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Water level change of lakes and sinkholes in Central Turkey under anthropogenic effects

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Abstract

Determining water level changes in lakes is significant for sustainable water supply planning, flood control, water resource management, and economic development with ecosystem sustainability. Trend analysis is a commonly used tool for detecting changes in hydrologic time series of quantities such as lake level, precipitation and temperature. Trend analysis of meteorological variables is very important for assessing the long-term changes in lake levels. This study examines long-term changes in the lakes in the Central Anatolia region of Turkey. Kızören and Timraş sinkhole lakes and Lakes Tuz and Beyşehir are some of the lakes located in this region. Changes in these lakes were examined along with changes in precipitation trends and human effects. The precipitation stations representing these lakes were determined using Thiessen polygons. In this study, the well-known nonparametric Mann–Kendall trend test (MK) was used. Before performing trend analysis, homogeneity and autocorrelation tests were applied for the time series. The standard normal homogeneity test (SNHT) was used to evaluate homogeneity. Trend analysis was performed before and after the change points the inhomogeneous series for the period of the homogeneous series. In addition, the modified Mann–Kendall method (MMK) was performed to examine the strong autocorrelations seen in the entire time series. The results showed that precipitation station data are homogeneous and lake levels are inhomogeneous. Trend analysis was performed by determining the change points for the inhomogeneous lakes. There were no significant trends after the change points for the Lake Tuz and Timraş sinkhole lake. These results are supported by the insignificant trends in precipitation stations. Contrary to the trend analysis results, the increase in the water level of Beyşehir Lake was determined to increment from the water transferred to the lake. The decrease in the water level of Kızören sinkhole was a result of anthropogenic effect rather than precipitation. The results confirm that lake levels have been affected by precipitation trends and anthropogenic effects.

Keywords Trend analyses · Homogeneity analyses · Lake water levels · Sinkhole

1 Introduction

Lakes are valuable water resources necessary for sustaining human life and activities, which have a significant effect on terrestrial and aquatic ecosystems and environments (Wantzen et al. 2008; Williamson et al. 2009; Beklioğlu et al. 2017; Waylen et al. 2019). At present, many lakes worldwide are adversely affected by water withdrawals resulting from human activities and climatic variation. Water withdrawal critically influences the sustainable development of a region and may adversely impact both water quality and quantity (McBean and Motiee 2006; Yuan et al. 2015). Water level fluctuation, which is a significant driver for lakes and a sensitive marker of change, plays an important role in lake ecosystems (Leira and Cantonati 2008). Detecting long-term changes in water levels is necessary for the sustainable management of lakes.

Fluctuations in lake levels are known to be sensitive indicators of changes in climate and can play an important role in monitoring present climate changes and predicting future changes (Tan et al. 2017). Therefore, differences in lake levels and their relationship with measured climate variables are important not only for understanding and monitoring the effects of climate change but also for analyzing the impacts of level

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changes (Zhang et al. 2015; Bohn et al. 2016). Lake water level fluctuations represent the result of a complex interaction of various water balance components. These components include the flow of incoming or outgoing rivers, direct precipitation to the lake surface, and groundwater change. In addition, meteorological factors such as precipitation in the lake drainage area, evaporation from the lake surface, wind speed, and humidity and temperature play important roles in lake water level fluctuations. As both gradual (trend) and sudden (shifting) changes in climate were particularly notable in the recent years, researchers have found that most of the changes in lake levels are related to meteorological variables such as temperature and precipitation (Kadioğlu et al. 1997; Şen et al. 1999; Altunkaynak 2007).

Understanding long-term trends in hydrometeorological variables is crucial for sustainable water resources management (Hu et al. 2017). Temporal and spatial changes in meteorological parameters may occur because of many reasons. The observed changes should be examined by various statistical methods. Trend and homogeneity analyses are important statistical methods widely used worldwide for assessing long-term changes in meteorological variables (Yu et al. 1993; Lenters 2001; Hamed 2008; Yin et al. 2016; Yagbasan et al. 2017, 2020; Keskin et al. 2018).

Many studies have delved into the changes in lakes along with changes in meteorological parameters. Yenilmez et al. (2011) analyzed the trends of water quality parameters, precipitation, lake volume, and temperatures recorded in Eymir Lake (Turkey) using the Mann–Kendall test (MK). Yagbasan et al. (2017) performed MK for trends in temperature, precipitation, and water levels in Mogan and Eymir lakes. Göncü et al. (2017) examined the changes in climate variables and four lake levels (Burdur, Eğirdir, Sapanca, and Tuz lakes) in Turkey using MK, seasonal Kendall, and regional Kendall tests. Belete et al. (2017) performed MK for long-term trends in Lake Hawassa (Etiyopya) and precipitation, streamflow, and potential evapotranspiration. Yagbasan et al. (2020) performed MK and modified Mann–Kendall test (MMK) for trends in climate variables and water levels in Mogan and Eymir lakes. However, few studies have explored the hydrological relationship between the trends of lake levels and meteorological variables. Further, there appears to be a lack of a trend analysis of sinkhole water levels. Therefore, this study focused on determining trends in monthly lake and sinkhole water levels and precipitation. Statistical analyses showed that precipitation has a crucial influence on the variations in lake levels. Precipitation is the main factor in the hydrological system. Hence, any change in the long-term trends of precipitation will have a direct effect on water resources parameters, particularly on lake levels (Yagbasan et al. 2017).

This study investigates long-term water level fluctuations in the lakes in the Central Anatolia region of Turkey together with precipitation variation. The precipitation stations representing the lakes were determined using Thiessen polygons. Hydrologically, the area of influence of meteorological stations was determined by Thiessen polygons (Thiessen 1911). In this method, the quantities measured at any station are assumed to be applicable halfway to the next station in any direction. The area of each polygon is used to assign a weightage for the precipitation amount of the station at the center of the polygon (Schumann 1998).

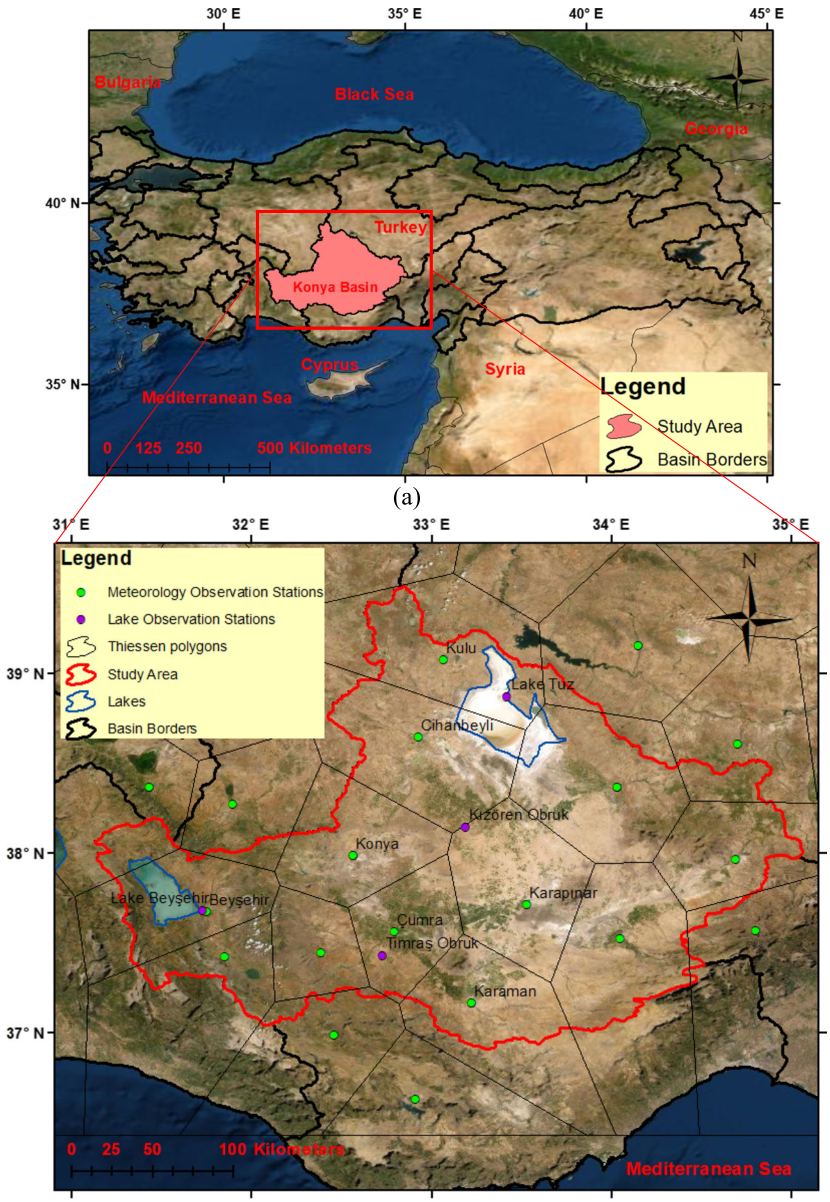
In this study, first, the homogeneity status of the time series and then the serial correlation status were investigated, and trend analyses were carried out. Standard Normal Homogeneity Test (SNHT) was performed to check whether the hydrological data came from the same population. The dependency in the long-term time series was checked via the autocorrelation *t*-test. Initially, the MK method was performed. Considering the strong correlations for lake levels, the MMK was performed additionally for identifying trends. The trends and homogeneity were examined at a 95% confidence level. It is believed that the potential impact of precipitation variables on sinkhole water level fluctuations has not been examined as yet. This study takes this point into consideration and analyzes the causes and hydrological consequences of variations in the water levels of Kızören and Timraş sinkholes located Konya in Central Anatolia.

2 Material and methods

2.1 Study area

Meteorologically, Konya basin is located in the central and southern parts of Central Anatolia region in Turkey. Konya basin extends 80 km in the north–south direction and 50 km in the west–east direction, and it lies between longitudes 32° 20′ E and 34° 00′ E and latitudes 38° 08′ N and 37° 06′ N. According to the long-term data of the meteorological stations located in the Konya basin, the average, the highest and the lowest annual temperatures are 11.6 °C, 40.6 °C, −28.2 °C, respectively. With an average annual precipitation of 323.3 mm, Konya basin with is one of the least wet parts of Turkey. Precipitation is in the form of convective precipitation in the region. The most important lakes in the region are Beyşehir and Tuz lakes (Fig. 1).

The Thiessen polygons in Fig. 1 were obtained from the Geographic Information Systems software using ArcGIS-Analysis tools. Lake Tuz, second largest lake in Turkey, is very shallow. Because the lake is shallow, extremely high evaporation occurs, leading to the concentration of salts in the lake. In fact, this lake meets 55% of the salt requirement in Turkey. Lake Tuz is a closed basin lake that does not flow out, and its surface area is 7414 km^2 (Dengiz et al. 2010). Despite the wide precipitation area, the feeding



(a)

(b)

Fig. 1 The study area (**a**), used stations covering Thiessen polygon in Central Turkey (**b**)

sources are weak. The streams that bring water to the lake are those that dry out completely or witness a decrease in the water in the summer. The average water depth of the lake is around 40 cm; it is 110 cm in May when precipitation increases. The lake dries out greatly in August. Lake Tuz and its surroundings are part of a specially protected area. It is the main breeding center of numerous bird species (Anonymous 2020).

Lake Beyşehir is the largest freshwater lake in Turkey (Guler et al. 2008). With a surface area of 650 km^2, it is the third largest lake in Turkey after Lake Van and Lake Tuz. It is located in a tectonic deposit and is surrounded by the mountains. The average depth of the lake is 5–6 m, and its maximum depth is 8–9 m. Lake Beyşehir is one of the specially protected areas of the country (it is home to 545 plant species, 163 bird species, and 16 fish species). Many migratory water birds visit Lake Beyşehir to hunt and breed (Bucak et al. 2018).

In addition to lakes, the Konya basin has geomorphological structures called sinkholes which play an important role in the water ecosystem. There are more than 20 sinkholes in the basin, which contains 33.3% of the country's groundwater. The ground-water flows from Konya Plain towards Lake Tuz, which is located at the lowest level of the plain. This groundwater dissolves the karstic rocks that it comes in contact with, forming underground cavities. When the groundwater level in these gaps decreases, the surface layers whose balance is disturbed collapse forming karstic structures called sinkholes (Recep and Tapur 2009). There are many sinkholes in the plain, and Timraş and Kızören sinkholes are some of the most important sinkholes (Günay et al. 2011).

Obruk or sinkhole lakes are commonly formed by karstic processes usually in plains containing limestones and carbonate evaporation products that dissolve easily in water. Kızören sinkhole was formed within the Neogene aged lacustrine formations and Paleozoic formations with crystallized limestones (Recep and Tapur 2009). It is located 75 km away from the city of Konya in Turkey (Fig. 2(a)). It has an approximately elliptical shape with a long axis of 180 m and a short axis of 150 m. It is 300 m wide and up to 145 m depth from the water surface. The water level in the sinkhole fluctuates during winter and summer, but the fluctuations generally do not exceed 1–2 m (Günay et al. 2011).

Timraş sinkhole is located approximately 40 km to the southeast of Konya and 46 km from the Konya–Karaman highway (Fig. 2(b)). This sinkhole is composed of limestone. It is an elliptical sinkhole whose large diameter is 325 m and a small diameter is 250 m. The maximum depth of the sinkhole is 32 m (Recep and Tapur 2009). Owing to the sweetness of the water, carp-type fish are found here. In addition, the caves and limestone cavities on the slopes are a habitat for pigeons. Owing to the ease of roadway access, the Timraş lake also witnesses a large number of visitors (Tapur and Bozyiğit 2016).

However, there is a growing concern about the possible impacts of climate change on the long-term sustainability of these lakes. Therefore, this study aims to stimulate the interdisciplinary monitoring and cooperation between hydrogeologists, hydrologists, ecologists, water resources managers, etc., to provide better protection and management of vulnerable and exceptionally valuable Lake Tuz, Lake Beyşehir, Kızören sinkhole, and Timraş sinkhole and their aquatic and terrestrial ecosystems.

2.1.1 Data

Monthly total precipitation data (mm) between 1964 and 2017 were obtained from the General Directorate of Meteorology. Table 1 gives the location of the meteorological and lake level observation stations used in the study. Table 2 gives the statistical properties used in the study.

Table 2 shows that the mean monthly precipitation varies from 21.05 to 40.71 mm. The standard deviation is varied between 22.45 and 38.06 mm, while the skewness and kurtosis varied between 0.91 to 1.59 and 0.45 to 3.48, respectively. For time series data to be considered normally distributed, the coefficient of skewness and kurtosis must be equal to 0 and 3, respectively (Akinsanola and Ogunjobi 2015). An average skewness was observed 1.17. Thus, the data used in this study are positively skewed and not normally distributed. Changes in lake levels and sinkhole levels also do not fit into the normal distribution.

2.2 Methods

In this study, an investigation of the long-term monthly lake level and precipitation series change analysis was performed. Firstly, the autocorrelation test was applied to the data. Secondly, the homogeneity conditions were examined, and trend analyses were carried out at homogeneous stations. In non-homogeneous stations, the most likely change point was determined, and trend analyses were performed on two part both before and after of time series.

2.2.1 Autocorrelation test

Many important studies in the literature have shown that the presence of autocorrelation (negative or positive) in a time series affects trend detection (Hamed and Ramachandra Rao 1998; Yue et al. 2002; González-Hidalgo et al. 2011;

Fig. 2 Kızören Sinkhole (**a**) and Timraş Sinkhole (**b**)

Table 1 Location information of the stations used in the study

Station type	Station name	Station No.	Latitude (N)	Longitude (E)	Elevation (m)
Meteorology observation station	Karapınar	17902	37.72	33.52	996
	Çumra	17900	37.56	32.79	1014
	Kulu	17754	39.08	33.06	1005
	Cihanbeyli	17191	38.65	32.92	969
	Beyşehir	17242	37.68	31.75	1141
Lake observation station	Kızören	16–050	38.14	33.19	974.72
	Timraş	16–052	37.43	32.72	1011.52
	Lake Tuz	1619	38.87	33.42	903.97
	Lake Beyşehir	D16G175	31.72	37.68	1121.80

Akinsanola and Ogunjobi 2015). The importance of autocorrelation in this study was investigated using the t test in Student lag − 1 in both long-term precipitations and lake levels series. The following equation was used to serial independence test.

$$t=\rho 1\sqrt{\frac{n{-}2}{1{-}\rho_1^2}} \tag{1}$$

where t is Student's t distribution test statistic for $(n-2)$ degrees of freedom. The computed t value is compared with t distribution according to the two-tailed confidence levels (CL). If the t value is greater than $|t_{1\text{-}\alpha/2}|$, the null hypothesis (H_0) is rejected. Otherwise, the H_0 hypothesis is accepted and this means that the serial independence is accepted.

2.2.2 Standard normal homogeneity test

This method developed by Alexandersson (1986) is used to test the homogeneity of many hydro-meteorological series (Khaliq and Ouarda 2007). It calculates the value of $T(c)$ by Eq. 2 by dividing it into two parts with reference to a "c" point of the studied series.

$$T(c)=c\bar{z}_1+(n{-}c)c\bar{z}_2^{\,2} \qquad c=1,2,3,\ldots,n \tag{2}$$

These parts are $\bar{z}_1=\sum_{i=1}^{c}(y_i{-}\bar{y})/\sigma)/c$ and $\bar{z}_2=\sum_{i=1+c}^{n}(y_i{-}\bar{y})/\sigma)/(n{-}c)$, where "$n$" is the number of data, "y" is years, z is the standardized work series of length n, and $\overline{z_1}$ and $\overline{z_2}$ are arithmetic mean values of the series. If the change occurs at a point "h," it reaches the maximum value of $T(c)$ at point $c=h$. T_0 test statistic is as in Eq. 3.

$$T_0=\max\nolimits_{1<0<n}T(c) \tag{3}$$

If the test statistic exceeds the value, the null hypothesis is rejected. T_0 test values depending on the number of data and 95% confidence level are given in Table 3. In Table 3, test critical levels (CL) are determined as a function of values and significance levels (Alexandersson 1986).

2.2.3 Mann–Kendall

The Mann–Kendall (MK) test is a nonparametric test. It is frequently used in the literature to detect the long-term trends

Table 2 Statistical properties of the stations

Station name	Unit	Min	Max	Mean	SD	SC	KS	Period
Karapınar	mm	0.0	109.20	31.80	26.29	0.91	0.45	64–12
Çumra		0.0	114.80	21.05	23.53	1.31	1.50	78–15
Kulu		0.0	130.90	31.56	26.26	0.93	0.50	64–16
Cihanbeyli		0.0	122.40	26.66	22.45	1.11	1.50	64–16
Beyşehir		0.0	231.20	40.71	38.06	1.59	0.89	64–17
Kızören	m	952.3	978.4	972.9	6.7	− 1.4	− 1.01	64–12
Timraş		987.7	1015.5	1007.2	7.4	− 1.0	− 0.17	78–15
Lake Tuz		904.0	906.0	905.0	0.2	0.5	0.77	64–16
Lake Beyşehir		1121.1	1125.5	1123.0	1.1	0.2	− 0.89	71–17

SD standard deviation, *SC* skewness coefficient, *KS* kurtosis

Table 3 T_0 test values depending on the number of data

Number of data	30	40	50	70	100	200	500	700	1000
CL ($\alpha = 5\%$)	7.65	8.10	8.45	8.80	9.15	9.55	10.20	10.45	10.50

of meteorological series. In this method, firstly, the test statistic value is calculated with the help of Eqs. 4 and 5 (Haktanir and Citakoglu 2014, 2015).

$$\mathrm{sgn}\left(x_j - x_i\right) = \begin{cases} 1; & \text{if} \quad x_j > x_j \\ 0; & \text{if} \quad x_j = x_i \\ -1; & \text{if} \quad x_j < x_i \end{cases} \tag{4}$$

In Eq. (4), x_i and x_j are the data values in time series i and j, respectively, and in Eq. (5), n is the number of data points, $\mathrm{sgn}(x_j - x_i)$is the sign function as;

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{\mathrm{n}} \mathrm{sgn}\left(x_j - x_i\right) \tag{5}$$

After that, the variance is computed as:

$$\mathrm{Var}(S) = \frac{\mathrm{n}(n-1)(2n+5) - \sum_{i=1}^{P} t_i(t_i - 1)(2t_i + 5)}{18} \tag{6}$$

In Eq. 6, n refers to the number of data, P shows the number of tied groups, and t_i indicates the number of ties of extent i. A tied group is a set of sample data and has the same value. Finally, with the help of Eq. 7, Mann–Kendall Z value is calculated.

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{Var}(S)}}; & \text{if} \quad S > 0 \\ 0 & \text{if} \quad S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{Var}(S)}} & \text{if} \quad S < 0 \end{cases} \tag{7}$$

The calculated Z value is compared with normal distribution confidence levels. If the calculated Z value is greater than $|Z| \geq |Z_{1-\alpha/2}|$, the null hypothesis ($H_0$) is rejected. Otherwise, the H_0 hypothesis is accepted and this means that the trend is not statistically significant (Mann 1945; Kendall 1975).

2.2.4 Modified Mann–Kendall

The modified Mann–Kendall (MMK) method is obtained by rearranging the variance in the original method (Malik and Kumar 2020). This process is used to calculate the new Z value by determining the autocorrelation effect. Adjusted variance value is calculated as given in Eqs. 8 and 9 (Yue et al. 2002).

$$V(S) = \mathrm{Var}(S)\frac{n}{n_s^*} = \frac{n(n-1)(2n+5)}{18}\frac{n}{n_s^*} \tag{8}$$

$$\frac{n}{n_s^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-i)(n-i-2)\rho_s(i) \tag{9}$$

where n/n_s^* represents a correction due to automatic correlation in the data. "n" is the actual number of observations and $\rho_s(i)$ is the autocorrelation of the observation ranks (González-Hidalgo et al. 2011).

3 Results

In this study, the autocorrelation of the time series was tested first. The tests values were compared with the critical values in 95% of the confidence interval. The results are listed in Table 4. Then, the homogeneity of the trends was tested in two parts by the SNHT. First, to understand the homogeneity effect better, the whole series was considered homogeneous and trend analyses were performed. The test values were compared with the critical values in 95% of the confidence interval; the results are listed in Table 5. Second, change points were determined for inhomogeneous stations, and trend analysis was conducted for these points.

The results of the autocorrelation test showed that the H_0 hypothesis can be rejected for the time series, and there was a strong autocorrelation effect. Therefore, the MMK method was performed as a trend analysis independent of this effect (González-Hidalgo et al. 2011).

The homogeneity of trends was tested by SNHT. A decreasing trend in 1 month and an increasing trend in another month indicates inhomogeneity between trends. In this case, the trends and slopes calculated by the tests may be inaccurate. Hence, the homogeneity between the monthly trends of the observations should be determined after performing the trend tests. For this purpose, one of the most common and well-known tests, SNHT was used. The results of SNHT and critical limits (T_0) are provided in Table 5.

Analysis of the SNHT results showed that the H_0 hypothesis is accepted because T_0 for all meteorological stations was lower than the critical T_0 value, and the P value was greater than the critical value of 0.05. In other words, the data are homogeneous. When the homogeneity conditions of the lake stations were examined, contrasting results were obtained, and the H_0 hypothesis was rejected as the data had an inhomogeneous change point. The change points were December 1998 for Kızören sinkhole, June 2006 for Timraş sinkhole, June 1990 for Tuz lake, and June 1989 for Beyşehir lake (Table 7). Thereafter, the long-term precipitation data were expected to show no trends since the data were homogeneous. To understand the situation, trend analysis

Table 4 Results of autocorrelations test

Station type	Station name	t value	Critical t value ($\alpha = 5\%$)	H_0
Meteorology observation station	Karapınar	4.983	1.964	Reject
	Çumra	4.159	1.964	Reject
	Kulu	6.174	1.964	Reject
	Cihanbeyli	5.520	1.964	Reject
	Beyşehir	6.189	1.964	Reject
Lake observation station	Kızören	203.96	1.964	Reject
	Timraş	180.776	1.964	Reject
	Lake Tuz	22.559	1.964	Reject
	Lake Beyşehir	136.181	1.964	Reject

was first performed for long-term precipitation data. Then, trend analysis was performed according to the change dates of the inhomogeneous lake levels. The results indicate that lake levels may tend to be inhomogeneous.

Trend analyses were conducted based on MK and MMK. The trend results and their critical limits are listed in Table 6.

Long-term MK and MMK methods showed similar results. No significant trend could be detected at the precipitation stations. While the lake levels do not show any tendency according to the Lake Tuz MMK method at a 95% confidence level, they show a decreasing trend compared with MK method. The long-term time series are shown in Figs. 3 and 4.

The Thiessen polygons show that Lake Tuz lies within the region of influence of Kulu and Cihanbeyli stations; Beyşehir lake, within that of Beyşehir station; Kızören sinkholes, within that of Cihanbeyli and Karapınar stations; and Timraş sinkholes, within that of Çumra station (Fig. 1). The time series according to the change points are shown in Figs. 5, 6, 7, and 8.

An analysis of the trend results before the change point showed that the trends in Kızören and Timraş station precipitation decreased, while the trend in Lake Tuz level increased, and Beyşehir lake level did not show any significant tendencies. An analysis of the trend results after the change point showed that the trend in Kızören station precipitation decreases; Timraş and Lake Tuz station precipitations do not show any significant tendencies; and the Beyşehir lake level shows a decreasing trend in MK result.

4 Discussion

According to the long-term autocorrelation test results, the precipitation data are homogeneous and do not show any trend. However, according to autocorrelation test results, the lake level data are not homogeneous and do not show any trend. This shows consistency in terms of homogeneity and trend (Demir et al. 2018). Further, the trend analysis results considering the point of change show that the methods yield consistent results, and the values decreased when MMK was performed (Akinsanola and Ogunjobi 2015). According to MMK, this trend is meaningless for Beyşehir lake levels. Because of the strong correlation between the data, other methods could not be used. The MMK, which takes into

Table 5 Results of SNHT test

Station type	Station name	T_0 value	Critical T_0 value ($\alpha = 5\%$)	P value	H_0
Meteorology observation station	Karapınar	4.983	10.348	0.192	Accept
	Çumra	4.159	10.348	0.187	Accept
	Kulu	6.174	10.348	0.236	Accept
	Cihanbeyli	5.520	10.348	0.212	Accept
	Beyşehir	6.189	10.348	0.237	Accept
Lake observation station	Kızören	472.96	10.233	< 0.0001	Reject
	Timraş	370	10.096	< 0.0001	Reject
	Lake Tuz	25.395	10.306	< 0.0001	Reject
	Lake Beyşehir	281.5	10.347	< 0.0001	Reject

Table 6 Results of trend methods

Station type	Station name	MK Z value	MMK Z value	Z critical value	MK trend	MMK trend
Meteorology observation station	Karapınar	− 0.196	− 0.203	± 1.96	No	No
	Çumra	− 0.609	− 0.612	± 1.96	No	No
	Kulu	− 1.351	− 1.324	± 1.96	No	No
	Cihanbeyli	− 0.627	− 1.827	± 1.96	No	No
	Beyşehir	0.710	0.608	± 1.96	No	No
Lake observation station	Kızören	*− 22.31*	*− 8.055*	± 1.96	*(-)*	*(-)*
	Timraş	*− 25.42*	*− 6.614*	± 1.96	*(-)*	*(-)*
	Lake Tuz	*− 2.15*	− 1.072	± 1.96	*(-)*	No
	Lake Beyşehir	*− 12.14*	*− 9.691*	± 1.96	*(-)*	*(-)*

(+): increasing trend, (-): decreasing trend

account the effect of autocorrelation, differs from other methods in this regard (Yu et al. 1993). The overall evaluation and comparison of the trend test results for all methods are summarized in Table 8.

The trends in the change of lake and sinkhole water levels and station precipitation determined using the Thiessen polygons agree with each other before the point of change (Fig. 5, 6, 7, and 8). However, after the point of change, the precipitation and lake and sinkhole water levels did not change similarly. For example, although Beyşehir lake level shows an increasing trend after the change point, the precipitation data at the corresponding station decrease. Further, the trends in Timraş and Kızören sinkhole water levels were in contrast to the precipitation trends. These findings show that lake levels are results of complex processes that have different effects.

Table 7 Results of trend methods according to the point of change

Change point	Variable	MK Z value	MMK Z value	Z critical value	MK trend	MMK trend
Before	Karapınar	− 0.074	− 0.087	± 1.96	No	No
	Cihanbeyli	− 0.042	− 0.033	± 1.96	No	No
	Kızören sinkhole	*− 12.06*	*− 7.569*	*± 1.96*	*(-)*	*(-)*
After	Karapınar	0.362	0.370	± 1.96	No	No
	Cihanbeyli	0.454	0.401	± 1.96	No	No
	Kızören sinkhole	*− 13.64*	*− 13.64*	*± 1.96*	*(-)*	*No*
Before	Çumra	− 0.910	− 0.708	± 1.96	No	No
	Timraş sinkhole	*− 20.97*	*− 8.268*	*± 1.96*	*(-)*	*(-)*
After	Çumra	− 0.355	− 0.584	± 1.96	No	No
	Timraş sinkhole	1.608	0.629	± 1.96	(-)	(-)
Before	Kulu	0.232	0.225	± 1.96	No	No
	Cihanbeyli	0.008	0.008	± 1.96	No	No
	Lake Tuz	*6.608*	*2.994*	*± 1.96*	*(+)*	No
After	Kulu	− 1.274	− 1.026	± 1.96	No	No
	Cihanbeyli	0.144	0.121	± 1.96	No	No
	Lake Tuz	− 0.507	− 0.432	± 1.96	No	No
Before	Beyşehir	0.630	0.549	± 1.96	No	No
	Lake Beyşehir	0.141	0.157	± 1.96	No	No
After	Beyşehir	− 0.011	− 0.011	± 1.96	No	No
	Lake Beyşehir	*4.065*	1.868	± 1.96	*(-)*	No

(+): increasing trend, (-): decreasing trend

Table 8 Comparison of the results of the trend analyses

Station Name	Change point	MK	MMK
Kızören Sinkhole	Before	🟨 MK	🟨 MMK
	After	🟨 MK	🟨 MMK
Timraş Sinkhole	Before	🟨 MK	🟨 MMK
	After	-	-
Lake Tuz	Before	🟦 MK	🟦 MMK
	After	-	-
Lake Beyşehir	Before	-	-
	After	🟨 MK	-

🟨 Decreasing trend   ☐- No trend   🟦 Increasing trend

Fig. 3 Time series of precipitation data: Beyşehir (**a**), Cihanbeyli (**b**), Çumra (**c**), Karapınar (**d**), and Kulu station (**e**)

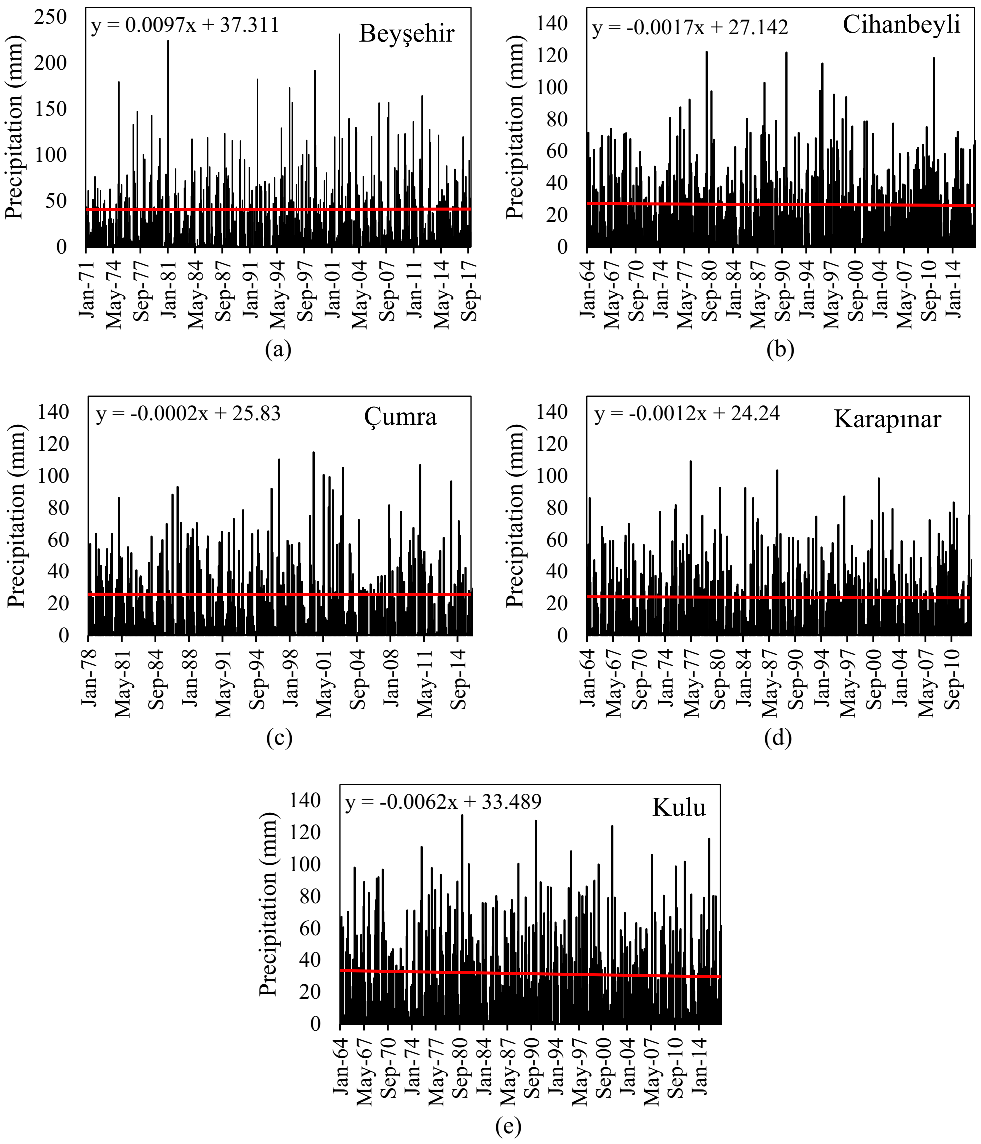


Fig. 4 Time series of lake water level: Lake Beyşehir (**a**), Lake Tuz (**b**), Kızören sinkhole (**c**) and Timraş sinkhole (**d**)

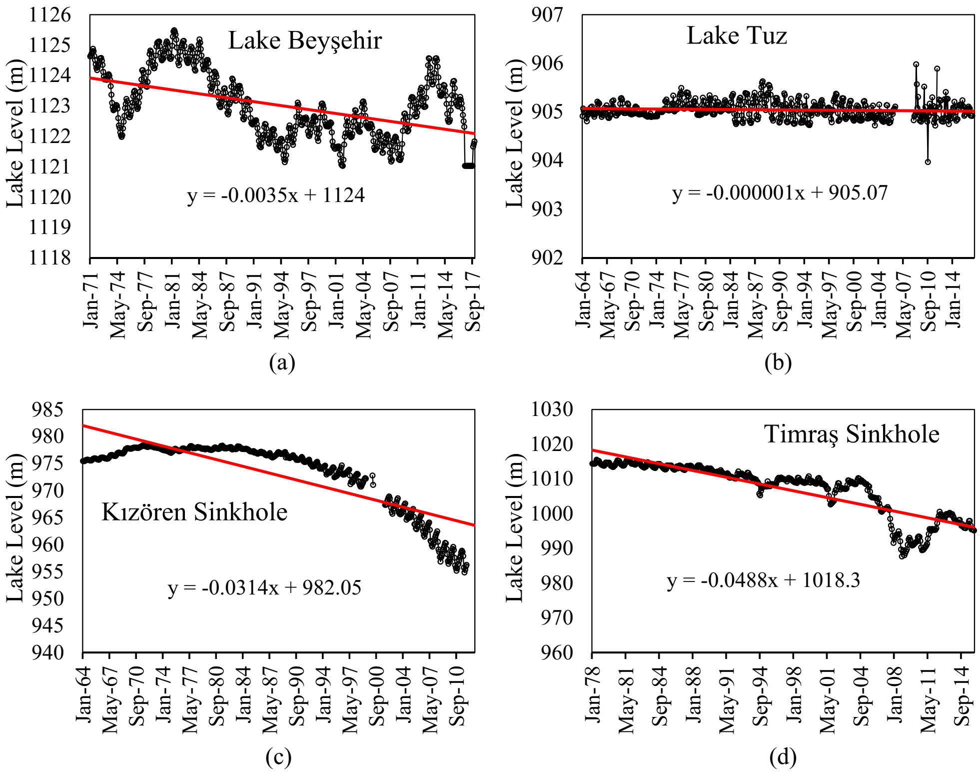


Fig. 5 According to the change point, Cihanbeyli (**a**) and Karapınar stations' precipitation heights (**b**) and Kızören sinkhole lake water levels (**c**)

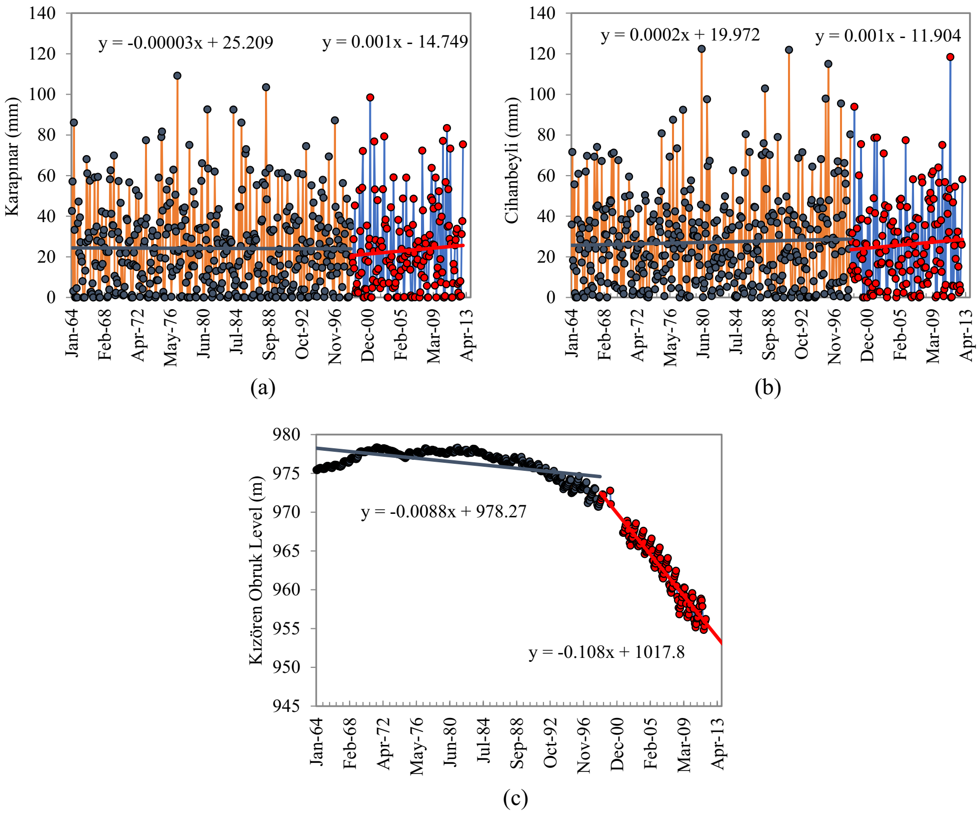
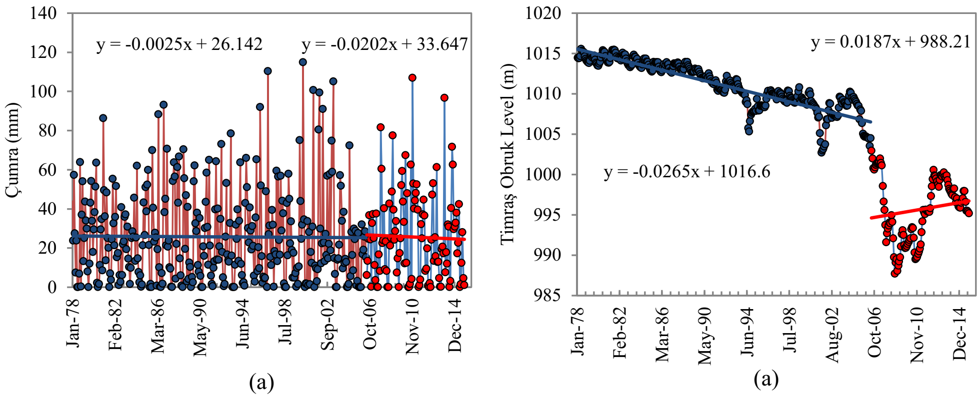


Fig. 6 Çumra station precipitation (**a**) and Timraş sinkhole lake water levels (**b**) according to the change point

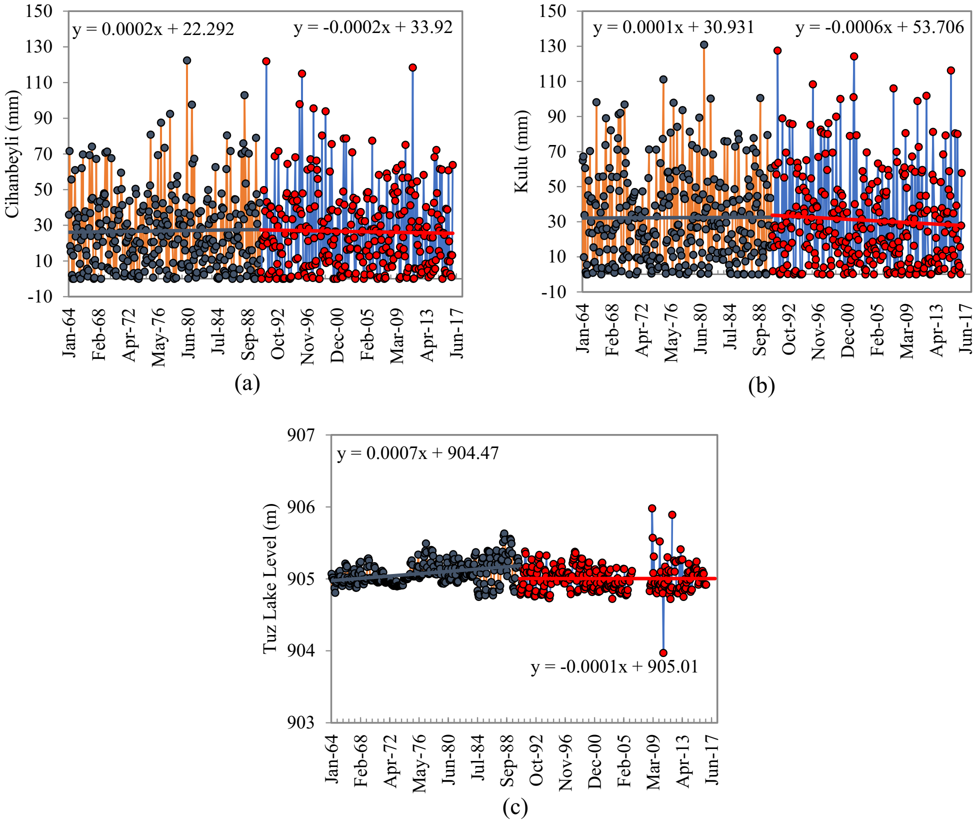


(a) (a)

One of the biggest impacts of climate change on humans is its impact on water resources (Hamerlík et al. 2016). In addition, global climate change (Yagbasan and Yazicigil 2012; Bhave et al. 2013, 2020; Safavi et al. 2015; Ortiz-Partida et al. 2016) intercontinental teleconnection (Belete et al. 2017) may be the probable cause of the changes in lake water levels. For example, these effects are clearly seen in the case of Lake Beyşehir. It was determined that water was transferred to the lake after 2008. According to state policies, an average of 135 million m^3 of water is transported annually through diversion tunnels to prevent the lake from drying out. The increasing trend in water level after 2008 is regarded as the effect of the waters transferred to the lake (Eroglu 2020).

Sinkholes are formed by natural factors (tectonism, climate, lithological character, etc.) and human activities (maximum use of groundwater, military ammunition trials, etc.) with the collapse of the ceilings of underground cavities such as underground caves. The main sources of water in a sinkhole are underground water and precipitation. Changes in sinkholes have been examined in recent years. In the case of Kızören sinkhole, there is a decrease in water level despite the increase in regional precipitation. This decrease is attributed to the increase in agricultural areas in the region in recent years; in these areas, the products that require water are important, and these regions are affected by the unconscious use of ground and surface waters, incorrect irrigation techniques,

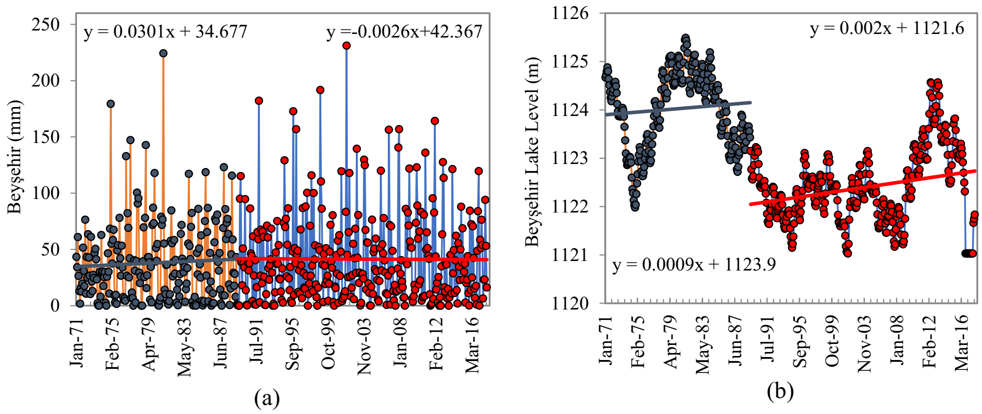
Fig. 7 Cihanbeyli (**a**) and Kulu (**b**) stations' precipitation, and Lake Tuz water levels (**c**) according to the change point



(a) (b)

(c)

Fig. 8 Beyşehir station precipitation (**a**) and Lake Beyşehir water levels (**b**) according to the change point



(a)

(b)

traditional agricultural practices, and presence of many illegal wells. In addition, there is no other source than the groundwater feeding the Kızören sinkhole (DSI 2020a,).

Recep and Tapur (2009) and Doğan and Yilmaz (2011) stated that groundwater moves from south to north in the Konya basin. Therefore, the increase observed in the Timraş sinkhole water level is attributed to the increase in precipitation at Karaman station and the groundwater movement caused by this increased precipitation. The time series of Karaman station's precipitation is shown in Fig. 9 according to the change point. The underground geology map is given in Fig. 10.

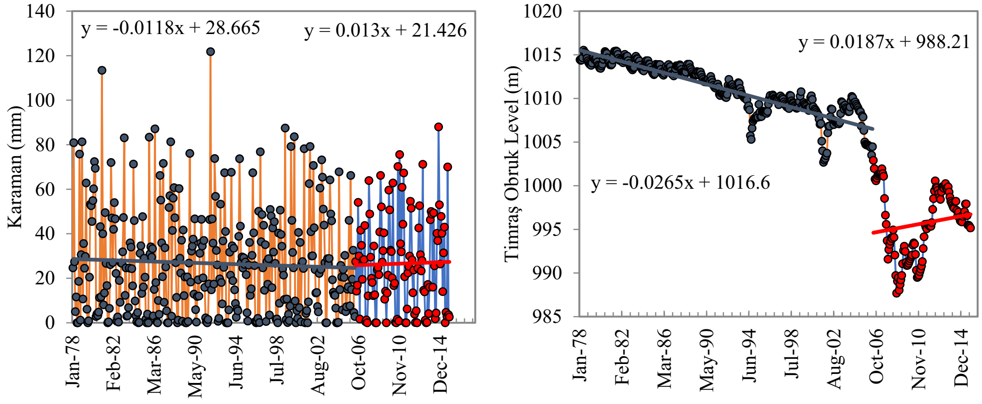
In Fig. 10, the water temperature was measured to determine the groundwater movement in the sinkhole area. As a result of this measurement, it has been found that the sinkhole waters mix into the groundwater and the groundwater flow direction is from W to E (Günay et al. 2011). As a result, the groundwater in the region moves from south to north and from west to east and ends in the Lake Tuz. In addition to the precipitation and groundwater movement, the Timraş sinkhole is also fed from the Çarşamba river (a river flowing into Çumra). In recent years, excess water from the river is transferred to Timraş sinkhole. Further, with the Blue tunnel project, which provides the water requirement of the basin, additional waters are transferred to the Timraş sinkhole (DSI 2020b). Due to these additional waters, sinkhole water levels have increased in recent years.

5 Conclusions

In this study, trend and homogeneity analyses were performed for long-term monthly precipitation and lake and sinkhole water level series for Central Anatolia for the period 1964–2017. Central Anatolia faces increasing demand for fresh water because of the population growth and agricultural development. The water levels of the two most important lakes of the region, Beyşehir and Tuz lakes, and the two most important sinkholes, Timraş and Kızören sinkholes, were examined based on the changes in precipitation at stations using Thiessen polygons.

Autocorrelation and homogeneity tests were performed before the trend analysis. SNHT was performed as the homogeneity test. Then, trend analyses were performed separately according to the homogeneity of stations and acceptance of the change point. MK and MMK were performed for the trend

Fig. 9 According to the change point, Karaman station's precipitation data (**a**) and Timraş Sinkhole water levels (**b**)



(a)

(b)

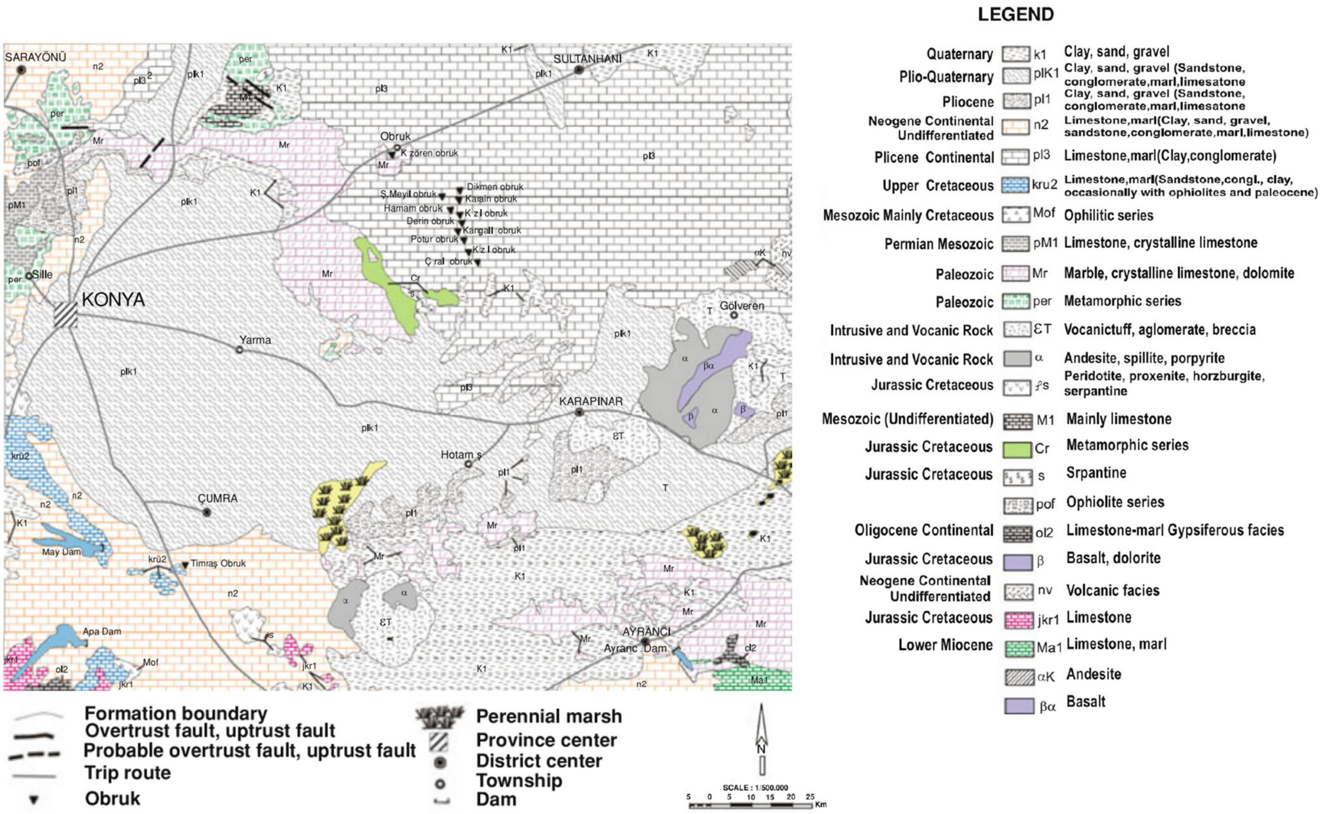


Fig. 10 Underground geology map, Günay et al. (2011)

analysis. All analysis results were examined for 95% of the confidence interval, and the following findings are highligted:

- In the autocorrelation test for precipitation data and water levels, the data showed strong autocorrelation.
- The precipitation data as well as the lake and sinkhole water level data were not homogeneous.
- As per the long-term trend analysis, no trend was determined in the homogeneous precipitation data. A decreasing trend was observed for inhomogeneous lakes and sinkholes by the trend analysis.
- It is difficult and misleading to make sense of the changes in lakes and sinkholes according to the long-term precipitation. This challenge can be tackled by considering the homogeneity change point.
- While the water levels in the lakes and sinkholes can be explained by the precipitation changes before the change points, the fluctuations after the change point are severe effects of anthropogenic activities.
- It was concluded that it is necessary to examine the hydraulic and geological situation of the region in addition to the Thiessen polygons when examining the trends of water levels, especially the sinkhole water levels.
- The MK and MMK results are very similar, and trend directions are compatible. MMK has been used successfully to detect the artificial tendency for Beyşehir station after the change point; this tendency cannot be detected by other tests because of the strong autocorrelation.

The apparent changes in the observed precipitation and lake and sinkhole water level series have major implications on water resource management, agricultural practices, hydroelectric power generation, and socioeconomic activities of the country. Therefore, adequate adaptive and mitigation measures should be taken for lakes and sinkhole to adapt to the changing climate.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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