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A scientific analysis on the water levels of Lake Beyşehir and drought conditions in the area

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ABSTRACT Lake Beyşehir is a crucial water resource for its region; however, its water level has visibly decreased over the past decade, thus posing a threat to the lake's sustainability. This study aims to investigate the causes behind this phenomenon and its impact on the lake surface area. To achieve this, the study uses monthly lake water level data from the Copernicus Land Service, meteorological data, and Sentinel-2 high-resolution satellite images. From these data sets, four indices are calculated for the period between 2015 and 2020: the Standardised Precipitation Index (*SPI*), Standardised Precipitation Evapotranspiration Index (*SPEI*), Normalised Difference Water Index (*NDWI*), and Modified Normalised Difference Water Index (*MNDWI*). The results of the analysis indicate a significant decrease in the lake water level over the past ten years, along with mild, extreme, and severe drought conditions. Additionally, the Sentinel-2 images show a gradual reduction in the lake surface area during the same period. The study underscores the urgent need to address the impacts of climate change on freshwater resources to ensure the sustainability of Lake Beyşehir and its surroundings.

1. Introduction

Societies make use of freshwater lakes and rivers for many purposes, among which tourism, trade, fishing, irrigation, and providing drinking water (Saber *et al.*, 2020). An important aspect of lakes is their great impact on the climate of their environment. For example, in summer, not only are lake areas cooler than non-lake areas, but people can live there without resorting to energy sources. Similarly, in winter, the warmer air of lake areas, compared to that of other areas, contributes to soil fertility, to the prevention of premature flowering of agricultural products, to the reduction of frost risk, etc. In addition, fishing activities in lakes contribute to the economy of the region. More importantly, in recent years, the effect of climate change on the Earth, and the increasing number of natural events, such as fires, floods and erosion, have heightened the importance of lake monitoring, lakes being one of the most important areas influenced by climate change. Lake water levels, rainfall amounts, signs of drought, agricultural activity yields, etc. can be considered as the most important factors for lake monitoring.

Water level changes and droughts are the most important consequences of weather and climate change. Water levels are influenced by factors such as precipitation, melting snow, drought, water evaporation, and drinking water use (https://www.epa.gov/climate-indicators/great-lakes, accessed September 2022). In particular, decreasing lake water levels may restrict the use of coastal facilities such as quays and piers, and interrupt fishing activities. Increasing lake levels have a negative impact on the towns and villages, as well as on agricultural and tourist activities in the coastal region. Lake levels have traditionally been measured with water gauges since the last century. Through the widespread use of satellite altimeters, which were originally planned and used to estimate the sea level in the oceans, coastal areas, and lakes, water gauges have become another method for estimating lake levels (Birkett, 1995; Aladin *et al*., 2005; Cretaux and Birkett, 2006; Stable *et al*., 2015; Arabsahebi *et al*., 2018). Despite a few limitations, satellite altimeters are available free of charge worldwide and, in recent years, have become a proven method for hydrology (Cretaux *et al*., 2011). The lake levels obtained from satellite altimeters and water gauges provide an RMS value of 3-5 cm (Shum *et al*., 2003; Cretaux *et al*., 2011).

Chen and Liao (2020), using the altimeter data of Cryosat-2, Jason-2, Jason-3, and Sentinel-3A, examined the water-level changes of 340 lakes (area > 10 km^2) in China between 2016 and 2019, and found that the estimated change was largely due to temperature (Chen and Liao, 2020). Using ENVISAT and CryoSat-2 satellite altimeter data to monitor the level of Lake Urmia in Iran, Tourian *et al*. (2015) found that the lake lost an average of 34±1 cm of water each year from 2002 to 2014 (Tourian *et al.*, 2015). Saber *et al*. (2020) reported that seasonal water level changes in Arrowhead Lake, which suffered drought between 2012 and 2018, were around 3.5 m (Saber *et al*., 2020).

Drought, another consequence of climate change, is defined by the U.S. Center for Climate and Energy Solution reports (https://www.c2es.org/content/drought-and-climate-change/, accessed September 2022) as "a deficiency of precipitation over an extended period of time [...], resulting in a water shortage". Since drought is an important consequence of climate change, its identification parameters must be monitored. Key factors in monitoring drought include precipitation, temperature, streamflow, ground and reservoir water levels, snow masses, and moisture. The following types of droughts have been defined for drought monitoring: meteorological, hydrological, agricultural, socioeconomic, and ecological (https://www.drought.gov/what-is-drought/drought-basics, accessed September 2022). Today, droughts can be easily determined using indicators based on these drought types, among which: the Standardised Precipitation Index (*SPI*), Standardised Precipitation Evapotranspiration Index (*SPEI*), Soil Moisture Anomaly (*SMA*), Anomaly of Vegetation Condition (*FAPAR Anomaly*), Low-Flow Index (*LFI*), and Heat and Cold Wave Index (*HCWI*), also Combined Drought Indicator (*CDI*) (https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1010, accessed September 2022). In addition, other remote detection methods used to examine drought include the Normalised Difference Vegetation Index (*NDVI*), a dimensionless index that describes the difference between the visible and near-infrared reflection of vegetation and is used to estimate the intensity of green in a land area, and the Normalised Difference Water Index (*NDWI*), which highlights open water features in a satellite image.

In the study conducted by Kumanlıoğlu (2019), drought was analysed using the *SPI*s and *SPEI*s over 1-, 3-, 6-, and 12-month periods. Tefera *et al*. (2019), instead, focused on examining the level of concurrence between the *SPI* and *SPEI* for monthly, 3-month, 6-month, 12-month, and 24-month time scales. Gautam *et al.* (2015) sought to evaluate the performance of the Modified Normalised Difference Water Index (*MNDWI*), *NDWI*, Water Ratio Index (*WRI*), and K-T transform and supervised classification technique, to investigate the impact of urbanisation on Bangalore's surface waterbody, identify waterbodies and select appropriate thresholds (Gautam *et al.*, 2015). Xu (2006) reported that an *MNDWI*, which provides more sensitive estimations due to the reduction of land noise on the *NDWI*, delivers better results (Xu, 2006). Perales *et al*. (2020) empirically estimated lake area, water level, and shoreline changes, during the 2005-2010 drought in 47 lakes in the northern Highlands Lake district of northern Wisconsin using high-resolution orthophotos (Perales *et al.*, 2020). Ayalkibet *et al*. (2022) obtained significant results for droughts by using data from GRACE, meteorological indices and the Warm Spell Duration Index (*WSDI*) to determine their targeted hydrological drought between 2002 and 2021 (Ayalkibet *et al*., 2022).

Lake Beyşehir, located in the central Anatolia region of Turkey, is the largest freshwater lake in the country. It is surrounded by agricultural lands, located at an altitude of approximately 1,120 m from the sea surface, and covers an area of approximately 650 km^2. This study aimed to investigate the reasons for the decrease in the water level of Lake Beyşehir. In this context, three different analyses were used to examine the causes of the changes in the lake level and region:

i) since the increasing air temperature and decreasing precipitation in the region are known, the lake level change between 1993 and 2021 was examined using the Water Level-Water Level V2 lakes NRT data catalogue provided by the Copernicus Global Land Service;
ii) in order to examine whether there was a long-term drought in the region, the *SPI*s and *SPEI*s were determined through meteorological data;
iii) the *NDWI*s and *MNDWI*s were calculated using Sentinel-2 data, which ESA put into operation in 2015, due to the serious water level drops reported by the media in some years.

The originality of this study lies in establishing a relationship between the decrease in the lake water level, and the meteorological and hydrological droughts. The use of this paper is recommended to determine the causes of water reduction in lakes with decreasing water levels.

2. Materials and methods

When examining the effects of climate change on the lake and its surroundings, two factors stand out: lake water level and drought. The lake water level is observed using water gauge and satellite altimeter data, and drought is examined through a large number of indices. In this study, the lake level was investigated using satellite altimetry data, and drought was examined meteorologically using the *SPI*s and *SPEI*s (the drought indices), and the *NDWI*s and *MNDWI*s (the water indices), obtained by remote sensing methods.

2.1. Study area

Lake Beyşehir is located in the central Anatolia region of Turkey, with most of it lying in Konya and only a small part in Isparta. It is the third largest lake in the country in terms of surface area, and the largest lake in the country in terms of freshwater lakes. The lake is surrounded by the Taurus Mountains to the west and south, and the Erenler Tepesi Mountain, which has volcanic features, to the east. It lies approximately 1,120 m above sea level, covering a surface area of approximately 650 km^2. Agricultural areas and city centres border the lake. Abundant carp, pike, perch, and tench fish populate the lake, which is under the protection of the National Park Law. In addition, the lake is a refuge for migratory birds, therefore, used for staging, breeding, and wintering.

Table 1 - Characteristics of Lake Beyşehir.

Name	**Lake Beyşehir**
Geographic coordinates	37°47’0’’ N, 31°33’0’’ E
Area	651 km^2
Height above sea level	1,123 m
NW-SE length	50 km
NE-SW width	26 km
Reservoir capacity	2,751,000,000 m^3
Maximum depth	10 m

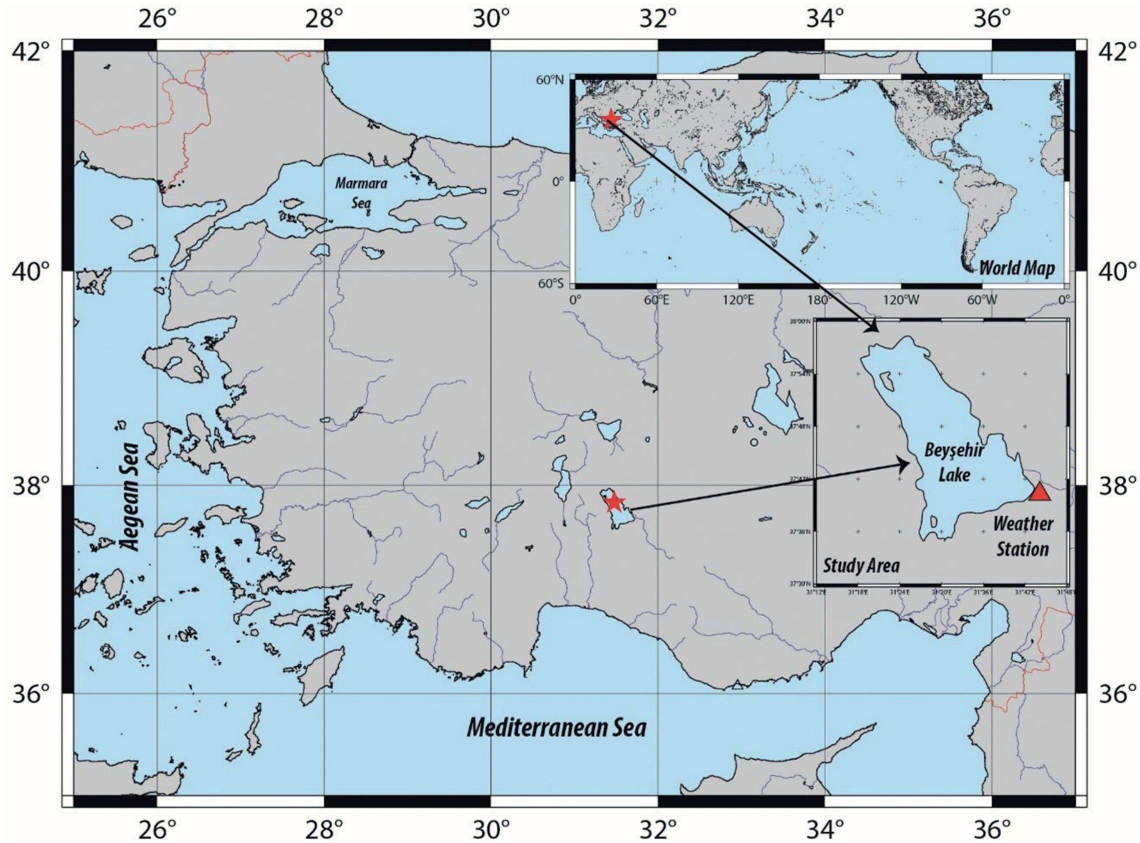

Fig. 1 - Lake Beyşehir.

2.2. The principle of satellite altimetry for lake water level determination

For centuries, lake levels have been traditionally determined using water gauges. However, satellite altimeters have emerged as another method after the launch of the Topex/Poseidon satellite in the early 1990s. Although it was originally designed for the oceans, its use has become common in coastal areas, lakes, and rivers with technological developments. The principle in altimeters is to process the signal reflected from the water surface by releasing a satellite radar wave. Through GNSS satellites, the position of the GNSS receiver on the altimeter satellite in orbit, relative to a reference surface (reference ellipsoid), determines the satellite altitude. The radar wave of the altimeter satellite has the characteristic of only being reflected by determined surfaces such as oceans, seas, lakes, etc., and, then, bouncing back. Using the amplitude and waveform of the outbound and return signal, it is possible to measure the wave height and wind speed over oceans, and, more generally, the backscattering coefficient and surface roughness for most surfaces on which the signal is projected. The main mathematical expression for satellite altimeters (*SSH*) is to subtract the corrected distance between the satellite and the water surface (S_{cor}) from the satellite height *(Alt)*:

$$SSH = Alt - S_{cor}. \quad (1)$$

The corrected distance is calculated from the instrumental errors (h_i), and the range correction and geophysical correction components. Range correction is calculated by eliminating ionospheric (h_{iono}) and dry/wet tropospheric effects (h_{dry} *and* h_{wet}). Geophysical correction is calculated by eliminating Solid Earth Tide Height (h_{stide}) and Pole Tide Height (h_{ptide}) values (Cretaux and Birkett, 2006; Zhao *et al*., 2017):

$$S_{cor} = S + (h_i + h_{iono} + h_{dry} + h_{wet} + h_{stide} + h_{ptide}). \quad (2)$$

Table 2 shows the models used in the corrections based on satellite altimeter missions (https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sealevel.html, accessed March 2022).

Table 2 - Corrections and models for satellite altimetry.

Corrections	**T/P**	**Jason-1**	**Jason-2**	**Envisat**	**GFO**	**SARAL/Altika**
Ionosphere	From dual frequency altimeter range measurements + GCP (GDR Correction)	From dual frequency altimeter range measurements		From GIM model		
Dry troposphere	From ECMWF model			From NCEP	From ECMWF	
Wet troposphere	From radiometer + GCP correction of radiometer drift affects + GCP correction of yaw effects	From enhanced radiometer correction (S. Brown)		From model	From radiometer	
Solid Earth tide height	From tide potential model (Schureman, 1958)					
Pole tide height	From Wahr (1985)					

In this study, satellite altimeter data were used to examine the water level change in Lake Beyşehir between 1993 and 2022. Multi-mission satellite altimeter data were obtained using the Water Level-Water Level V2 lakes NRT data catalogue made available by the Copernicus Global Land Service. Since the data were ready-made data, on which the necessary corrections and models had already been done, they were used without requiring any further changes.

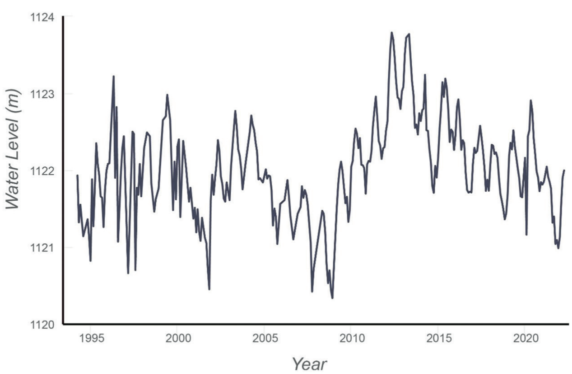

Fig. 2 - Time series of the Lake Beyşehir water level.

Fig. 2 shows that a balanced water level was observed between 1993 and 2005, a decrease occurred between 2005 and 2009, and, then, an increase between 2009 and 2013. Since 2013, a continuously decreasing lake water level has been observed. So, the time span selected for the studies covered the last ten years. The least-squares estimation was used to examine the statistical significance of this decrease. Fig. 3 shows the residual and 3-sigma threshold for lake level values between 2013 and 2020. At this time, 110 data were used, and the residuals were found to have an approximately normal distribution. The histogram presented an average value of 0.08 m, and the values ranged from 1,120.5 to 1,123.7 m.

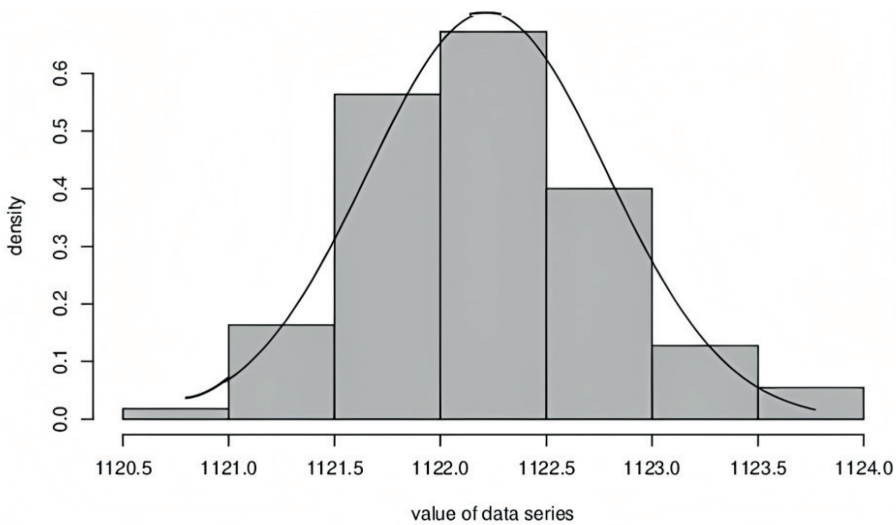

Fig. 3 - Water level histogram and fitted normal density.

2.3. Drought indices (SPI and SPEI)

SPI was developed by McKee *et al*. (1993) and is widely used to characterise drought on a temporal scale (McKee *et al*., 1993). *SPI* is based on a long-term record of precipitation over a specified period of time in the region (Benzougagh *et al*., 2022). *SPI* values can be calculated for different time scales (such as 1, 3, 6, 9, 12, 24, and 48 months). *SPI* can be calculated mathematically using Eq. 3. *SPI*-3 represents short-term meteorological drought and *SPI*-12 represents hydrological drought:

$$SPI = \frac{X_i - {X_i}^{Ave}}{\sigma}. \quad (3)$$

In Eq. 3, X_i is the total amount of precipitation in a month, X_i^{Ave} is the average amount of precipitation for that same month and σ represents standard deviation.

However, the *SPEI* was proposed by Vicente-Serrano *et al*. (2010) as an index that captured the effect of increasing air temperature on water pressure/demand (Vicente-Serrano *et al*., 2010). Similarly to the *SPI*, it can be calculated for different time scales (1-48 months) (Pei *et al*., 2020). In addition, the *SPEI* is a multi-scale drought index consisting of climatic data. It can be used to determine the onset, duration, and magnitude of drought conditions relative to normal conditions in a variety of natural and managed systems such as crops, ecosystems, rivers, and water resources. The *SPEI* proposed by Vicente-Serrano *et al.* (2010), can be calculated using Eq. 4 through the standardised function approach by Abramowitz and Stegun (1965):

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \tag{4}$$

with:

$$W = \sqrt{-2\ln(Pr)},$$

$$Pr = 1 - f(x),$$

and C_0 = 2.515517, C_1 = 0.8022853, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308.

Here, *Pr* is the probability of exceeding a determined different time series value, and C_0, C_1, C_2, d_1, d_2, and d_3 are the coefficients.

In this study, starting from 2013 when the lake level began to decrease, *SPI*-3 and *SPEI*-3 (the meteorological drought indices), and *SPI*-12 and *SPEI*-12 (the hydrological drought indices) were calculated using models (Eqs. 3 and 4) (McKee *et al*., 1993; Vicente-Serrano *et al*., 2010). The results are shown in Table 3. The calculations were made using monthly total precipitation and monthly average temperature data obtained from the Turkish Meteorology General Directorate, and R-Studio software *SPI/SPEI* packages were used.

Table 3 - The drought indices: *SPI* and *SPEI*.

Year	*SPI*-3	*SPI*-12	*SPEI*-3	*SPEI*-12
2015	0.279526	0.75656	0.425817	-0.16133
2016	-0.53934	0.33599	-0.04402	-0.79074
2017	-0.67039	0.082278	-0.36106	-0.80201
2018	-1.23021	-0.82610	-0.98602	-0.88055
2019	-0.24886	-0.75763	-0.75222	-0.93971
2020	-2.09298	-1.63813	-2.12112	-2.56193
2021	-0.81990	-0.508916	-2.16551	-1.73156

2.4. Satellite-based drought indices (NDWI and MNDWI)

NDWI and *MNDWI* are two satellite-based indices used to examine regional droughts (Benzougagh *et al*., 2022; Amalo *et al*., 2018). The spectral feature of the satellite image used also consists of combinations of spectral reflections from two or more wavelengths that indicate the relative status of drought-related features.

The *NDWI*, used to examine water features in satellite images, determines the relationship between a water body, soil, and vegetation. The combination of *Green*-*NIR* (visible green and near infrared) is used to identify understated changes in the water components in water bodies. The primary use of the *NDWI*, proposed by McFeeters (1996), is to detect and monitor small changes in the water content of water bodies. The disadvantage of this index is that it is sensitive to structures that can lead to an overestimation of water bodies. The *NDWI* is calculated as:

$$NDWI = \frac{Green-NIR}{Green+NIR} = \frac{B3-B8}{B3+B8}. \quad (5)$$

The *MNDWI* was proposed by Xu (2006), as land noise on the *NDWI* has certain shortcomings in obtaining information about water. Thus, land noise is reduced in the *MNDWI*, and more sensitive results can be achieved. The *MNDWI*, which uses Green and Short-Wave Infrared (*SWIR*) bands, can be expressed as:

$$MNDWI = \frac{Green-SWIR}{Green+SWIR} = \frac{B3-B11}{B3+B11}. \quad (6)$$

The values calculated using the formulae imply that they are wetlands if they are greater than zero. For example, if the *NDWI* and *MNDWI* values are greater than zero, it is understood that the area is a sea, lake, river, or an area that has received precipitation or irrigation.

In this study, data from the Sentinel-2 satellite, which was put into operation by ESA in 2015, was used. Sentinel-2 provides wide-area high-resolution multispectral imaging, with 13 spectral features, which enables different spectral resolutions. Information about Sentinel-2 is given in Table 4.

Table 4 - Sentinel-2 satellite information.

Parameter	**Sentinel-2**
Start date	23 June 2015
Wide swath	290 km
Revisit time	5 days
Spatial resolution	10 m (4 bands: RGB and *NIR*)
Spatial resolution	20 m (6 bands: Red Edge and *SWIR*)
Spatial resolution	60 m (3 bands: Atmospheric correction)

In the study, the MSIL1C images of the Sentinel-2 satellite were used to calculate the *NDWI* and *MDWI* values. MSIL1C represents the multispectral instrument Level-1C data set. In Level-1C, data are obtained using the Digital Elevation Model (DEM) and re-obtained with a fixed Ground Sampling Distance (GSD) of 10, 20, and 60 m, depending on the resolution of the different spectral bands. Level-1C products include total ozone column, total water vapour column, and mean sea level pressure data provided by cloud masking, and ECMWF. The data were downloaded from the Copernicus Open Access Hub (https://scihub.copernicus.eu/, accessed September 2022). In evaluating the data, the open-source SNAP software (provided by ESA free of charge to users), was used. This software produced the data based on the steps of the algorithm shown in Fig. 4. These steps were explained with examples in the webinar given over ESA's RUS-Copernicus service, and participants were encouraged to use this algorithm in their own studies (https://rus-copernicus.eu/portal/rus-webinar-drought-monitoring-from-space-with-sentinel-2/, accessed September 2022).

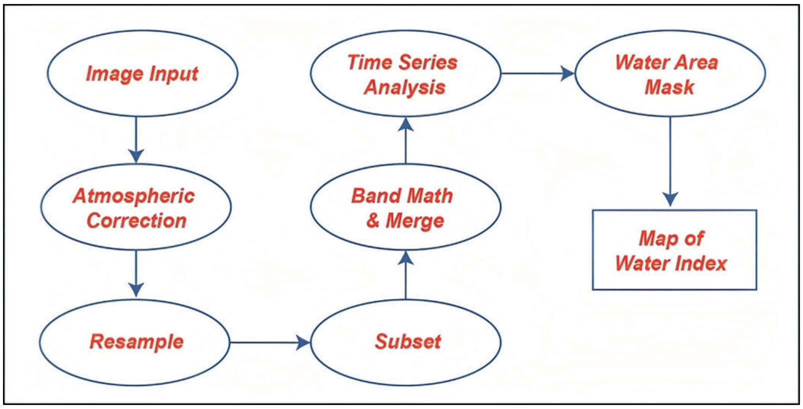

Fig. 4 - The SNAP software algorithm for the *NDWI* and *MDWI*.

The *NDWI* was calculated, for the month of July of each year (as shown on the map in Fig. 5), by using high-resolution multispectral optical images, which are considered to be of good quality, and the *Green-NIR* (visible green and near infrared) combination (Eq. 5) proposed by McFeeters (1996). Similar to the calculation of the *NDWI*, the *MDWI* was calculated using high-resolution multispectral optical images of July of each year, as suggested by Xu (2006) and based on the algorithm shown in Fig. 4 (Xu, 2006), where positive values indicate wetland areas. In the *MNDWI*, land noises are reduced by using Green and *SWIR* bands as shown in Eq. 6. Fig. 6 shows the map with the *MNDWI*.

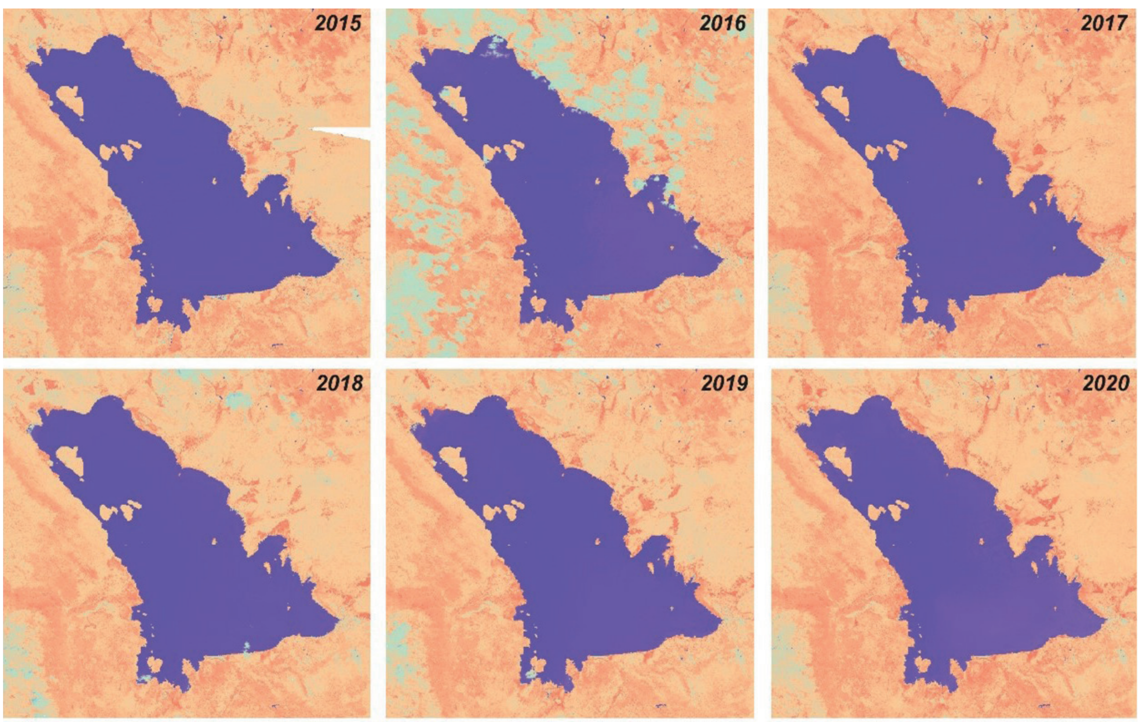

Fig. 5 - The *NDWI* map by years.

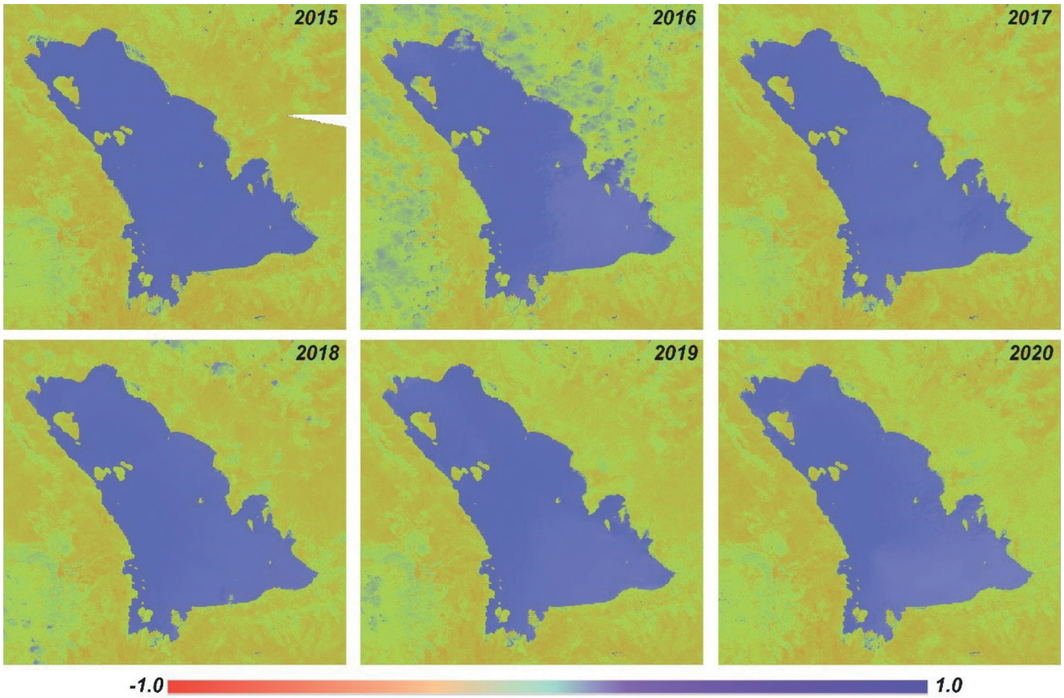

Fig. 6 - The *MNDWI* map by years.

3. Results and discussion

In order to examine the water level of Lake Beyşehir, between 1993 and 2022, monthly lake levels were calculated using satellite altimeter data. As seen in Fig. 2, there was a decreasing trend in, and after, 2013. In order to reveal whether the decrease in the lake level between 2013 and 2022 was statistically significant, first of all, outliers were removed based on the Gaussian distribution function (3-sigma) (Soltanpour *et al*., 2017). Then, the least-squares estimation was applied to these data. The script prepared with Matlab software was used for this analysis. The lake level showed a decreasing trend of 2.47±0.5 cm/yr, between 2013 and 2022 (Fig. 7).

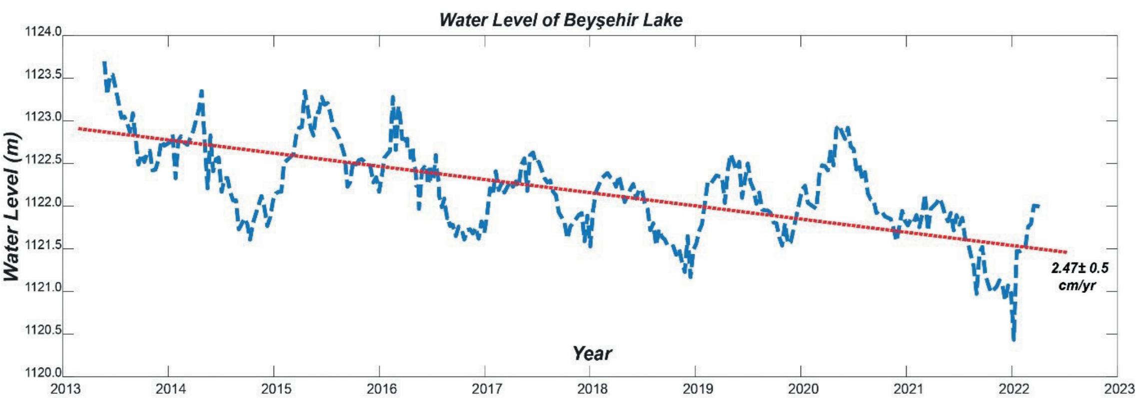

Fig. 7 - Time series of the Lake Beyşehir level.

Demir and Keskin (2020) reported a decrease in the lake level, due to significant changes in the amount of precipitation, water resources management, agricultural practices, and socio-economic activities.

SPI-3 and *SPEI*-3, which indicate short-term drought, and *SPI*-12 and *SPEI*-12, which indicate hydrological drought, were calculated as suggested by McKee *et al*. (1993) and Vicente-Serrano *et al*. (2010). The results are shown in Table 3 (McKee *et al*., 1993). The linear Pearson correlation coefficient function was used to figure out whether there was a correlation between the *SPI* and *SPEI* values. A positive correlation was found between the *SPI*s and *SPEI*s (Freedman *et al*., 2007). *SPI*-3 and *SPEI*-3, and *SPI*-12 and *SPEI*-12 correlation (*r*) values were found to be 0.7676 and 0.8371, respectively.

The classification in Table 5 was used in the interpretation of the *SPI* and *SPEI* (Gumus and Algin, 2016; Kumanlioğlu, 2019). In the table, drought was expressed with eight different grades. Negative indices indicate periods with drought, while positive indices indicate periods with no drought.

The examination of the *SPI*-12 and *SPEI*-12 values given in Table 3 (indicating the presence or absence of hydrological drought), on the basis of the classification in Table 5, revealed negative indices increasing over the years in the region. Accordingly, it can be declared that there was hydrological drought in the region (Table 6).

The drought analysis study carried out in the region by Sarış and Gedik (2021) also supports the results given in Table 6. Based on *SPI*-12 analysis, they reported that Beyşehir was one of the regions with the highest level of drought in the Konya plain.

The *NDWI* and *MNDWI* were obtained using Sentinal-2 high-resolution multispectral images evaluated in SNAP software by following the processing steps in Fig. 4. The results are shown in

Table 5 - *SPI* and *SPEI* drought classification.

Drought severity	*SPI*	*SPEI*
Extremely wet	$SPI > 2$	$SPEI > 2$
Severely wet	$1.5 < SPI \leq 2$	$1.5 < SPEI \leq 2$
Moderately wet	$1.0 < SPI \leq 1.5$	$1.0 < SPEI \leq 1.5$
Mildly wet	$0 < SPI \leq 1$	$0 < SPEI \leq 1$
Mild drought	$-1 < SPI \leq 0$	$-1 < SPEI \leq 0$
Moderate drought	$-1.5 < SPI \leq -1$	$-1.5 < SPEI \leq -1$
Severe drought	$-2 < SPI \leq -1.5$	$-2 < SPEI \leq -1.5$
Extreme drought	$-2 \leq SPI$	$-2 \leq SPEI$

Table 6 - Drought severity by years.

Year	*SPI*-12	Drought severity	*SPEI*-12	Drought severity
2015	0.75656	Mildly wet	-0.16133	Mild drought
2016	0.33599	Mildly wet	-0.79074	Mild drought
2017	0.082278	Mildly wet	-0.80201	Mild drought
2018	-0.82610	Mild drought	-0.88055	Mild drought
2019	-0.75763	Mild drought	-0.93971	Mild drought
2020	-1.63813	Severe drought	-2.56193	Extreme drought
2021	-0.508916	Mild drought	-1.73156	Severe drought

Figs. 5 and 6. However, since the change in the lake area was not clear in the images, the change in the lake area, in two different regions of the lake surface, was displayed as a function of time.

The change in the water surface area in regions A and B is shown in Fig. 8. A focus on the shape revealed that the water surface area decreased synchronously with drought over the years. In addition, these values showed a high correlation with the decrease in the water level.

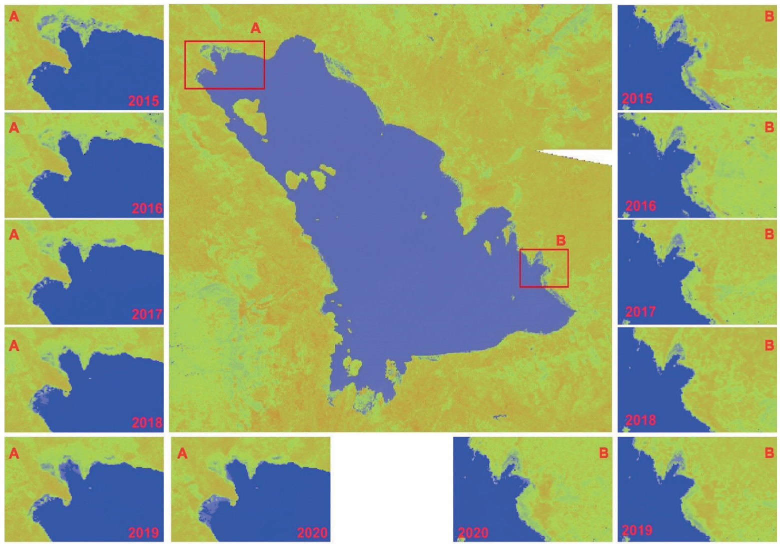

Fig. 8 - The change in the water surface area of Lake Beyşehir (example of A and B sections).

Table 7 shows the water surface area obtained from the Sentinel-2 images in June of each year, and the lake level values obtained from the multi-mission satellite altimeter solutions. Here, a positive high correlation was found between the decrease in the water level and the shrinkage of the lake area, which was calculated to be 0.96.

Table 7 - Lake level and area by years.

Year	Month	Water level (m)	Lake area (km^2)
2015	June	1,123.070	636.467
2016	June	1,122.350	632.391
2017	June	1,122.420	632.159
2018	June	1,121.900	629.280
2019	June	1,122.170	629.107
2020	June	1,121.750	628.786

4. Conclusions

Over the past 10 years, there has been a significant decrease in the water level of Lake Beyşehir, the third largest lake in Turkey. In this study, the level of Lake Beyşehir was examined using the Water Level-Water Level V2 lakes NRT data introduced by the Copernicus Global Land Service. The water level, which was relatively stable between 1993 and 2013, showed a decreasing trend between 2013 and 2022. To understand whether this decrease was significant or not, the least-squares-estimation method was applied, and a decreasing trend of 2.47±0.5 cm/yr of the lake level was encountered. Since the most probable cause of the decrease in the lake level is drought, monthly average temperature and monthly total precipitation data were obtained from the meteorological station in the region, and *SPI*s and *SPEI*s were calculated. Based on *SPEI*-12, an indicator of hydrological drought, it was found that there was a mild drought between 2015 and 2018, a severe drought in 2019, and an extreme drought in 2020. Remote sensing methods, enabling satellite-based results, are widely used in the determination of regional droughts. In this study, the *NDWI*s and *MNDWI*s, which are among Sentinel-2 multispectral high-resolution optical images that provide important results on hydrological droughts, were calculated, and the change in lake water surface area was determined by years. Between 2015 and 2021, an 8 km^2 shrinkage in the lake water surface area was detected. In addition, a 96% correlation was found between the decrease in the surface area and the lake level.

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REFERENCES

Abramowitz M. and Stegun I.A.; 1965: *Handbook of mathematical functions, with formulas, graphs, and mathematical tables*. Dover Publications, Mineola, NY, USA, 1046 pp.

Aladin N., Cretaux J.F., Plotnikov I.S., Kouraev A.V., Smurov A.O, Cazenave A., Egorov A.N. and Papa F.; 2005: *Modern hydro-biological state of the small Aral Sea*. Environmetrics, 16, 375-392, doi: 10.1002/env.709.

Amalo L.F., Ma'rufah U. and Permatasari P.A.; 2018: *Monitoring 2015 drought in west Java using Normalized Difference Water Index (NDWI)*. IOP Conf. Ser.: Earth Environ. Sci., 149, 012007, 7 pp**.,** doi: 10.1088/1755-1315/149/1/012007.

Arabsahebi R., Voosoghi B. and Tourian M.J.; 2018: *An estimation of tropospheric corrections using GPS and synoptic data: improving Urmia Lake water level time series from Jason-2 and SARAL/AltiKa satellite altimetry*. Adv. Space Res., 61, 2406-2417, doi: 10.1016/j.asr.2018.02.013.

Ayalkibet M.S., Jiahua Z., Da Z., Elias G.A., Jiaqi H., Foyez A.P., Guoping Z. and Qi L.; 2022: *Hydrological drought evaluation using GRACE satellite-based drought index over the lake basins, east Africa.* Sci. Total Environ., 852, 158425, **?? pp.,** doi: 10.1016/j.scitotenv.2022.158425.

Benzougagh B., Meshram S.G., El Fellah B., Mastere M., Dridri A., Sadkaoui D., Mimich K. and Khedher K.M.; 2022: *Combined use of Sentinel-2 and Landsat-8 to monitor water surface area and evaluated drought risk severity using Google Earth Engine*. Earth Sci. Inf., 15, 929-940, doi: 10.1007/s12145-021-00761-9.

Birkett C.M.; 1995: *The contribution of TOPEX/POSEIDON to the global monitoring of climatically sensitive lakes*. J. Geophys. Res. C: Oceans, 100, 25179-25204, doi: 10.1029/95JC02125.

Chen J. and Liao J.; 2020: *Monitoring lake level changes in China using multi-altimeter data (2016-2019)*. J. Hydrol., 590, 125544, 18 pp., doi: 10.1016/j.jhydrol.2020.125544.

Cretaux J.F. and Birkett C.M.; 2006: *Lake studies from satellite radar altimetry*. C.R. Geosci., 338, 1098-1112, doi: 10.1016/j.crte.2006.08.002.

Cretaux J.F., Jelinski W., Calmant S., Kouraev A., Vuglinski V., Bergé-Nguyen M., Gennero M.C., Nino F., Abarca Del Rio R., Cazenave A. and Maisongrande P.; 2011: *SOLS: a lake database to monitor in the Near Real Time water level and storage variations from remote sensing data*. Adv. Space Res., 47, 1497-1507, doi: 10.1016/j.asr.2011.01.004.

Demir V. and Keskin A.Ü.; 2020: *Water level change of lakes and sinkholes in central Turkey under anthropogenic effects*. Theor. Appl. Climatol., 142, 929-943, doi: 10.1007/s00704-020-03347-5.

Freedman D., Pisani R. and Purves R.; 2007: *Statistics*, 4th ed. International student edition, W.W. Norton & Company, New York, NY, USA, 701 pp.

Gautam V.K., Gaurav P.K., Murugan P. and Annadurai M.; 2015: *Assessment of surface water dynamics in Bangalore using WRI, NDWI, MNDWI, supervised classification and K-T transformation*. Aquat. Procedia, 4, 739-746, doi: 10.1016/j.aqpro.2015.02.095.

Gumus V. and Algin H.M.; 2016*: Meteorological and hydrological drought analysis of the Seyhan-Ceyhan River basin, Turkey*. Meteorol. Appl., 24, 62-73, doi: 10.1002/met.1605.

Kumanlioğlu A.A.; 2019: *Characterizing of meteorological and hydrological droughts. A case study: Gediz River basin, Turkey*. Meteorol. Appl., 27, e1857, 17 pp., doi: 10.1002/met.1857.

McFeeters S.K.; 1996: *The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features*. Int. J. Remote Sens., 17, 1425-1432, doi: 10.1080/01431169608948714.

McKee T.B., Doesken N.J. and Kleist J.; 1993: *The relationship of drought frequency and duration to time scales*. In: Proc. 8th Conference on Applied Climatology, Anaheim, CA, USA, pp. 179-184.

Pei Z., Fang S., Wang L. and Yang W.; 2020: *Comparative analysis of drought indicated by the SPI and SPEI at various timescales in inner Mongolia, China*. Water, 12, 1925, 20 pp., doi: 10.3390/w12071925.

Perales K.M., Hein C.L., Lottig N.R., Vander Z. and Jake M.; 2020: *Lake water level response to drought in a lake rich region explained by lake and landscape characteristics*. Can. J. Fish. Aquat. Sci., 77, 1836-1845, doi: 10.1139/cjfas-2019-0270.

Saber A., James D.E. and Hannoun I.A.; 2020: *Effects of lake water level fluctuation due to drought and extreme winter precipitation on mixing and water quality of an alpine lake, case study: Lake Arrowhead, California*. Sci. Total Environ., 714, 136762, doi: 10.1016/j.scitotenv.2020.136762.

Sarış F. and Gedik F.; 2021: *Meteorological drought analysis in Konya closed basin*. J. Geog., 42, 295-308, doi: 10.26650/jgeog2021-885519.

Schureman P.; 1958: *Manual of harmonic analysis and prediction of tides. Revised 1940 edition reprinted 1958 with corrections, reprinted 2001.* United States Government Printing Office, Washington DC, USA, 317 pp., doi:10.25607/OBP-155.

Shum C., Yi Y., Cheng K., Kuo C., Braun A., Calmant S. and Chambers D.; 2003: *Calibration of Jason-1 altimeter over Lake Erie*. Mar. Geod., 26, 335-354, doi: 10.1080/714044525.

Soltanpour A., Pirooznia M., Aminjafari S. and Zareian P.; 2017*: Persian Gulf and Oman Sea tide modeling using satellite altimetry and tide gauge data (TM-IR01).* Mar. Georesour. Geotechnol., 37, 1-11, doi: 10.1080/1064119x.2017.1366608.

Stable T.A., Giocoli A., Perrone A., Piscitelli S., Telesca L. and Lapenna V.; 2015*: Relationship between seismicity and water level of the Pertusillo reservoir (southern Italy)*. Boll. Geof. Teor. Appl., 56, 505-517, doi: 10.4430/bgta0161.

Tefera A.S., Ayoade J.O. and Bello, N.J.; 2019: *Comparative analyses of SPI and SPEI as drought assessment tools in Tigray region, northern Ethiopia*. SN Appl. Sci., 1, 1265, 14 pp., doi: 10.1007/s42452-019-1326-2.

Tourian M.J., Elmi O., Chen Q., Devaraju B., Roohi S. and Sneeuw N.; 2015: *A spaceborne multisensor approach to monitor the desiccation of Lake Urmia in Iran*. Remote Sens. Environ., 156, 349-360, doi: 10.1016/j.rse.2014.10.006.

Vicente-Serrano S.M., Beguería S., López-Moreno J.I.; 2010*: A Multiscalar Drought Index Sensitive to global warming: the Standardized Precipitation Evapotranspiration Index*. J. Clim., 23, 1696-1718, doi: 10.1175/2009JCLI2909.1.

Wahr J.M.; 1985: *Deformation induced by polar motion*. J. Geophys. Res., 90, 9363-9368, doi: 10.1029/jb090ib11p09363.

Wessel P., Smith W.H.F., Scharroo R., Luis J. and Wobbe F.; 2013: *Generic mapping tools: improved version released*. Eos, Trans. Am. Geophys. Union, 94, 409-410, doi: 10.1002/2013EO450001.

Xu H.; 2006: *Modification of Normalised Difference Water Index (NDWI) to enhance open water features in remotely sensed imagery*. Int. J. Remote Sens., 27, 3025-3033, doi: 10.1080/01431160600589179.

Zhao Y., Liao J.J., Shen G.Z. and Zhang X.L.; 2017*: Monitoring lake level changes by altimetry in the arid region of central Asia*. IOP Conf. Ser.: Earth Environ. Sci., 74, 012004, 6 pp., doi: 10.1088/1755-1315/74/1/012004.

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