Evaluation of formation mechanism of lakes in terms of morphometric aspect; lakes region and their vicinity, SW of Turkey

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The formation mechanism of lakes located on the Lakes Region and their vicinity are assumed to have a tectonic origin but this assumption is still controversial. Because, tectonic movements, volcanic activity, and dissolution of limestone caused the formation of morphologically different type lakes in the region. In this study, Lake Avcıgöl, Lake Aksahehir, Lake Boyşehir, Lake Burdur, Lake Eğirdir, Lake Çavuşçu, Lake Salda, and Lake Yarıslı, located in the Lakes Region and their vicinity, were taken into consideration to evaluate their formation mechanism in terms of morphometric aspect. In the study, the lake surface areas are extracted from the Sentinel-2 satellite image by applying the Normalized Difference Water Index (NDWI) and Otsu Thresholding methods. Then lake morphology was quantified with morphometric metrics (Elongation Ratio, Compactness, Circularity Ratio) and Main Axis Orientation. The relationships between morphometric parameters and tectonic activity were evaluated by using tectonically active fault lines bounding the lake areas. The results reveal that the digital morphometric approach taken here not only allows more accurate measurement of lake morphology but also sheds light to understand the formation mechanisms of lake areas.

Introduction

Geomorphometry, whose origins date back to antiquity, first began to develop as a scientific field in the 18th century with the findings of Barnabe Brisson, Carl Gauss, and Alexander Von Humboldt (Pike et al., 2009). From this period to the present, many studies have been carried out on the subject. Horton (1945), who reinforced his academic career at the end of the 19th century, did important works in the fields of ecology, earth sciences, and hydrology. In 1942, he published the Horton equation to better examine the formation processes and structures of basins, he classified the basins according to age and drainage conditions, defined the concepts such as flow pattern, drain pressure, current frequency, and examined the formation and development of streams (Horton, 1945). Chorley (1957) made a study on the effects of climatic factors and climate on land morphometry, showed a new method to evaluate the spatial morphometry. Hakanson (1981) published a very comprehensive study on the basics of lake morphometry, which defined the morphometric parameters required for lake morphometry. Zavoianu (1985) explained and applied many morphometric parameters that we use today to a sample basin.

Recent developments in remote sensing, Geographic Information Systems (GIS), and computer technology provided comfort in the morphometric analysis, and the development of GIS programs brought about high precision measurements of the morphometric parameters. Patton and Baker (1976) conducted a study on morphometry and floods for a small drainage basin (<100 mi²) with aerial photographs taken from low altitudes, giving them a different perspective. One of the most important features of this study, separated from its predecessors, is that the remote sensing method is one of the first studies in the field of morphometry. Keller and Pinter (1996) published the works on the study of the relationship between tectonism and geomorphometry. Blais and Kalff (1995) published important works in which the effects of sedimentation on lake morphometry were investigated. Apart from these basic studies on basin, tectonism, and geomorphometry, Cox (1994), Hurtrez et al. (1999), Burbank and Anderson (2001), Kühni and Pfiffner (2001), Montgomery and Willett (2001), Azor et al. (2002), Tari and Tüysüz (2008), Perez-Peña et al. (2009), Apel (2011), Azañón et al. (2012), Sarp and Duzgun (2012), and Bhat et al. (2013) are also made some important studies related to this subject. In these studies, the formation mechanism of a region or basin, the tectonic activity of the basin, sometimes as a supportive study in floods, erosions, landslide risk analyzes or basin - settlement planning were taken into consideration.

The development of technological opportunities and increasing the accessibility of the high-resolution data led to the intense interest of the morphometric analyzes in the 21st century especially in the fields of lithology (tectonic, morphic, erosion, landslide, etc.) and hydrology (watershed planning, flood, limnology, etc.). Although it is a new field, it is possible to say that there is a young and dynamic working area by looking at the increase in recent studies (Küçük, 2018).

In this study, eight large lakes (Avcıgöl, Aksahehir, Boyşehir, Burdur, Eğirdir, Çavuşçu, Salda, and Yarıslı) located in the Lakes Region and their vicinity were investigated. In the study area, tectonic movements, volcanic activity, and dissolution of limestone caused the formation of morphologically different types of lakes. The lakes lie in a northward
curve of the Taurus range known as the Isparta Angle and the same tectonism likely formed both the Isparta Angle and the graben features (Kazanci and Roberts, 2019). According to Nemec and Kazanci (1999) tectonic faulting caused the formation of Neogene basins in southwestern Anatolia, with the current lakes being placed there in Late Quaternary times. Koçyiğit (1984) stated that the geologic events and the features representing the Neotectonic period in SW of the Turkey and adjacent areas are a result of the tensional tectonic regime.

Although, the majority of the lakes in the Lakes Region are assumed to have a tectonic origin this assumption is still controversial. Because, morphotectonic features like fault scarps, a stepped series of active normal faults, preserved around lakes allow delineating the tectonic history of the lakes is not observed for all lakes. For that reason, in the study morphotectonic properties that are preserved in the recent landscape were used to sheds light on the formation mechanisms of lakes.

### Study Area

The study area known as Lakes Region covers a large area where the Mediterranean, Aegean, and Central Anatolia regions intersect. The boundaries of the region are generally shaped by Lake Acıgöl, Lake Akşehir, Lake Burdur, Lake Eğirdir, Lake Salda, Lake Yarıslı, and Lake B yeşehir basins (Fig. 1). The region is more concave than the surrounding area due to tectonically active faults fractures. This area, where tectonic traces are intensely observed, is shaped by the Fethiye - Burdur Fault Zone (FBFZ) in the southwest and by the Akşehir Fault Zone (AFZ) in the north (Fig. 2). Isparta Bend (IB), which is referred to as FBFZ and also known as Isparta Angle, is one of the most important factors shaping the regional topography of the area (Avşar, 2013). In the region, the elevation values are at least 746 m with a maximum of 2985 m.

### Site Geology

Interpreting the general characteristics of the site, which covers the intersection of the Aegean - Mediterranean - Central Anatolia regions and its environs, is a transition region between the Central Anatolia Region and the West Anatolia Expansion Zone (Avşar, 2013). This region, which transfers the energy of the East and Central Anatolian Congestion Zones to the Western Stress Zone via the İnönü - Eskişehir Fault Zone (IEFZ) and FBFZ, has undergone a serious deformation due to faulting and has reached today's structural diversity (Fig. 2). The aforementioned studies have tried to describe the FBFZ; yet, they have stated different characteristics of the FBFZ. Early studies indicated that FBFZ in the west wing of the Isparta Angle and is expressed as the left lateral strike fault zone in the southern Pliny-Strabo transformation region (Kaymakçı et al., 2014; Elitez et al., 2016; Ozbakır et al., 2017). However, Hall et al. (2014) explained that FBFZ is considered to be a normal faulting zone without remarkable strike-slip prop-

![Figure 1. Location map of the study area.](image)
properties. Additionally, geology, seismology, and GPS studies made on Burdur-Fethiye route have indicated the existence of a large and complex deformation zone consisting of hundreds of active left-sided strike-slip and normal faults (Barka and Reilinger, 1997).

Acıgöl graben is one of the NE-SW trending grabens in SW Anatolia, Turkey. The base of the Acıgöl graben consists of ultramafic rocks and Mesozoic-Paleogene carbonates (Göktaş et al., 1989; Şenel, 1997; Konak and Şenel, 2002). In the Acıgöl Basin, the Neogene basin fill is composed of coarse clastic of alluvial fans, fine clastics of fluvial channel deposits, and lacustrine deposits including evaporitic intercalations. These Neogene basin fills unconformably overlying on the Quaternary units (Göktaş et al., 1989).

The geomorphological, sedimentological, and hydrological features of the Akşehir basin have developed mainly due to the tectonic structure. The most important tectonic structure in the study area is the Sultandağı Fault, which lies to the south of the lake area. This fault played an important role in the development of the graben characteristic of the basin (Kale, 2018; Özçelik, 2019).

The Burdur basin of SW Turkey is a NE-SW trending half-graben with a major basement fault along its SE margin. In the Basin Continental, syn-rift sedimentation starts in late Miocene early Pliocene times and sustained till the end of the Pliocene, when the basin-controlling basement fault became inactive. Meanwhile, the faulting activity moved to NW and caused the collapse of the present-day basin containing Lake Burdur (Price and Scott, 1991).

There are different opinions about the formation mechanism of Lake Eğirdir in the literature. According to Alagöz (1944) the Lake Eğirdir depression originated from karst during the Pliocene-Pleistocene, when it was also filled with water. Lahn (1945, 1948) suggested that the lake depression had a tectonic origin and was filled with water in the last part of the Neogene. Ardel (1953) stated that the lake was caused by the collapse of a large polje and the small islands in the lake supported this explanation. According to Kazancı (1993) in the south of Lake Eğirdir, the series of alluvial cones running towards the lake includes pyroclastic fall deposits. These pyroclastics are products of Pliocene Gölcük (Isparta) volcanism, and thus the lake basin developed before the mid-late Pliocene.

Lake Eğirdir occupies, together with Lake Beyşehir and Lake Burdur, a wetland area termed the ‘Lake District’. The age of the Lake Eğirdir basin is related to the displacements caused by the South-western Anatolian Fault and the Kırkavak Fault on the eastern margin of the Isparta Angle, which took place during the Middle Miocene. The position of the three lakes is also closely related to the Isparta Angle (Blumenthal, 1963), or the Isparta Angle (Koçyiğit, 1983).

Lake Salda is a closed basin, formed in the tectonic space, located within the Yeşilova (Burdur) province in south-western Anatolia (Davraz et al., 2019). The basin of the lake consists of various rock units, including peridotites, alluvium, limestone, dunites, conglomer-
mates, melange, sandstone, mudstones, and chert (Kazancı et al., 2004; Danladi an Akçer-Ön, 2018). The mountainous surroundings of Lake Salda include ultramafic and karstified carbonate rocks (Brathwaite and Zedef, 1996; Kazancı et al., 2004).

Lake Yarışlı is a closed basin, located SW of Lake Burdur. In the lake basin area, allochthonous and autochthonous rock units are found (Davraz and Çakmak, 2016). Units belonging to the Lycian Napes (Graciansky, 1972; Poisson, 1977) constitute the main rocks of the study area. The visible basis of the area is the Ophiolitic Melange (Poisson, 1977; Şenel et al., 1989; Şenel and Bölükbaş, 1997; Moix et al., 2013; Coşkuner, 2017; Yılmaz and Caran, 2019), most of which are serpentinized ophiolitic rocks and mapped limestone blocks within this community. The Ophiolitic Melange consists of serpentinite, peridotite, amphibolite, gabbro, basalt, spilite, pyroclastics, and limestone blocks within the matrix made of sandy-clayey sediments (Coşkuner et al., 2019).

Site Hydrogeology

When the study area is examined hydrologically; the Acıgöl drainage basin has very poor rivers and seasonal rivers. The rivers in the basin are generally shallow and some streams do not reach the lake even when the rainfall reaches the maximum (Bahadır and Özdemir, 2011) (Fig. 3). The main streams feeding the Lake Acıgöl can be said to be Değirmen Stream and Çimçim Stream. Although the Teke Stream and its environs in the north of the basin show a more frequent drainage structure in the area, today most of these rivers cannot reach the lake bowl. According to Erinç (1967), the old terraces and river valleys found in this region are 30 m from the present level of Lake Acıgöl. It can be interpreted that the gradual collapse occurred as a result of the tectonic activities occurring in the Pleistocene changed the direction of many streams feeding the lake (Erinç, 1967). In the same period, Lake Akşehir is another lake whose hydrological balance change due to tectonic and climatic events. It is possible to find traces of this change through the cliffs and terraces in some areas around the lake, ranging from 965 to 1,000 m (Bahadır, 2013). Akar Çay Stream, which gave its name to the basin in which Lake Akşehir is also located, is one of the most important nutritional sources for Lake Eber and Lake Akşehir. But now Lake Akşehir has lost its connection with this basic resource due to regulator construction the stream and now Adıyan River has become the main source of nutrition for Lake Akşehir (Bahadır, 2013).

The studies conducted in the Lake Beyşehir drainage basin indicate that the basin extends to Yalvaç and Eğirdir before the Neogene and the terraces to the north of the basin are formed during this period (Birlicek, 1982). Lake Beyşehir, located in Konya closed basin section of the site, with the effect of the surrounding relief, especially in the spring months, melting snow waters, spring waters, and underground waters feeding on the base of the ground outside the north of Eğri Stream, east of Bağ Deresi Stream, Sarıöz Stream and Beyşehir Channel (Çarşamba Stream), in the south of the Bitüşük Beyşehir Channel with the evacuation of the water, it forms the main drainage network of the lake.
The rivers in the Lake Burdur drainage basin are generally flood-type, periodic streams (Gülle and Atayeter, 2016). The main streams feeding the lake are Eren Stream and Bozçay Stream which is located in the south of the basin. Apart from these, streams such as Özdere and Kuzgun Streams, which form the branches of the Büğdüz River and Eren Stream, are important sources for Lake Burdur but they are usually dried in the summer months (Fig. 3).

The Lake Çavuşçu drainage basin, which is included in the Sakarya basin section of the site, has many seasonal rivers. Rivers that feed the rather shallow Lake Çavuşçu are Çiğil Stream, Mahmuthisar Stream, Bulçuk Stream, and Battal Stream ( Dönmez, 2010).

Lake Eğirdir is the main source of the Kaşkara basin and the Kovada basin. This lake extends in the K-G direction and provides a unique view of the northern part of the lake at an angle of about 40° to the west as a result of the deformation experienced in the FBFZ-IB line ( Karaman, 2010). Located in the north of the lake, seasonal rivers coming from the Kaşkara basin, Karakuş Mountains and Sultan Mountains, and Pupa Stream and Özdere stream are the main streams feeding the lake (Figs. 2 and 3).

The Lake Salda drainage basin, located on the western border of the Burdur drainage basin, has a relatively small basin with an approximately 187.6 km² surface area. Nevertheless, after Lake Van, it is the second deepest lake of Turkey (128 m) ( Kazancı and Roberts, 2019). Apart from the Düden River, which is one of the main sources feeding the lake. The Lake area is fed by Kurucan Stream from the north-west and Kuruçay Stream and Değirmen Stream from the south. Again, within the boundaries of the Lake Burdur drainage basin, between the Lake Salda and Lake Burdur drainage basin, the Lake Yarışlı drainage basin collects water from a basin of approximately 300 km² area. The flows of most of the streams in the basin show a decrease in dry periods. Suuçutu Stream, one of the most important rivers feeding the lake area (Fig. 3).

**Data Sets**

ASTER GDEM with 30 m resolution, Sentinel-2 multispectral satellite imagery with 10 m resolution belonging to in April 2017, and 1/500,000 scale fault maps are the main data sets used to estimate the formation mechanism of the lakes and lakes basin.

ASTER GDEM data and Sentinel-2 satellite image in GeoTIFF format are freely downloaded from the Global land cover facility (https://earthexplorer.usgs.gov/) web site. Fault lines and lithological units of the basin area are digitized from the 1/250,000 and 1/500,000 scale geological maps generated and published by the General Directorate of Mineral Research and Exploration of Turkey (MTA) (http://www.mta.gov.tr/v3.0/hizmetler/500bas).

**Methodology**

The method of the study comprises three different phases, as given in Fig. 4. The first phase is the determination of the lake boundaries from the Sentinel-2A by using NDWI and Otsu Thresholding. The second phase is the extraction of the lake catchment areas from the ASTER GDEM data. The third phase is the application of the morphometric indices (Elongation Ratio (Re), Compactness (Rc), Circularity Ratio (c)) and main axis orientation (α) analysis to the lake surface areas. The final phase is the evaluation of the morphometric parameters to determine tectonic activity and determination of the relation among the lake, basin, and fault lines by using main axis orientation (α).

**Normalized Difference Water Index (NDWI)**

The water body has strong absorbability and low radiation in the range from visible to infrared wavelengths. This property has involved the delineation of open water using thematic information extraction techniques. The NDWI index proposed by McFeeters (1996) is most appropriate for water body mapping. This index uses the Green and Near Infra-Red (NIR) bands of remote sensing images by using the advantage of reflective differences of these bands. The NDWI can enhance the water information effectively in most cases (Sentinel-Hub, 2019). It is sensitive to built-up land and often results in overestimated water bodies. NDVI is calculated as given in Eq. (1):

$$NDWI = \frac{Green - NIR}{Green + NIR}$$ (1)

The resulted NDWI values are range from -1 to +1. In the resulted NDWI image, water features have positive values and thus are enhanced, while vegetation and soil usually have zero or negative values and therefore are suppressed.

**Otsu Thresholding**

In image segmentation, thresholding is an effective tool to separate the object from the background when the gray levels are substantially different between them (Sahoo et al., 1988). The basic idea of automatic thresholding is to automatically choose the most appropriate gray level threshold value to separate objects of interest in an image from the background according to their gray level distribution (Hui-Fuang, 2006). Among the global thresholding techniques, the Otsu method (Otsu, 1979) is one of the better threshold selection methods for general real-world images in terms of uniformity and shape dimensions. This method selects the threshold values that maximize the cross-class variances of the histogram (Hui-Fuang, 2006).

**Morphometric Analysis**

There are many indices developed for morphometric applications.
However, in this study, well-known indices have been chosen, especially to prove the tectonic activity of the lakes. Applied indexes (Elongation Ratio ($R_e$), Compactness ($R_c$), Circularity Ratio ($c$), Main Axis Orientation ($\alpha$)) do not require expert interaction and give clear results.

### Elongation Ratio ($R_e$)

Elongation ratio ($R_e$) is one of the main areal properties of the basin expressing the overall plan form and dimensions of the basin. In tectonically active regions, $R_e$ is also indicative of regional stress direction. $R_e$ is calculated as given in Eq. (2):

$$R_e = \frac{2 \sqrt{A}}{L_b}$$

where $A$ is the basin area and $L_b$ is the maximum length of the basin parallel to the mainstream. The $R_e$ values range from 1.0 for a circle to 0.0 for a straight line. Strahler (1964) states that basin elongation ranges from 0.6 to 1.0 depending on the region's climate and geological characteristics. The values close to 1.0 indicate the areas having a very low slope and low elevation; values between 0.6 and 0.8 are associated with high relief and high slope (Dar et al., 2013). According to Cuong and Zuchiewicz (2001), $R_e$ values less than 0.5 indicates that the basin is tectonically active. The values between 0.5 and 0.75 indicate tectonically medium activity and a value greater than 0.75 can be considered as an inactive basin.

### Compactness ($R_c$)

The variation of the physiographical conditions due to tectonic activity in a region plays an important role in the basin shape formation. In tectonically active regions generally, basins are more elongated compared to those tectonically inactive regions. This physical property of the basin can be used as one of the indicators for determining the tectonic activity of the region. Basin compactness ($R_c$) is one of the indicators of this. $R_c$ is calculated by using the Eq. (3)

$$R_c = \frac{L}{W}$$

where $L$ and $W$ represent the length and width of the basin, respectively. The resulted $R_c$ values range from 0 to 1 and values away from 1 indicate the increasing tectonic activity (Morgenstern et al., 2011; Sarp and Duzgun, 2012).

### Circularity Ratio ($c$)

The Circularity Ratio ($c$) is used to determine how much the shape of an object deviates from a perfect circle. It is affected by the length and frequency of the streams, geological structures, land use/land cover, climate, relief, and slope of the basin (Patel, 2012). $c$ values close to zero refer to away from circularity; and values close to 1 refer to the conditions closest to circularity (Miller, 1958; Morgenstern et al., 2011). $c$ is calculated by using the Eq. (4)

$$c = \frac{4\pi A}{P^2}$$

where $A$ is the basin area and $P$ is the basin perimeter. In practice, the $c$ is never equal to unity, because the variation of physiographical factors and the general relief slope always impart an elongated shape to basins (Zavoianu, 1985).

### Direction of Major Axis ($\alpha$)

By measuring the orientation of the tectonically active fault lines, lake surface areas the influence of the tectonic activity on the lake areas was evaluated. In this study direction of the main axis ($\alpha$) of the lake, areas were defined by the general compass direction of the maximum length ($L_{max}$).

The $L_{max}$ of the lake surface areas were considered as the long axes of minimum bounding rectangle constructed on the lake surface area. The results of the $\alpha$ are given as azimuth bearing which uses all 360° of a compass bearing to indicate direction. The $\alpha$ values are obtained in terms of the numerical meaning of the angle of the main extension axis of the lake area. To easily read and interpret these numerical values, the extension values are visualized on the graphs. Thus, the effects of tectonic activity in the direction of the extension of the lake basin axes can be easily interpreted.

### Results

The lake surface areas are extracted from the Sentinel 2A satellite images by applying NFSI and Otsu thresholding (Fig. 5). The main reason for using these methods is to prevent the effect of expert knowledge and opinion in the determination of lake surface area and to provide consistency between the boundaries of the lake surface areas and to minimize the margin of error due to their surface water reflectance values. By using this method, all kinds of bias and error in determining the lake surface areas by manual digitization are eliminated.

According to derived results, Lake Beyşehir presents the largest surface area (628.5 km²), while Lake Yarışlı presents the smallest surface area (14.7 km²) among the studied lakes (Table 1). The required width and length values for the morphometric analysis were calculated by fitting the minimum bounding rectangle over the lake surface areas.

The results of $R_e$, $R_c$, and $c$ measurements for the eight lakes are summarized in Table 2. In the lake areas, $R_e$ values vary between 0.50 and 0.89, indicating a high rate of tectonic influence on the formation of Lake Eğirdir, moderate tectonic influence on the formation of Lake Acıgöl, Lake Akşehir, Lake Beyşehir, Lake Burdur, and no tectonic influence on the formation of Lake Çavuşçu, Lake Salda, and Lake Yarışlı.

The resulted $R_c$ values vary between 1.19 and 3.02. If the $R_c$ values are sorted in itself. The order of the tectonic influence on the lakes starting from low to high is as follows: Lake Yarışlı (1.19), Lake Salda (1.28), Lake Akşehir (1.60), Lake Beyşehir (1.75), Lake Çavuşçu (1.76), Lake Acıgöl (2.71), Lake Eğirdir (2.74), Lake Burdur (3.02). The differences in these $R_c$ values reveals the degree of influence of the slope, relief, structure, and tectonics of geological formations (Singh, 1970).

The resulted $c$ values vary from 0.05 and 0.71. The higher the value represents the more circularity in the shape of the basin and vice-versa. According to $c$ values, Lake Acıgöl, Lake Salda, and Lake Yarışlı are close to circularity indicating the mature stage of the lakes. On the other hand; Lake Akşehir, Lake Beyşehir, Lake Burdur, Lake Çavuşçu, and Lake Eğirdir are far from circularity indicating not only the young stage of these lakes but also a high rate of tectonic influences on the lake areas.

Pre-existing fault structures adopted from Koçyiğit (1984) given in Fig. 6 were used for understanding how preexisting structures such as regional tectonic faults affect the orientation and the formation pro-
cess of the lakes. Because the orientation of lake basins may be controlled with the same tectonic stress that also formed the fault lines. The closeness of the lake axis orientation and the azimuth directions of the main faults limiting the lake area indicates that the lake area is affected by the tectonic activity.

According to lake axis orientation and azimuth direction of the main faults bounding the lake area (Fig. 7), the major axis orientation of the Lake Acıgöl is 69° and the azimuthal direction of Northern and Southern bounding fault axes are 64.1° and 70.2°, respectively. The azimuthal direction of the major axis of the fault that bound the Lake Akşehir is 48.7° and the main axis orientations of the Lake Akşehir is 53.2°. The azimuthal direction of the major axis of the Beyşehir Faults that bound the Lake Beyşehir is 146.2° and the main axis orientations of the Lake Beyşehir is 153.2°. It is therefore very likely that there is a genetic connection between the fault lines and Lake Acıgöl, Lake Akşehir, Lake Beyşehir basins.

The azimuthal direction of the southwestern and northeastern major axis of the faults that bound the Lake Burdur are 48.6° and 25.4°, respectively. And conversely, the main axis orientation of the Lake Burdur is 55°. This result can be interpreted that the effects of the SW bounding fault are higher than the NE bounding fault on the formation of the lake basin. The western and NE of major axis directions of the faults that bound the Lake Çavuşçu are 174.5° and 14°, respectively. On the other hand, the main axis orientations of Lake Çavuşçu is 176.7°. This result can be interpreted as a more dominant tectonic influence of the western bounding fault on the formation of the lake basin concerning the northeastern bounding fault.

The direction of the major axis of the faults that bound the Lake Salda is 85.5° and the main axis orientation of the Lake Salda is 174.3°. On the other hand, the direction of N and E major axis of the faults that bound the Lake Yarışlı are 25.1° and 48.6°, respectively. And conversely, the main axis orientation of the Lake Yarışlı is 170.3°. This result can be interpreted that the Lake Yarışlı and Lake Salda are tectonically very less or no affected by the bounding faults. It is therefore very likely

| Lake Name   | Max. Length (km) | Max. Width (km) | Surface Area (km²) |
|-------------|------------------|-----------------|--------------------|
| Acıgöl      | 10.1             | 3.7             | 24.7               |
| Akşehir     | 15.4             | 9.6             | 93.9               |
| Beyşehir    | 44.5             | 25.4            | 628.5              |
| Burdur      | 24.6             | 8.2             | 130.6              |
| Çavuşçu     | 5.8              | 3.3             | 15                 |
| Eğirdir     | 48.1             | 17.8            | 456.8              |
| Salda       | 8.8              | 6.9             | 44.1               |
| Yarışlı      | 4.9              | 4.1             | 14.7               |

Figure 5. Lake surface areas obtained by applying Normalized Difference Water Index (NDWI) and Otsu thresholding.

Table 1. Descriptive properties of the lake surface areas
Table 2. Morphometric metrics (Elongation, Compactness, Circularity) of the lakes and main axis orientation of lakes and bounding faults

| Index | Name         | Elongation Ratio (Re) | Compactness (Rc) | Circularity Ratio (c) | Main Axis Orientation (α) | Origin                      |
|-------|--------------|-----------------------|------------------|-----------------------|---------------------------|-----------------------------|
|       | Indicators of tectonic activity | Re ≤<0.5 Tectonically active (0.5< Re ≤0.75 Tectonically medium active Re≥=0.75 Tectonically inactive |                   |                       |                           |                             |
|       |              | Tectonic activity increases away from “1” | 0; 1, 1=perfect circle; mature stage | The main axis of the lake and the faults in the vicinity are interpreted in terms of their angle to the north |                           |                             |

| Lake Name | Value | Result | Value | Result | Value | Result | Value | Result |
|-----------|-------|--------|-------|--------|-------|--------|-------|--------|
| Acıgöl    | 0.54  | Moderate activity | 2.71  | Tectonic effect is high | 0.52  | Far from circularity | Lake axis= 69° N fault axis= 64.1° S fault axis= 70.2° | Axes of faults and lake close to each other | Tectonic | (Kazancı and Roberts, 2019) |
| Akşehir   | 0.71  | Moderate activity | 1.60  | Tectonic effect is low | 0.05  | Too far from circularity | Lake axis= 53.2° Fault axis= 48.7° | Axes of faults and lake close to each other | Tectonic | (Kazancı and Roberts, 2019) |
| Beyşehir  | 0.64  | Moderate activity | 1.75  | Tectonic effect is low | 0.08  | Too far from circularity | Lake axis= 153.2° Fault axis= 146.2° | Axes of faults and lake close to each other | Tectonic | (Kazancı and Roberts, 2019; Aksu, 2011) |
| Burdur    | 0.52  | Moderate activity | 3.02  | Tectonic effect is high | 0.47  | Far from circularity | Lake axis= 55° SW fault axis= 48.6° NE fault axis=25.4° | Axes of the SW fault and lake close to each other | Tectonic | (Kazancı and Roberts, 2019) |
| Çavuşçu   | 0.76  | Tectonically inactive | 1.76  | Tectonic effect is low | 0.47  | Far from circularity | Lake axis= 176.7° W fault axis= 174.5° NE fault axis=14 ° | Axes of the W fault and lake close to each other | Damming (regulated) | (Kazancı and Roberts, 2019) |
| Eğridir   | 0.50  | Tectonically active | 2.74  | Tectonic effect is high | 0.15  | Too far from circularity | Lake axis= 176.7° S fault axis= 178.7° E fault axis=15.6 ° | Axes of faults and lake close to each other | Tectonic | (Kazancı and Roberts, 2019; Aksu, 2011; Karaman, 2010) |
| Salda     | 0.85  | Tectonically inactive | 1.28  | Tectonic effect is very low | 0.71  | Closest to circularity | Lake axis= 174.3° Fault axis= 85.5° | Axes of faults and lake far from each other | Tectonic | (Kazancı and Roberts, 2019) |
| Yarıslı    | 0.89  | Tectonically inactive | 1.19  | Tectonic effect is very low | 0.66  | Close to circularity | Lake axis= 170.3° N fault axis= 25.1° E fault axis=48.6° | Axes of faults and lake far from each other | Tectonic | (Kazancı and Roberts, 2019) |
that there is very little or no genetic connection between the fault lines and these lake basins.

**Discussion**

Lakes may present variable form in terms of their formation and evolution, which are dependent on interactions with tectonic forces, surface morphology, lithology, and climate, etc. conditions. For a good interpretation of quantitative morphometric features such as size, form, and special factors, the lake form and its function must be fully understood (Hakanson, 2004). Our investigations highlight the diversity of lake types present in the Lakes Region and its vicinity. Based on the available literature and this study we made some preliminary generalizations about the formation process of the lakes. Not surprisingly, the majority of the lakes of the study area are directly or indirectly affected by tectonic activity.

In the study, these pre-mentioned formation processes were also verified in the study with the morphometric parameters. Fault lines bounding the lake areas, used for the directional analysis, are taken from the previous study made by Kocyiğit (1984). For this reason, no land-controlled questioning the accuracy of the fault lines. The error rate occurring during the georeferencing of the printed map used for digitization is made to be less than half of the contour spacing according to USGS standards and there may be errors in the horizontal direction depending on the scale.

The application of morphometric indices is the backbone of the study. These indexes are mostly formulated by subtracting from the basin shape and the behavior of drainage lines. In these analyses, the fact that the bathymetric data of the lakes are not integrated into the morphometric indices is seen as a deficiency in terms of objective evaluation of the accuracy of the analysis results.

Some lakes basins lie in full symmetric graben (e.g., Burdur, Açığöl) or half-graben (e.g., Beyşehir), while Lake Eğirdir occupies a complex double-basin tectonic structure (Kazancı and Roberts, 2019). The Burdur basin of SW Turkey is a NE-SW trending half-graben with a major basement fault along its SE margin (Price and Scott, 1991). Continental syn-rift sedimentation began in the early Pliocene in late Miocene and continued until the end of the Pliocene, where basin-controlling basement fault was ineffective. Meanwhile, the fault activity moved to NW and caused the collapse of the present-day basin where Lake Burdur is located (Price and Scott, 1991). In this study, the tectonic origin of the Lake Burdur is verified with the Elongation Ratio (Re), Compactness (Rc), Circularity Ratio (c), and the main axis of the lake and the faults in the vicinity.

All fault structures determined around Lake Eğirdir and Lake Beyşehir showed that both lakes continue to be formed in the system.
of the graben basin and extended (Aksu, 2011). According to Reeves (1968) classification, Lake Akşehir is a semi-circular lake (Atalay, 1977; Kazancı et al., 1994). The Akşehir Fault, which extends to the south of the study area, has played a major role in the development of a graben characteristic of the Lake Akşehir basin (Kale, 2018). This fault is a normal fault with a small component of strike-slip (Topal et al., 2016). Based on modeling of the 2000 Sultandağı and 2002 Çay earthquakes, the Akşehir Fault has an average dip of about 60° to the NE (Koçyiğit and Özacak, 2003). A clear fault scarp runs along the western side of the lake, and a series of large alluvial fans form a transitional zone between the Sultan Mountains and Lake Akşehir. These also indicate the tectonic activity of the region affecting the lake basin formation. In this study, the tectonic origin of the Lake Akşehir is verified with the Elongation Ratio (Re), Circularity Ratio (c), and the main axis of the lake and the faults in the vicinity.

Acıgöl fault scarp, a large number of water discharges along the Acıgöl fault and leaning of lake Acıgöl towards the south of the basin, indicates that the Acıgöl Fault is a tectonically active normal fault (Topal, 2018). In this study, the tectonic origin of the Lake Acıgöl is verified with the Elongation Ratio (Re), Compactness (Rc), Circularity Ratio (c), and the main axis of the lake and the faults in the vicinity.

The origin of the Lake Salda basin is not clear, since it does not lie in a graben, as do the other large lakes of south-west Anatolia (Kazancı and Roberts, 2019). The results of the Elongation Ratio (Re), Compactness (Rc), Circularity Ratio (c), and the main axis of the lake and the faults in the vicinity showed that Lake Salda is likely karstic origin.

The study area is tectonically active in both space and time and is tectonically highly disturbed by earthquakes, folding, faulting, and other neotectonics movements. All these have a direct impact in controlling the morphology of the lakes. However potential lithologic controls, need to be examined before assigning the level of tectonic influence.

Conclusions

In the study, four different morphometric indexes (Re, Rc, c, and α) were applied to the lake basin areas to determine the formation process and the relation of the lake areas with tectonic activity.

According to the results, in the area faulting has played an important role in lake basin formation. The tectonic origin of the Lake Acıgöl, Lake Akşehir, Lake Beyşehir, Lake Burdur, and Lake Eğirdir and the karstic origin of the Lake Salda has been validated by the Re, Rc, c, and α values. In general, the smaller lakes are karstic in origin while larger ones are formed in graben, although some lakes are influenced by both tectonic and karstic processes, such as Lake Beyşehir.

References

Aksu, H.H., 2011. Tectonic interpretation of Eğirdir and Beyşehir Lake basins by geophysical studies. Thesis (Ph.D.), Süleyman Demirel University, Turkey, (In Turkish)
Alagöz, C.A., 1944. A research on the karst phenomena in Turkey. Turkish Geographical Review, v. 0, pp. 86-92, (in Turkish)
Apel, E.V., 2011. Shells on a sphere: tectonic plate motion and plate
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