were used in this study. They are shown in Fig. 1. To comply with the homogeneity condition, seven

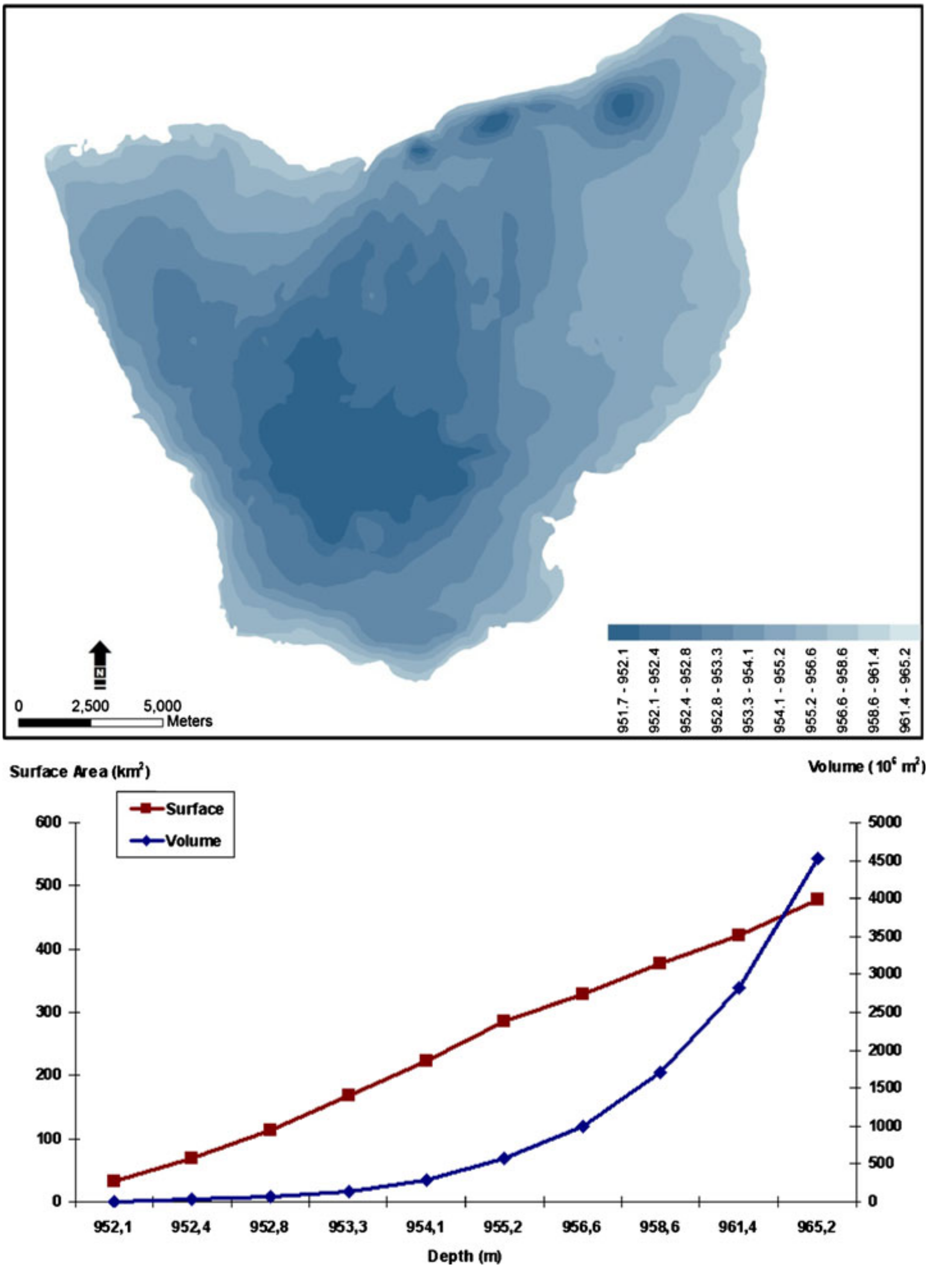

Fig. 5 Bathymetric map (*top*), depth and volume (*bottom*) relationship of the Akşehir Lake

discharge gauging stations were distributed over the study area. Stream discharge was monitored at four locations along the Akarçay River and its triturates on the catchment of the Eber Lake. There are two discharge gauging stations on the catchment of the Akşehir Lake. One is located along the Adıyan stream, which is the

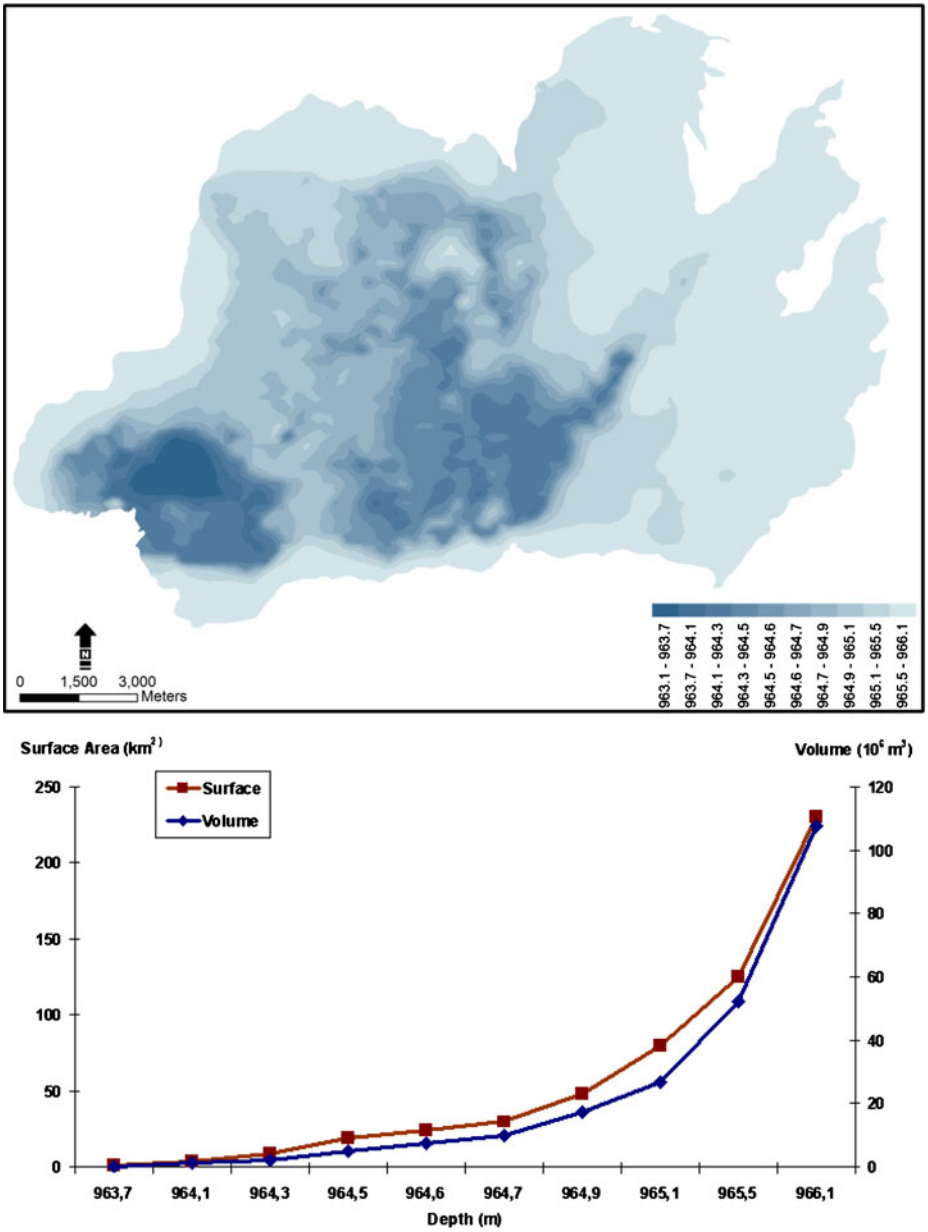

Fig. 6 Bathymetric map (*top*), depth and volume (*bottom*) relationship of the Eber Lake

main feeder of the Akşehir Lake, and the other is located at an outlet of the Eber Lake.

Figure 7 shows the yearly total discharge at five locations along the Akarçay River and its triturates between 1966 and 2004. In general, five stream gauging stations on the catchment of the Eber Lake (68% of the total area of Akarçay Basin) exhibited a

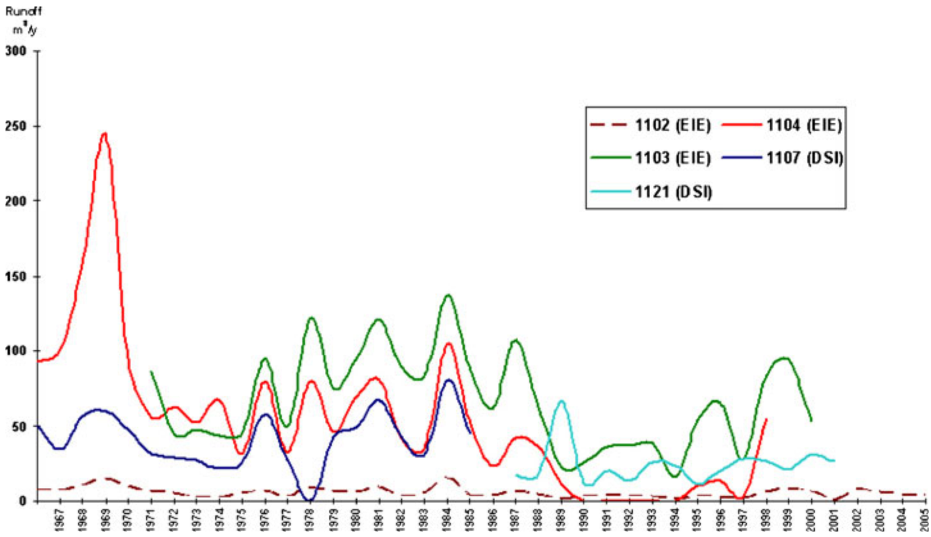

Fig. 7 Discharges of stations on the Eber Lake catchment

downward trend over the 38 years. Of the five stream gauging stations, 1,104 station is important because of its drainage area (which represents an area of 4,231 km^2 or 85% of the Eber Lake catchment) and because it is long enough and has uninterrupted records. This station is located 10 km north of the Eber Lake. The Akarçay River usually dries up downstream before reaching the Eber Lake during the dry season, which has a dramatic impact on the water level of the Eber Lake.

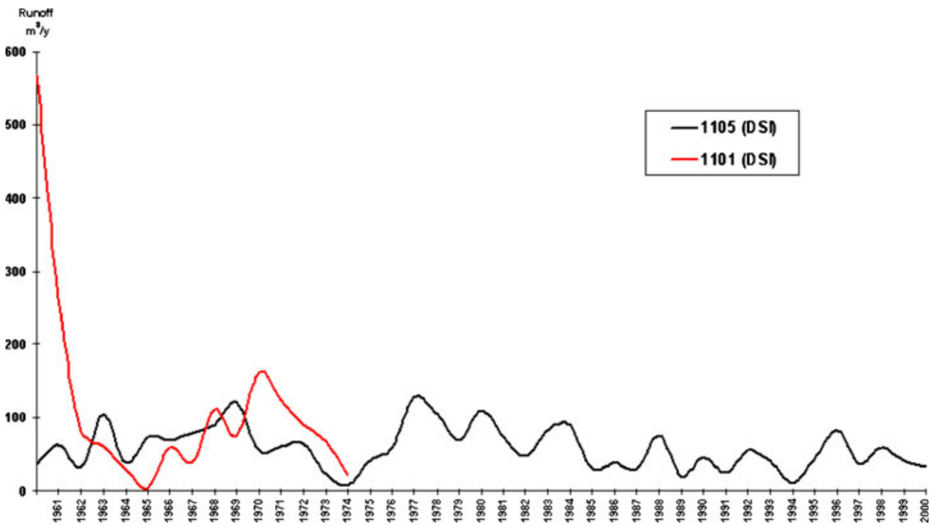

Fig. 8 Discharges of stations on the Akşehir Lake catchment

Figure 8 depicts the yearly total discharge at two locations in the catchment of the Akşehir Lake (32% of the total area). A stream discharge gauging station (no 1101) is located on the Adıyan stream and the other (1105) is located at the outlet of the Eber Lake that once fed the Akşehir Lake via a small channel. This latter station is important because of the showing water balance between the Eber Lake and Akşehir Lake. Station 1101 shows a dramatic fall after 1960 with no discharges recorded after 1974. However, the flow to the Akşehir Lake from the outlet of the Eber Lake continued until 1990 when the Eber regulator was constructed. However, station 1105 shows a slight downward trend over the 40 years.

7 Water Balance

The purpose of studying the water balance is to determine whether the inputs (rainfall on the lake and tributary inflows) balance the outputs (evaporation from the lake, outflows and changes in storage). The Eber and Akşehir Lakes are closed lakes and there are no outlet, the only way of water loss is though evaporation, therefore the water balance equation for the lakes can be written as follow:

$$\Delta h = P + R_s - E$$

Where Δh is the yearly change in lake level (mm), P is the yearly precipitation over the lake (mm), R_s is the yearly surface runoff water into the lake and E is the yearly evaporation from the lake surface (mm).

Tezcan et al. (2002) reported that infiltration doesn‘t occur towards the Eber and Akşehir Lakes from alluvium due to its having widespread impervious clay levels therefore groundwater doesn‘t play an important role on the discharge or recharge of the Eber and Akşehir Lakes based on hydrogeology and isotopic investigation. Therefore, precipitation, surface flow and evaporation data were used to exanimate water balance of two lakes.

Precipitation data were measured in Eber meteorological station for the Eber Lake and Taşköprü meteorological station for the Akşehir Lake. They are located at very closed the lakes. Bolvadin discharge gauging station (1104) for Eber Lake and Adıyan stream gauging station (1101) for Akşehir Lake were used to acquire yearly records of surface flow. Lake water level records for two stations were averaged to obtain yearly records of lakes level variations dating back to 1965. Evaporation over the lakes were calculated by Tezcan et al. (2002) and Sener et al. (2009) based on Penman-Monteith method. Evaporation data calculated until 1998 were taken from Tezcan et al. (2002) and other data were also calculated by Sener et al. (2009).

Table 4 Statistics of the components of the water balance for the Akşehir Lake

	Minimum	Maximum	Mean	Std. deviation
P	275	633	417	84
R_s	7	127	59	30
E	933	1,436	1,116	141
Δh	−10	7	1	4

P is precipitation over the lake (mm), R_s is the surface runoff water inflow into lake (m^3), *E* is evaporation from the lake surface (mm), Δh is the yearly change in lake level (mm)

Statistics of the components of the water balance for the Lake Akşehir between 1965–2005 were listed in Table 4 and Fig. 9. The mean annual precipitation over the lake was 417 mm, surface runoff water inflow into lake was 59 m^3, evaporation from lake was 1,116 mm, and the change in lake level was 1 mm (Table 4).

Statistics of the components of the water balance for the Eber Lake between 1965–2001 were listed in Table 5 and Fig. 10. The mean annual precipitation over the lake was 345 mm, surface runoff water inflow into lake was 73 m^3, evaporation from lake was 987 mm, and the change in lake level was 0 mm (Table 5).

The time series of annual lakes water balance components from 1965 and 2005 in the Akşehir Lake and from 1995 to 2001 in the Eber Lake and are shown in Figs. 9 and 10.

In general, both lakes, year–year lake level variation were well in phase with change of precipitation, runoff and evaporation. There were indication that peaks

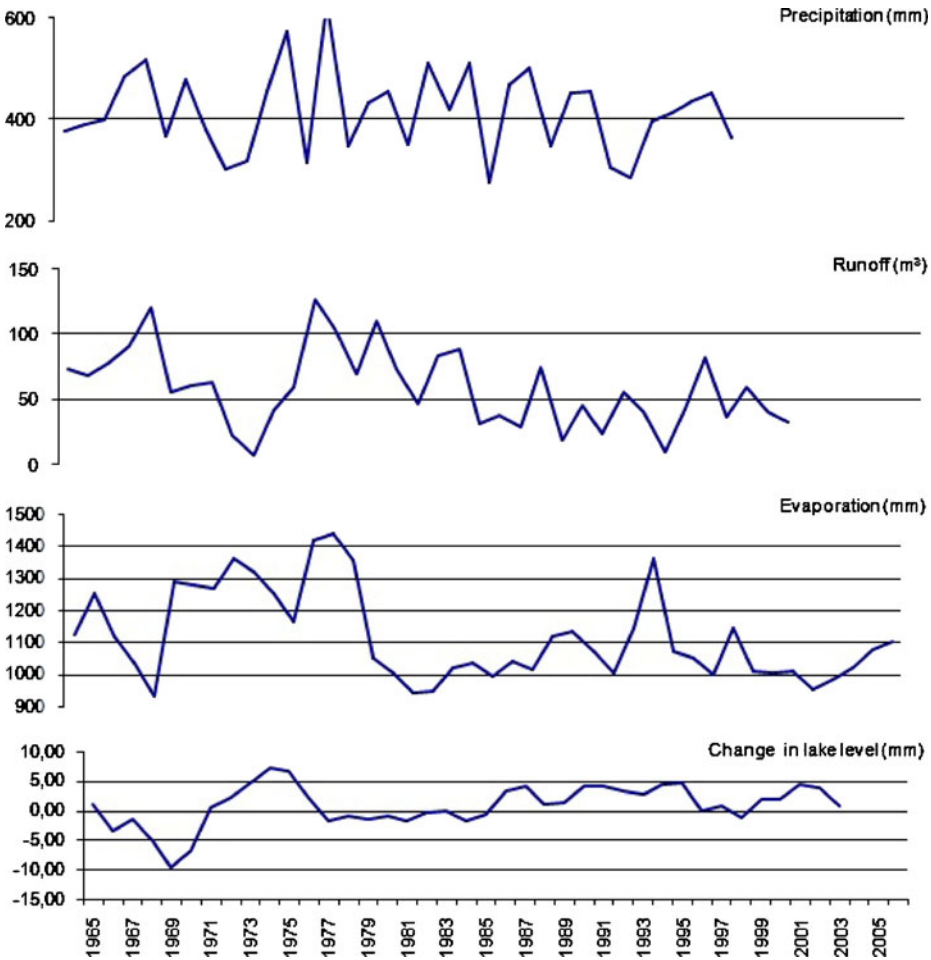

Fig. 9 Water balance components of the Akşehir Lake. From *top to bottom*, the time series are: precipitation (mm), runoff (m^3), evaporation (mm) and yearly changes in lake level (mm)

Table 5 Statistics of the components of the water balance for the Eber Lake

	Minimum	Maximum	Mean	Std. deviation
P	215	514	345	70
R_s	3	244	73	50
E	871	1,167	987	17
Δh	−6	4	0	2

P is precipitation over the lake (mm), R_s is the surface runoff water inflow into lake (m^3), *E* is evaporation from the lake surface (mm), Δh is the yearly change in lake level (mm)

in the rise of lakes level corresponded to the highest precipitation and runoff but the lowest evaporation, vice versa the peaks in the decline of lakes level corresponded to the lowest precipitation and runoff but the highest evaporation. This suggests that the decreasing precipitation and runoff or increasing evaporation are closely related to decline to the lakes level.

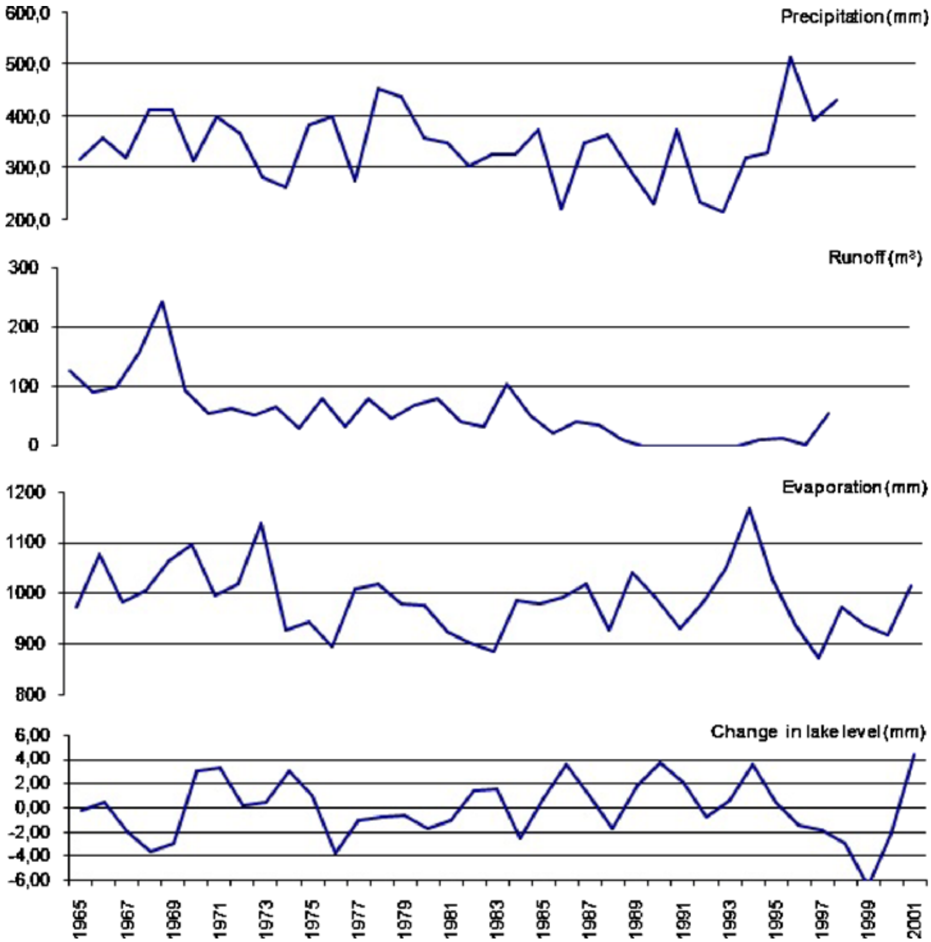

Fig. 10 Water balance components of the Eber Lake. From *top to bottom*, the time series are: precipitation (mm), runoff (m^3), evaporation (mm) and yearly changes in lake level (mm)

8 Causes of the Changes in the Coastline and Water Level

The causes of lake level fluctuations are usually attributed to anthropogenic and/or climatic factors. In other words, a lake's water balance is controlled both by water use from human activities (via population growth and irrigation systems) and climatic conditions (via precipitation, temperature and river discharge). These factors are discussed in the following sections.

9 Effect of Water Uses on Lake Level Variation

Water use is by definition the amount of water distributed to each sector. Water use can be broadly classified into agricultural, domestic, industrial uses. Meriç (2003) take water into account as an input to analyze the water use by each sector on Akarçar Basin. Of the overall water use in 2000, agricultural use accounted for 92%, domestic use 8% and industrial use about less than 1% (Meriç 2003). Table 6 illustrates the total and proportional water use of domestic, industrial and agricultural sectors in 1970 and 2000.

Agricultural use comprises of water used for farmland irrigation, animal husbandry and livestock. Although the total amount of water used in agriculture has increased in recent years, it remains the largest water user. Agriculture has long been a major source of income for many people living in the Akarçay Basin. The total of agricultural water use has increased from 121, 455 hm^3 in 1970 to 226,950 hm^3 in 2000.

The area of the farmland grew rapidly in the early 1970s through the growth of wheat, barley, potatoes, maize, cherries and vegetables. The area of farmland for agricultural irrigation was 13,263 ha, and irrigation accounted for 92% of the total water consumption in 2000. The quantity of cattle, sheep and goats and poultry in the Akarçay Basin area was 161,780 l/day, 414,070 l/day and 8,714,441 l/day, respectively, the mean annual water consumption for livestock was 5,686 hm^3, about 10% of the total water consumption in the basin.

In the basin since 1965, many irrigation systems have been built for agricultural irrigation, domestic use and flood control. These activities derive water from the dams, pounds and rivers to use on agriculture production areas during the dry season, enhancing evapotranspiration and infiltration and reducing the surface runoff. Three dams (Akdeğirmen, Selevir and Seyitler) (Fig. 1) and seven pounds (Kayabelen, Tınaztepe, Kırka, Erkmen, Ayaini, Seydiler and Ozburun) were constructed on the Akarçay River and its tributaries. The total volume and area of dams and pounds are 160,391 hm^3 and 1,640 km^2, respectively. The water surface area of irrigation systems (1,640 km^2) is very small compared with the water surface area of the Eber Lake (1,301 km^2). However, the water volume of irrigation systems (160,391 hm^3)

Table 6 Total and proportional water uses by each sector on Akarçay Basin in 1970 and 2000

	Agricultural use		Domestic use		Industrial use	
	hm^3	%	hm^3	%	hm^3	%
1970	121,455	93	9,878	7	0.112	<1
2000	226,950	92	19,474	8	0.223	<1

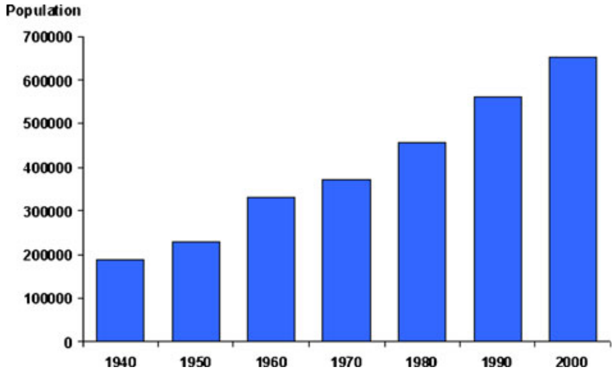

Fig. 11 Population growth on Akarçay Basin

almost compares to the water volume of the Eber Lake (215,000 hm^3). This is very important because it derives water from rivers for human activities such as agricultural irrigation and domestic uses upstream of lakes catchments. The water volume, nearly the entire water volume of the Eber Lake, is being held upstream of lakes catchments by dams and pounds. In addition, over the past two decades more than 1,636 legal and illegal water wells (between 10 and 70 m deep) have been built for irrigation purposes (Meriç 2003).

Domestic use refers to the water used for urban households, urban public sector, rural households. The water consumption for domestic use has increased substantially since 1970 with improvements in the standard of living, migration from rural to urban areas and growing population contributes partly to the increase.

The pressures on the Akarçay Basin area have been increased by the very high rates of human population growth, especially around the lakes themselves. The total population of the basin increased from 187,819 in 1940 to 650,831 in 2000, a growth of 463,012 people in six decades (Fig. 11). The population density reached 81 people per km^2 in 2000—only slightly lower than the average population density of the whole country (90 people per km^2) and is expected to increase at an average annual growth rate of 0.5%. In 2000, about 53% and 47% of the catchment's population lived in urban and rural areas, respectively, inhabiting in one city, nine towns and more scattered villages in the area. Half the total income in the basin was derived from agricultural activities, whereas the remaining income was generated from small-scale production, local business and trading (Meriç 2003).

Industrial use refers to the amount of water withdrawn for industrial purposes, mainly food and marble industries. Industry was not well developed in this area, and as such water use for industrial use accounts for less than 1% of the total water consumption.

10 Effect of Climatic Factors on Lake Level Variation

To estimate precipitation, temperature and evaporation on the catchments of lakes between 1975 and 2008, we used the monthly series of climate (1975–2008) from the Afyonkarahisar meteorological station because it is long enough and has uninterrupted climate records. Precipitation showed obvious fluctuations, with little increasing trends over the 33 years. The mean annual precipitation was 417 mm, and the lowest and the highest precipitation values were 521.8 mm in 1976 and 271.1 mm in 2004, respectively. Over the same periods, temperature showed a small increasing trend in the basin. The mean annual temperature was 11.2°C and the lowest and highest temperatures were 9.4°C in 1992 and 12.7°C in 2001. Although the annual mean precipitation and annual temperature vary substantially, they showed only a small increasing trend over the record period (Fig. 12).

Tezcan et al. (2002) reported that water levels of the Akşehir and Eber Lakes were sensitive to changes in both precipitation and temperature. The patterns of influence of precipitation and temperature on the lake levels, however, were different because

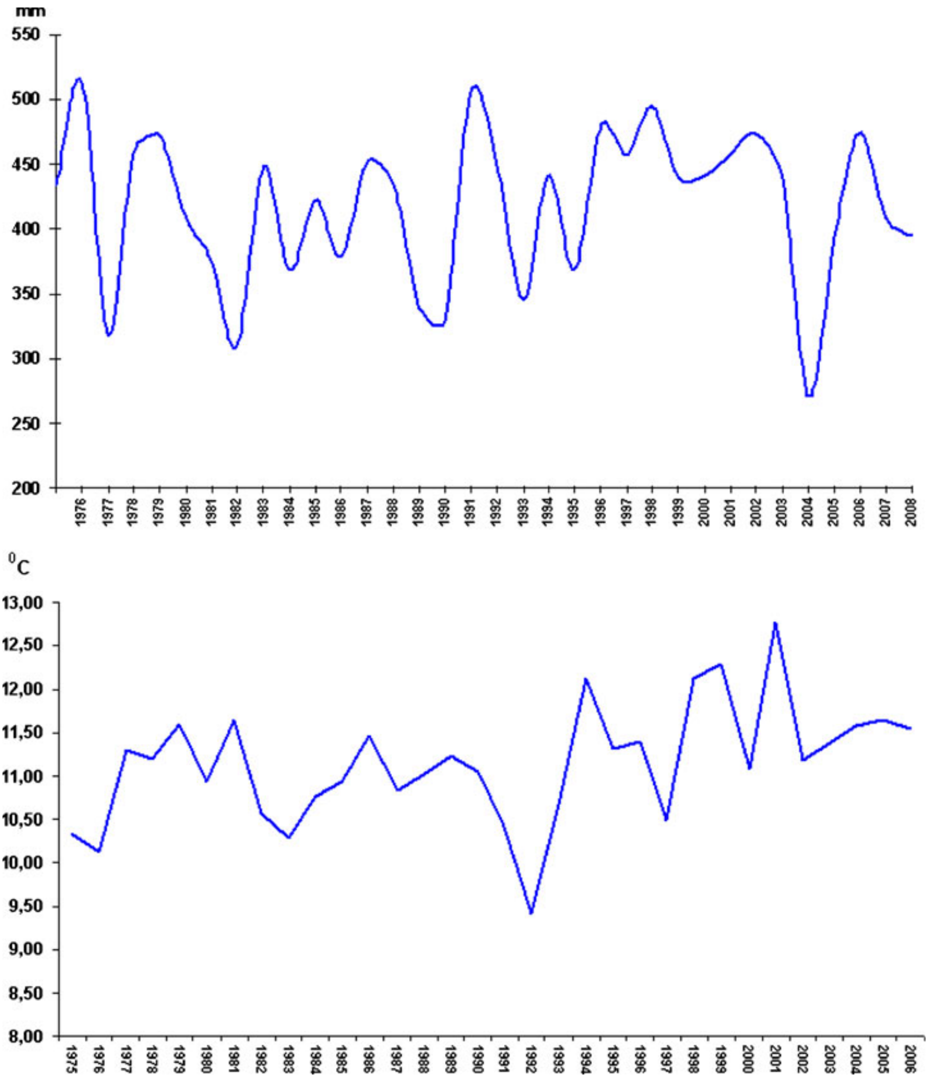

Fig. 12 Annual rainfall (*top*) and temperature (*bottom*) Afyonkarahisar meteorological station

changes in precipitation affected the surface runoff inflow into the lakes, whereas the changes in temperature affected evaporation through the outflow of the lakes.

11 Conclusion

This study investigated coastline and water level changes of lakes to identify the causes for the decline in lake levels using the satellite imagery, remote sensing techniques and in situ water level measurements, monthly temperature, precipitation and runoff data from 1975 to 2009. The results of imagery analyses showed that the water surface areas of the Akşehir and Eber Lakes decreased between 1975 and 2009 from 356,929 to 126,482 km^2 and 119,882 to 85,663 km^2, a loss of 64.5% and 28.4% over the 34-year period, respectively. The results of the ground lake level data (in situ) indicated that the Akşehir Lake level declined by 2.67 m from 956.02 m to 953.35 from 1975 to 2004, and the Eber Lake level also declined by 2.03 m from 966.75 m to 964.72 m from 1975 to 2004. The lakes have experienced a severe decline in water levels in recent decades. They are shallow lakes and as such small changes in depth can result in great changes in spatial extent. The results of hydrologic, climatic and human activities data analyses suggest that the change of lake levels might depend more on anthropogenic factors than on climatic factors.

The use of Landsat images, remote sensing techniques and hydrologic and climatic data provided valuable information on the temporal and spatial changes in the coastlines and water reserves of the Akşehir and Eber Lakes and the impact of human activity and climate on lake levels and water reserves. Therefore, these methods could be applied more extensively for lake monitoring purposes.

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