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ORIGINAL PAPER

# Trend analysis of lakes and sinkholes in the Konya Closed Basin, in Turkey

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## Abstract
This study aims to investigate the trend of water-level changes in lakes (Lake Tuz and Lake Beyşehir) and sinkholes (Timraş and Kızören) in the Konya Closed Basin located in Turkey. Water-level changes in these lakes and sinkholes were investigated along with changes in meteorological parameters (precipitation, temperature, and evaporation) and groundwater trends that indicate the climate in the region. Several statistical tests can be used to determine the significance of hydrological trends over time. These tests are divided into two categories: parametric and nonparametric. In this study, the nonparametric Innovate Sen trend test, the Modified Mann–Kendall trend test, and the parametric Linear trend test were used. According to the trend analysis, the water levels of Kızören and Timraş sinkholes decreased over time, while the water levels of lakes Tuz and Beyşehir increased. These results are supported by the trends in the meteorological data and groundwater level data of the stations determined with the Thiessen polygons and sub-basin boundaries.

**Keywords** Konya Closed Basin · Sinkhole · Modified Mann–Kendall trend test · Linear Trend test · Innovate Sen trend test

## 1 Introduction

Humans, who have a significant position in the environment of terrestrial and aquatic ecosystems, need the presence of lakes, which are valuable water resources (Wantzen et al. 2008; Williamson et al. 2009; Waylen et al. 2019). Many lakes around the globe are facing multiple types of threats owing to combined effects such as water withdrawals resulting from human activities and climate variation (McBean and Motiee 2008; Yagbasan and Yazicigil 2012; Yuan et al. 2015; Yagbasan et al. 2020). These effects, which have a critical influence on regional sustainable development, can adversely impact both water quality and quantity (McBean and Motiee 2006; Yuan et al. 2015). The fluctuation of lake water levels plays an important role in lake ecosystems (Leira and Cantonati 2008). It is

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necessary to establish sustainable management of the lakes to detect long-term changes in water levels (Demir and Keskin 2020).

Fluctuations in lake water levels are known to be sensitive indicators of changes in climate and groundwater and can play an important role in monitoring climate changes today and in the future (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 analyzing impacts on relevant ecosystems (Zhang et al. 2015; Bohn et al. 2016). Lake water level fluctuations can result from the complex relationship of various water balance components. These components include the flow entering or leaving the lake, direct precipitation to the lake surface, and groundwater change (Pan et al. 2018). In addition to meteorological factors such as precipitation on the lake drainage area, evaporation from the lake surface, wind speed, humidity, and temperature in the adjacent sub atmosphere play an important role in water level fluctuations in the lakes. Gradual (trend) or sudden (shifting) climate change problems have been particularly notable in recent years. Researchers have found that most of the changes in the lake level are related to meteorological variables such as precipitation, temperature and evaporation (McBean and Motiee 2008; Zoljoodi and Didevarasl 2014; Yagbasan et al. 2017, 2020).

Understanding long-term trends in hydrometeorological variables and groundwater changes is highly significant for sustainable water resource management (Hu et al. 2017; Citakoglu and Minarecioglu 2021). Meteorological parameters can change for many reasons, depending on the time and space. These observed changes should be determined by various statistical methods. The trend and homogeneity analysis are two important statistical methods that are widely used around the world for assessing the 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).

Precipitation and groundwater are the main sources of water in sinkholes. Sinkholes are formed by a combination of natural factors (tectonic, climate, and lithological character), human activities (maximum use of groundwater, mining, and military ammunition trials), and the collapse of the ceilings of underground cavities, such as underground caves (Gutierrez et al. 2014; Parise 2015, 2019). Therefore, the focus of this study is on determining monthly trends in groundwater levels, precipitation, temperature, and evaporation. Statistical analysis results in existing literature revealed that meteorological parameters and groundwater levels have a crucial impact on changes in lake water levels. Precipitation, temperature, and evaporation are the main elements in the hydrological system. Hence, a change in the long-term trends of these meteorological parameters will have a direct effect on water resources, particularly the lake water levels. In addition, climate changes and human activities are probable causes of changes in lake water levels (Demir and Keskin 2020; Yagbasan et al. 2020).

Sinkholes are among the most common landforms of karst landscapes worldwide (Waltham et al. 2005; Parise et al. 2015, 2018). They are divided into two main categories: solution and subsidence sinkholes (Waltham et al. 2005; Williams 2005; Gutiérrez et al. 2008, 2014), occur in a variety of sizes and are morphologically expressed as a function of the mechanisms originating them (Waltham et al., 2005). In many countries, sinkholes are among the most significant geohazards in karst areas, with negative societal consequences in terms of economic losses (particularly in urban areas), social degradation, and human life loss (Scheidt et al. 2005; Del Prete et al. 2010; Galve et al. 2011; Festa et al. 2012). Sinkholes cause the most damage in Wink, Texas, USA (Kim et al. 2016); Sivas, Turkey (Yilmaz 2007); Tournaisis, southern Belgium (Kaufmann and Quinif 2002); Tampa, Florida (Brinkmann et al. 2008) and southeastern Minnesota, USA (Gao and Alexander

2008); Apulia, southern Italy (Delle Rose and Parise 2002; Bruno et al. 2008; Margiotta et al. 2021); Ebro River valley, NE Spain (Galve et al. 2009); the shores of the Dead Sea between Israel and Jordan (Frumkin et al. 2011; Nof et al. 2013, 2019); Naples, southern Italy (Guarino and Nisio 2012); Elba Island, central Italy (Intrieri et al. 2015); Hamadan, Iran (Taheri et al. 2015) Lazio, Italy (Ciotoli et al. 2016); and Karapınar, Turkey (Ozdemir 2015, 2016; Orhan et al. 2017, 2020, 2021).

Only a few studies on the hydrological relationship between lakes water levels, groundwater levels, and meteorological variables are available in the literature. Some examples are as follows; Yenilmez et al. (2011) used the Mann–Kendall (MK) and linear trend (LT) methods to analyze the trend of water quality parameters, precipitation, lake volume, and temperatures observed in the Eymir Lake (Turkey). Bahadır (2012) used the LT method to analyze the precipitation and the water level trend in the Kovada Lake (Turkey). Yagbasan et al. (2017) used the (MK) trend method to analyze the temperature, precipitation, and water levels in the Mogan and Eymir Lakes. Göncü et al. (2017) used the (MK), seasonal Kendall, regional Kendall, and LT methods to examine the change in the climate variables and water levels of four lakes (Burdur, Eğirdir, Sapanca, and Tuz) in Turkey. Belete et al. (2017) used the (MK) trend test for long-term precipitation, streamflow, and potential evapotranspiration trends for the water level of Lake Hawassa (Ethiopia). Yagbasan et al. (2020) used the (MK), Modified Mann–Kendall (MMK), and LT tests to analyze trends in climate variables and water-level changes in the Mogan and Eymir Lakes.

The Konya Closed Basin (KCB) is the major agricultural production region in Turkey. The future of agriculture in this region is threatened by the decrease in groundwater levels due to climate change and other anthropogenic factors (Orhan 2021). In addition, the decrease in groundwater levels results in the formation of many sinkholes. In recent years, these sinkholes have spread from agricultural to urban regions, posing a threat to human life (Orhan et al. 2020). Since the region is a closed basin, the groundwater flow is influenced by meteorological parameters and eventually ends up in lakes. This study aimed to investigate the long-term fluctuations of precipitation temperature, evaporation, and groundwater changes in lakes in the Central Anatolia region of Turkey. In this study, the homogeneity characteristic of the time series was investigated. Subsequently, trend analyses were conducted. The standard normal homogeneity test (SNHT) was used to determine if the hydrological data came from the same population. Nonparametric MMK, Sen's innovative trend (ST), and parametric LT methods were used for trend analyses.

## 2 Materials and methods

### 2.1 Study area

The KCB is located in the central and southern parts of the Central Anatolia Region. Agriculture is the most important economic activity in the KCB, with the primary crops being beets, corn, and wheat. In Turkey, the KCB is one of the driest sectors, with a semi-arid climate, which causes cold moist winters and hot dry summers (Orhan et al. 2020). According to the long-term data from meteorological stations (Fig. 1) in the KCB, the average annual temperature is 11.6 °C (max 40.6 °C, min − 28.2 °C). The average annual precipitation is 323.3 mm (Demir and Keskin 2020). Precipitation is convective in the region. Evapotranspiration often exceeds total precipitation (393.50 mm). Lakes Beyşehir and Tuz are the region's most important lakes (Fig. 1a and d).

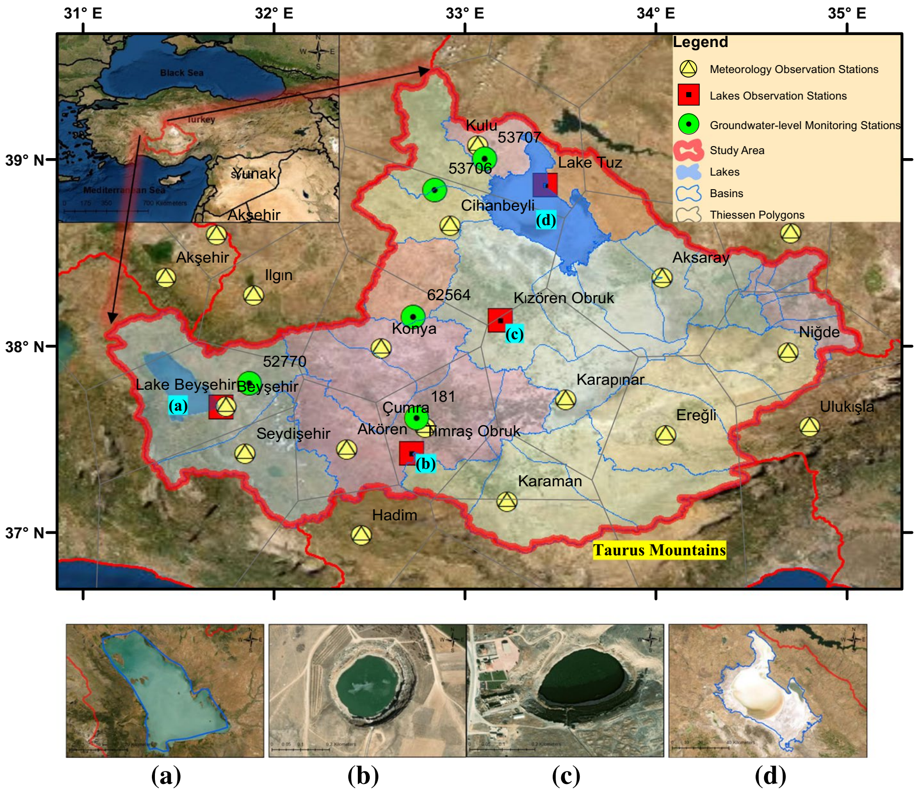



**Fig. 1** Lake Beyşehir (**a**), Timraş Sinkhole (**b**), Kızören Sinkhole (**c**), LakeTuz (**d**)

Lake Tuz is the second largest lake in Turkey by surface area and is extremely shallow. Since the lake is shallow, intense evaporation creates a high salt concentration in the lake (Göncü et al. 2017). This lake provides 55% of Turkey's salt requirements. 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 widespread precipitation, the feeding sources are limited. During the summer, the streams that supply water to the lake either diminish in volume or dry up. The average depth of the lake is approximately 40 cm, but it increases to 110 cm in May when precipitation increases. In August, the lake dries up considerably. Lake Tuz and its surroundings are both designated as a specially protected area. Many eccentric bird species breed in the surrounding environment (Anonymous 2020). Lake Beyşehir is Turkey's largest freshwater lake (Guler et al. 2008). It is the third-largest lake after Lake Van and Lake Tuz, with a surface area of 650 km$^2$, and surrounded by mountains in a tectonic deposit. Although the average depth of the lake is 5–6 m, its maximum depth is 8–9 m. Lake Beyşehir, similar to Lake Tuz, is a protected area in Turkey and a home to 545 plant species, 163 bird species, and 16 fish species. Many water birds migrate to Lake Beyşehir to hunt and breed (Bucak et al. 2018).

The KCB has over 300 sinkholes, which hold 33.3% of the country's groundwater (Orhan et al. 2021). The sinkholes are formed because of the dissolution of carbonate rocks by carbon dioxide ($CO_2$) rich groundwater and the collapse of the ceiling of underground cavities at a later stage in the KCB. If the collapse reaches the groundwater level, water accumulation is observed at the bottom of the sinkhole (Recep and Tapur 2009). Timraş and Kızören are the most important sinkholes in the region (Fig. 1b and c) (Günay et al. 2011, 2015). The Timraş Sinkhole was formed within Neogene-aged lacustrine limestones. The Timraş Sinkhole is located approximately 40 km southeast of Konya and 46 km from the Konya–Karaman highway (Fig. 1b). It is an ellipse-shaped sinkhole composed of limestones with long and short diameters of 325 m and 250 m, respectively. The deepest point of the sinkhole has been recorded at 32 m (Recep and Tapur 2009). The formation of the Kızören Sinkhole is based on two stages. The Kızören Sinkhole was formed in two phases within Paleozoic aged crystallized limestones and Neogene lacustrine formations (Recep and Tapur 2009). This sinkhole is located 75 km away from the city of Konya, Turkey (Fig. 1c). It has an elliptical shape, with a long axis of 180 m and a short axis of 150 m. It is up to 145 m deep below the water surface (Günay et al. 2011).

#### 2.1.1 Geological and Hydrogeological Background of the KCB

Konya Basin consists of allochthonous and autochthonous rocks (Robertson and Ustaömer 2009). Although Paleozoic schists can be found near the base, they are overlain by Paleozoic and Mesozoic marbles and carbonates. Sedimentary and volcanic rocks from the Tertiary period lie on top of younger (Miocene–Pliocene) lacustrine deposits (Association of Cave Research 2021). Figure 2 depicts the geological map of the study area.

As shown in Fig. 2, both the Kızören Sinkhole and the Timraş Sinkhole are located in the limestone region (Günay et al. 2011). Groundwaters are provided by the Taurus Mountains (Fig. 1) located to the south of the KCB. The Taurus Mountains are the highest in the region. Over time, sinkholes are formed as the ground dissolves owing to a lowering in groundwaters. Except in the Lake Beyşehir basin, where groundwaters move toward Lake Beyşehir, groundwater moves from south to north toward Lake Tuz in other sub-basins (sub-basins are colored in Fig. 1) (Günay et al. 2011). During the flow from the Konya Plain to Lake Tuz, the groundwater dissolves karstic rocks and underground cavities are formed. Owing to the decrease in the groundwater level that fills these gaps, the surface layers, which have a disturbed balance, collapse and karstic shapes emerge (Recep and Tapur 2009).

#### 2.1.2 Data

Monthly total precipitation data (mm), monthly average temperature (°C) and monthly total evaporation (mm), were obtained from the General Directorate of Meteorology in meteorology stations (Fig. 1). Lake level data and groundwater-level data (m) were obtained from the Directorate General for State Hydraulic Works. Other informations about the stations are tabulated in Table 1. Unfortunately, due to various regulations made by the government agency, the data could not be obtained after 2017. The data used in the study cover the time interval between 1964 and 2017. Table 1 shows the location of the meteorological, lake level observation and the groundwater-level observation stations employed in the study. Table 2 shows the statistical properties and data periods used in the study. The distribution of long-term average groundwater levels in the study area is given in Fig. 3.

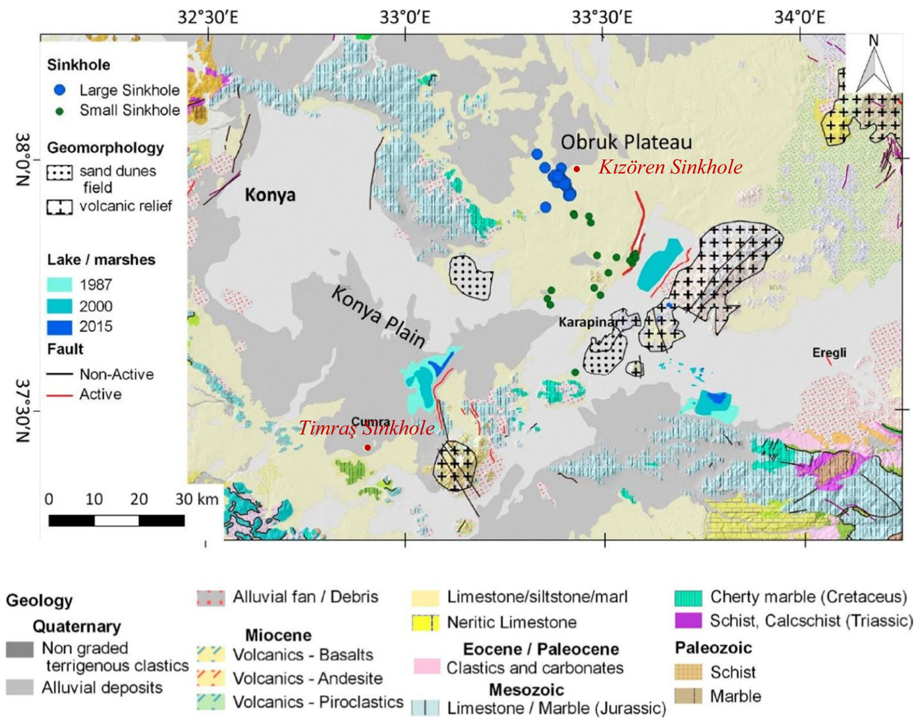



**Fig. 2** Geological and geomorphological map of the study area (adapted from Kuzucuoglu et al. (1998) and Caló et al. (2017))

## 2.2 Methods

In this study, an investigation of the long-term monthly lake water level, sinkhole water level, groundwater level, precipitation, temperature, and evaporation series analysis was performed. Firstly, the homogeneity conditions were examined. Later trend analyses were carried out.

### 2.2.1 Standard normal homogeneity test (SNHT)

This method developed by Alexandersson is used to test the homogeneity of many hydrometeorological series (Khaliq and Ouarda 2007). The value of $T(c)$ (Eq. 1) is calculated by dividing it into two parts with reference to a "c" point of the studied series (Eqs. 2 and 3).

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

$$\bar{z}_1 = \sum_{i=1}^{c} (y_i - \bar{y})/\sigma)/c \tag{2}$$

$$\bar{z}_2 = \sum_{i=1+c}^{n} (y_i - \bar{y})/\sigma)/(n-c) \tag{3}$$

**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 |
| | Konya | 17244 | 37.99 | 32.56 | 1031 |
| | Aksaray | 17192 | 38.38 | 34.03 | 965 |
| 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 |
| Groundwater-level observation stations | Cihanbeyli | 53706 | 32.84 | 38.84 | 968.5 (Depth, – 100) |
| | Selçuklu | 62564 | 32.73 | 38.16 | 987.99 (Depth, – 83) |
| | Beyşehir | 52770 | 31.87 | 37.80 | 1220.5 (Depth, – 140) |
| | Çumra | 181 | 32.75 | 37.62 | 1011.2 (Depth, – 250) |
| | Kulu | 53707 | 33.10 | 39.01 | 997.21 (Depth, – 150) |

**Table 2** Statistical properties of the stations

| | Station Name | Symbol & Unit | Max | Min | Mean | SD | SC | Period |
|---|---|---|---|---|---|---|---|---|
| Meteorology observation station (precipitation) | Karapınar | P (mm) | 109.20 | 0.00 | 23.86 | 21.21 | 1.04 | 1964–2017 |
| | Çumra | | 114.80 | 0.00 | 25.79 | 23.61 | 1.15 | 1978–2017 |
| | Kulu | | 130.90 | 0.00 | 31.49 | 26.19 | 0.93 | 1964–2017 |
| | Cihanbeyli | | 122.40 | 0.00 | 26.58 | 22.41 | 1.11 | 1964–2017 |
| | Beyşehir | | 231.20 | 0.00 | 40.71 | 38.09 | 1.59 | 1964–2017 |
| | Konya | | 124.00 | 0.00 | 27.74 | 24.37 | 1.09 | 1964–2017 |
| | Aksaray | | 119.00 | 0.00 | 28.78 | 23.99 | 0.79 | 1964–2017 |
| Meteorology observation station (temperature) | Karapınar | T (°C) | 25.70 | −9.40 | 11.13 | 8.40 | −0.12 | 1964–2017 |
| | Çumra | | 26.30 | −7.90 | 11.47 | 8.33 | −0.14 | 1978–2017 |
| | Kulu | | 26.50 | −7.70 | 10.40 | 8.60 | −0.07 | 1969–2017 |
| | Cihanbeyli | | 28.40 | −7.00 | 11.29 | 8.58 | −0.07 | 1964–2017 |
| | Beyşehir | | 25.10 | −7.40 | 10.84 | 7.99 | −0.08 | 1964–2017 |
| | Konya | | 27.70 | −8.00 | 11.59 | 8.59 | −0.08 | 1964–2017 |
| | Aksaray | | 27.10 | −6.10 | 12.12 | 8.30 | −0.12 | 1964–2017 |
| Meteorology observation station (evaporation) | Karapınar | E (mm) | 326.90 | 2.00 | 167.29 | 76.21 | −0.23 | 1971–2011 |
| | Çumra | | 260.50 | 1.20 | 147.54 | 62.39 | −0.40 | 1988–2011 |
| | Kulu | | 339.60 | 2.00 | 162.70 | 82.77 | −0.17 | 1969–2017 |
| | Cihanbeyli | | 340.60 | 0.90 | 159.81 | 79.81 | −0.17 | 1973–2017 |
| | Beyşehir | | 337.20 | 0.01 | 137.88 | 69.43 | 0.03 | 1966–2017 |
| | Konya | | 393.50 | 0.40 | 157.97 | 86.34 | 0.17 | 1964–2017 |
| | Aksaray | | 379.70 | 0.20 | 181.14 | 83.25 | −0.21 | 1973–2017 |
| Lake observation station | Kızören | WL (m) | 978.35 | 945.30 | 971.27 | 8.57 | −1.24 | 1964–2017 |
| | Timraş | | 1015.53 | 987.68 | 1007.19 | 7.38 | −1.02 | 1978–2015 |
| | Lake Tuz | | 905.98 | 903.97 | 905.04 | 0.18 | 0.52 | 1964–2016 |
| | Lake Beyşehir | | 1125.49 | 1121.03 | 1123.14 | 1.12 | 0.13 | 1964–2017 |

**Table 2** (continued)

| | Station Name | Symbol & Unit | Max | Min | Mean | SD | SC | Period |
|---|---|---|---|---|---|---|---|---|
| Groundwater-level observation stations | Cihanbeyli | GWL (m) | −21.9 | −26.3 | −24.06 | 0.79 | −0.51 | 2000–2017 |
| | Selçuklu | | −1.66 | −42.55 | −11.02 | 9.97 | −1.23 | 1967–2017 |
| | Beyşehir | | −7.49 | −18.49 | −12.29 | 2.75 | −0.60 | 2004–2017 |
| | Çumra | | −1.27 | −25.16 | −7.30 | 5.57 | −1.14 | 1967–2017 |
| | Kulu | | −8.1 | −15.09 | −11.18 | 1.81 | −0.41 | 2000–2017 |

*SD* standard deviation, *SC* skewness coefficient

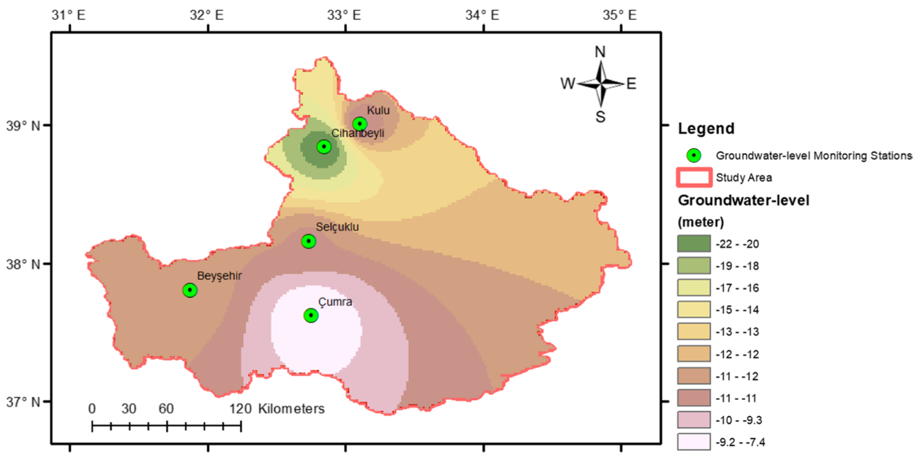



**Fig. 3** Distribution of long-term average groundwater levels

**Table 3** $T_0$ test critical values depending on the number of data

| Number of data | 30 | 40 | 50 | 70 | 100 | 200 | 500 | 700 | 1000 |
|---|---|---|---|---|---|---|---|---|---|
| CL (95%) | 7.65 | 8.10 | 8.45 | 8.80 | 9.15 | 9.55 | 10.20 | 10.45 | 10.50 |

where "$T$ $(c)$" SNHT statistics value, "$n$" is the number of data, "$y$" is years, z is the standardized work series of length n, $\overline{z_1}$ 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 $c = h$. $T_0$ is the test statistic of the SNHT method and is obtained with the help of Eq. (4).

$$T_0 = \max_{1 \le c \le n} T(c) \tag{4}$$

If the test statistic $T_0$ exceeds the $T_0$ critical value, the null hypothesis ($H_0$) is rejected. $T_0$ test values depending on the number of data and 95% Confidence Level (CL) is given in Table 3 (Alexandersson 1986).

### 2.2.2 Modified Mann–Kendall (MMK)

This method tests if there is a trend in the time series data (Mann 1945; Kendall 1975). It is a non-parametric rank-based procedure, robust to the influence of extremes and suitable for application with skewed variables (Hamed 2008). Test statistic value is calculated with the help of Eqs. (5 and 6).

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} 1; & \text{if } x_j > x_j \\ 0; & \text{if } x_j = x_i \\ -1; & \text{if } x_j < x_i \end{cases} \tag{5}$$

In Eq. (5), $x_i$ and $x_j$ are the data values in time series i and j, respectively and in Eq. (6), n is the number of data points, sgn $(x_j – x_i)$ is the sign function follow as;

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \tag{6}$$

After that, the variance is computed follow as;

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{P} t_i(t_i-1)(2t_i+5)}{18} \tag{7}$$

In Eq. (7), $n$ 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. (8), Mann–Kendall $Z$ value is calculated.

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}; & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases} \tag{8}$$

The MMK method is obtained by rearranging the variance in the original MK method. This process is used to calculate the new $Z$ value by determining the auto-correlation effect. Adjusted variance value is calculated as given in Eqs. (9 and 10) (Yue et al. 2002).

$$V(S) = Var(S) * \frac{n}{n_s^*} = \frac{n(n-1)(2n+5)}{18} * \frac{n}{n_s^*} \tag{9}$$

$$\frac{n}{n_s^*} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{i=1}^{n-1} (n-i)(n-i-2)\rho_s(i) \tag{10}$$

In Eq. (10), $n/n_s*$, represents a correction due to automatic correlation in the data. "$n$" is the actual number of observations and $\rho_s(i)$ is the auto-correlation of the observation ranks (González-Hidalgo et al. 2011). 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, and thus, the $H_a$ (alternative hypothesis) hypothesis is accepted. $H_0$ hypothesis states that the trend is statistically insignificant, $H_a$ hypothesis states that the trend is significant (Mann, 1945; Kendall, 1975).

### 2.2.3 Linear trend (LT)

This method basically rests on the slope of a line. It is a widely used method to determine the tendency of dependent and independent variables in hydrological time series. The regression equation is given below (Keskin et al. 2018).

$$Y = \beta_0 + \beta_1 X \tag{11}$$

In Eq. (11), $\beta_0$ is a constant value and $\beta_1$ is the slope of the line. It is also referred to as regression analysis, and trends (increasing or decreasing) are interpreted according to the student's t-test critical level value of the slope value ($\beta_1$). If $|t_{cal}|$ exceeds $\pm t_{cri}$, there is a statistically significant trend (Yagbasan et al. 2020).

### 2.2.4 Sen trend (ST)

In this method, first, time series is divided into two sub-series. Each sub-series is sorted in an ascending manner. Then, the first sub-series ($X_i$) is located on the X-axis, and the other sub-series ($X_j$) is located on the Y-axis in the Cartesian coordinate system (Fig. 4). If data are placed on the 1:1 (45°) straight line, it can be said that there is no trend (a trendless time series). If data are accumulated in the triangular area below the 1:1 (45°) straight line, there is a decreasing trend. If data are accumulated in the upper triangular area of the 1:1 (45°) straight line, there is an increasing trend (Şen 2012).

Initially, trend directions were interpreted graphically, then a new mathematical process was developed by Sen. (Şen 2014, 2017). The steps of this method are given in Eqs. (12–16).

$$E(s) = \frac{2}{n}\left[E(\overline{y}_2) - E(\overline{y}_1)\right] \tag{12}$$

$$\sigma_s^2 = \frac{4}{n^2}\left[E(\overline{y}_2^2) - 2E(\overline{y}_2\overline{y}_1) - E(\overline{y}_1^2)\right] \tag{13}$$

$$\rho_{\overline{y}_2\overline{y}_1} = \frac{E(\overline{y}_2\overline{y}_1) - E(\overline{y}_2) - E(\overline{y}_1)}{\sigma_{\overline{y}_2}\sigma_{\overline{y}_1}} \tag{14}$$

$$\sigma_s^2 = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{(1-\rho_{\overline{y}_2\overline{y}_1})} \tag{15}$$

$$CL_{(1-\alpha)} = 0 \pm S_{\mathrm{critical}}\sigma_s \tag{16}$$

where $\overline{y}_1$, mean of the first data set; $\overline{y}_2$, mean of the second data set; $\rho$, correlation between first and second data; s, slope value; n, number of data; σ, standard deviation of all data; $\sigma_s$, slope standard deviation; $Z$ critical values in one-way hypothesis at 95% (for example) confidence level. Critical upper and lower values are established for hypothesis test limits (Eq. 16). If each station's slope value, s, is outside the lower and upper confidence limits,

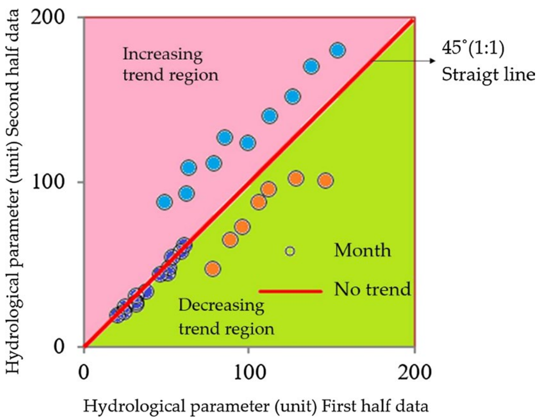



**Fig. 4** ST method trend regions (Keskin et al. 2018)

the alternative hypotheses, $H_a$, is verified, indicating a trend (Yes) in time series. The type of trend is stated depending on the slope value (s) sign. Slope (s) can be positive or negative. While positive slope (+) is indicating an increasing trend in time series, negative slope (-) shows a decreasing trend (Yagbasan et al. 2020).

## 3 Results

In this study, the SNHT approach was first used to test the homogeneity of the trends. Table 4 shows the results of comparing the test values to the critical limits ($T_0$) in a 95% confidence interval. Subsequently, trend analyses were conducted using the MMK, LT, and ST methods over long-term periods. The MMK and ST methods used in the study are non-parametric tests, whereas LT is a parametric test. Table 5 presents the results of the MMK, LT, and ST methods, as well as their critical limits (in 95% of the confidence interval). As shown in Table 5, the precipitation, groundwater, and lake levels are considered to have a statistical trend at the time series if the $Z$, $t$, and $s$ values of the stations are higher than the critical limits. The direction of the trend is determined by the sign of the $Z$, $s$, or $t$ value. The positive and negative signs indicate increasing and decreasing trends, respectively.

The SNHT results showed that the $H_0$ hypothesis is accepted (except for the evaporation data of the Konya and Beyşehir stations) because the $T_0$ value of all meteorology stations is lower than the $T_0$ critical value, and the $p$-value ($H_0$ hypothesis) is greater than 0.05, which is the critical value. These results indicate that the meteorological data are homogeneous (Demir and Keskin 2020). However, when the homogeneity conditions of the lake and groundwater stations were examined, the $H_0$ hypothesis was rejected, and it was established that the data were nonhomogeneous. Trends typically occur when data are nonhomogeneous (Demir et al. 2018). These results show that, contrary to the homogeneous precipitation data, the lake water and groundwater levels tend to trend.

The MMK and LT methods showed similar results. No significant trend could be detected at the precipitation stations. The evaporation data of Beyşehir and Konya stations showed increasing trends using both methods. In addition, increasing trends were determined for evaporation data at the Cihanbeyli station and for temperature data at the Cumra, Kulu, Cihanbeyli, and Aksaray stations.

The results of the MMK method for Lake Tuz indicated no trend in the lake water levels, whereas other stations showed a decreasing trend with the MMK and LT methods. When the groundwater levels were examined, the three trend methods revealed a decreasing trend in the Selçuklu and Çumra stations and an increasing trend in the Beyşehir station. The increasing trend detected at the Kulu and Cihanbeyli stations is statistically significant for the ST and LT methods but not for the MMK method. Except for the Çumra station, all precipitation stations and lake levels showed a decreasing trend using the ST method. Except for the Karapınar evaporation data, temperatures and evaporations from other meteorological parameters showed an increasing trend at all stations. Linear trend graphs for all data time series are shown in Figs. 5, 6, 7, 8, 9.

Except for the Beyşehir station, the long-term precipitation series in Fig. 5 depicts a decrease in precipitations in the KCB. From the linear regression equation ($y = ax + b$), it was determined that the precipitation data of the Beyşehir station increase by 0.0013 mm/month. Meanwhile, the precipitation data of the Karapınar, Çumra, Kulu, Cihanbeyli, Konya, and Aksaray stations decrease by 0.0012, 0.0002, 0.0062, 0.0017, 0.0020, and

**Table 4** Results of the SNHT test

| Station type | Station name | $T_0$ value | Critical $T_0$ value ($\alpha = 5\%$) | $P$ value | $H_0$ |
|---|---|---|---|---|---|
| Meteorology observation station (precipitation) | Karapınar | 4.158 | 10.348 | 0.649 | Accept |
| | Çumra | 2.973 | 10.140 | 0.843 | Accept |
| | Kulu | 4.023 | 10.348 | 0.685 | Accept |
| | Cihanbeyli | 2.434 | 10.348 | 0.944 | Accept |
| | Beyşehir | 6.189 | 10.348 | 0.237 | Accept |
| | Konya | 2.240 | 10.348 | 0.961 | Accept |
| | Aksaray | 4.094 | 10.348 | 0.672 | Accept |
| Meteorology observation station (temperature) | Karapınar | 6.814 | 10.348 | 0.239 | Accept |
| | Çumra | 9.124 | 10.233 | 0.070 | Accept |
| | Kulu | 3.642 | 10.278 | 0.755 | Accept |
| | Cihanbeyli | 5.842 | 10.348 | 0.343 | Accept |
| | Beyşehir | 5.588 | 10.348 | 0.377 | Accept |
| | Konya | 5.368 | 10.348 | 0.419 | Accept |
| | Aksaray | 5.892 | 10.348 | 0.337 | Accept |
| Meteorology observation station (evaporation) | Karapınar | 2.553 | 9.747 | 0.912 | Accept |
| | Çumra | 1.545 | 9.355 | 0.984 | Accept |
| | Kulu | 1.627 | 9.509 | 0.985 | Accept |
| | Cihanbeyli | 3.978 | 9.898 | 0.639 | Accept |
| | Beyşehir | 38.657 | 9.934 | < 0.0001 | Reject |
| | Konya | 28.422 | 0.054 | < 0.0001 | Reject |
| | Aksaray | 6.105 | 9.842 | 0.280 | Accept |
| Lake observation station | Kızören | 504.88 | 10.310 | < 0.0001 | Reject |
| | Timraş | 370 | 10.096 | < 0.0001 | Reject |
| | Lake Tuz | 25.395 | 10.306 | < 0.0001 | Reject |
| | Lake Beyşehir | 323.09 | 10.350 | < 0.0001 | Reject |
| Groundwater-level observation stations | Cihanbeyli | 49.82 | 9.45 | < 0.0001 | Reject |
| | Selçuklu | 471 | 10.28 | < 0.0001 | Reject |
| | Beyşehir | 126 | 9.42 | < 0.0001 | Reject |
| | Çumra | 473 | 10.28 | < 0.0001 | Reject |
| | Kulu | 51.33 | 9.41 | < 0.0001 | Reject |

0.0014 mm/month, respectively. However, these trends are statistically insignificant according to the LT method (Table 5).

In Fig. 6, the long-term temperature series depicts that temperatures have been increased in the Konya closed basin. The temperature data of the Karapınar, Çumra, Kulu, Cihanbeyli, Konya, Beyşehir, and Aksaray stations increasing by 0.002, 0.0038, 0.0033, 0.0035, 0.0018, 0.0009, and 0.0033 C°/month, respectively. However, these trends are statistically insignificant according to the LT method (Table 5).

In Fig. 7, the long-term evaporation series depicts that evaporations have been increased like temperatures, except for the Aksaray station. The evaporation data of the Karapınar, Çumra, Kulu, Cihanbeyli, Beyşehir, and Konya stations increasing by 0.0022, 0.1452,

**Table 5** Results of trend methods

| Station type | Station Name | MMK Z value | Z Critical Value | MMK trend | LT t value | t Critical Value | LT trend | ST s value | ±CL | ST trend |
|---|---|---|---|---|---|---|---|---|---|---|
| Meteorology observation station (precipitation) | Karapınar | −0.20 | ±1.96 | No | −0.25 | ±1.96 | No | −0.0019 | 0.00024 | (−) |
| | Çumra | −0.61 | ±1.96 | No | −0.02 | ±1.96 | No | −0.00027 | 0.0011 | No |
| | Kulu | −1.32 | ±1.96 | No | −1.12 | ±1.96 | No | **−0.0045** | 0.00043 | (−) |
| | Cihanbeyli | −1.82 | ±1.96 | No | −0.36 | ±1.96 | No | **−0.00085** | 0.0004 | (−) |
| | Beyşehir | 0.608 | ±1.96 | No | 0.16 | ±1.96 | No | **−0.0049** | 0.00073 | (−) |
| | Konya | −0.97 | ±1.96 | No | −0.38 | ±1.96 | No | **−0.0027** | 0.00063 | (−) |
| | Aksaray | −0.56 | ±1.96 | No | −0.28 | ±1.96 | No | **−0.023** | 0.00038 | (−) |
| Meteorology observation station (temperature) | Karapınar | 1.26 | ±1.96 | No | 1.15 | ±1.96 | No | **0.0017** | 0.00007 | (+) |
| | Çumra | **5.52** | ±1.96 | (+) | 1.72 | ±1.96 | No | **0.00424** | 0.00015 | (+) |
| | Kulu | **2.00** | ±1.96 | (+) | 1.57 | ±1.96 | No | **0.0043** | 0.00012 | (+) |
| | Cihanbeyli | **2.21** | ±1.96 | (+) | 1.93 | ±1.96 | No | **0.00338** | 0.00007 | (+) |
| | Beyşehir | 0.53 | ±1.96 | No | 0.51 | ±1.96 | No | **0.00044** | 0.00005 | (+) |
| | Konya | 1.13 | ±1.96 | No | 1.01 | ±1.96 | No | **0.00117** | 0.00007 | (+) |
| | Aksaray | **2.31** | ±1.96 | (+) | 1.87 | ±1.96 | No | **0.00312** | 0.00007 | (+) |
| Meteorology observation station (evaporation) | Karapınar | 0.01 | ±1.96 | No | 0.19 | ±1.96 | No | 0.00004 | 0.00549 | No |
| | Çumra | 0.61 | ±1.96 | No | 0.26 | ±1.96 | No | **0.06609** | 0.01685 | (+) |
| | Kulu | 0.42 | ±1.96 | No | 0.11 | ±1.96 | No | **0.08824** | 0.01164 | (+) |
| | Cihanbeyli | **2.21** | ±1.96 | (+) | 0.57 | ±1.96 | No | **0.00338** | 0.00007 | (+) |
| | Beyşehir | **5.20** | ±1.96 | (+) | **3.64** | ±1.96 | (+) | **0.20604** | 0.00344 | (+) |
| | Konya | **3.25** | ±1.96 | (+) | **2.51** | ±1.96 | (+) | **0.14063** | 0.00471 | (+) |
| | Aksaray | 0.11 | ±1.96 | No | −0.04 | ±1.96 | No | **0.08109** | 0.00491 | (+) |
| Lake observation station | Kızören | **−13.94** | ±1.96 | (−) | **−38.82** | ±1.96 | (−) | **−0.0395** | 0.00044 | (−) |
| | Timraş | **−6.61** | ±1.96 | (−) | **−37.81** | ±1.96 | (−) | **−0.046** | 0.0071 | (−) |
| | Lake Tuz | −1.07 | ±1.96 | No | **−2.104** | ±1.96 | (−) | **−0.00017** | 0.00001 | (−) |
| | Lake Beyşehir | **−8.97** | ±1.96 | (−) | **−16.36** | ±1.96 | (−) | **−0.0047** | 0.00007 | (−) |

**Table 5** (continued)

| Station type | Station Name | MMK Z value | Z Critical Value | MMK trend | LT t value | t Critical Value | LT trend | ST s value | ±CL | ST trend |
|---|---|---|---|---|---|---|---|---|---|---|
| Groundwater-level observation stations | Cihanbeyli | −0.57 | ±1.96 | No | **2.02** | ±1.97 | (+) | **0.0029** | 0.00047 | (+) |
| | Selçuklu | **−14.86** | ±1.96 | (−) | **−43.56** | ±1.96 | (−) | **−0.049** | 0.0005 | (−) |
| | Beyşehir | **9.42** | ±1.96 | (+) | **16.35** | ±1.96 | (+) | **0.045** | 0.001 | (+) |
| | Çumra | **−7.47** | ±1.96 | (−) | **−44.11** | ±1.96 | (−) | **−0.028** | 0.0003 | (−) |
| | Kulu | 0.57 | ±1.96 | No | **2.03** | ±1.96 | (+) | **0.017** | 0.0006 | (+) |

(+): Increasing trend, (−): Decreasing trend

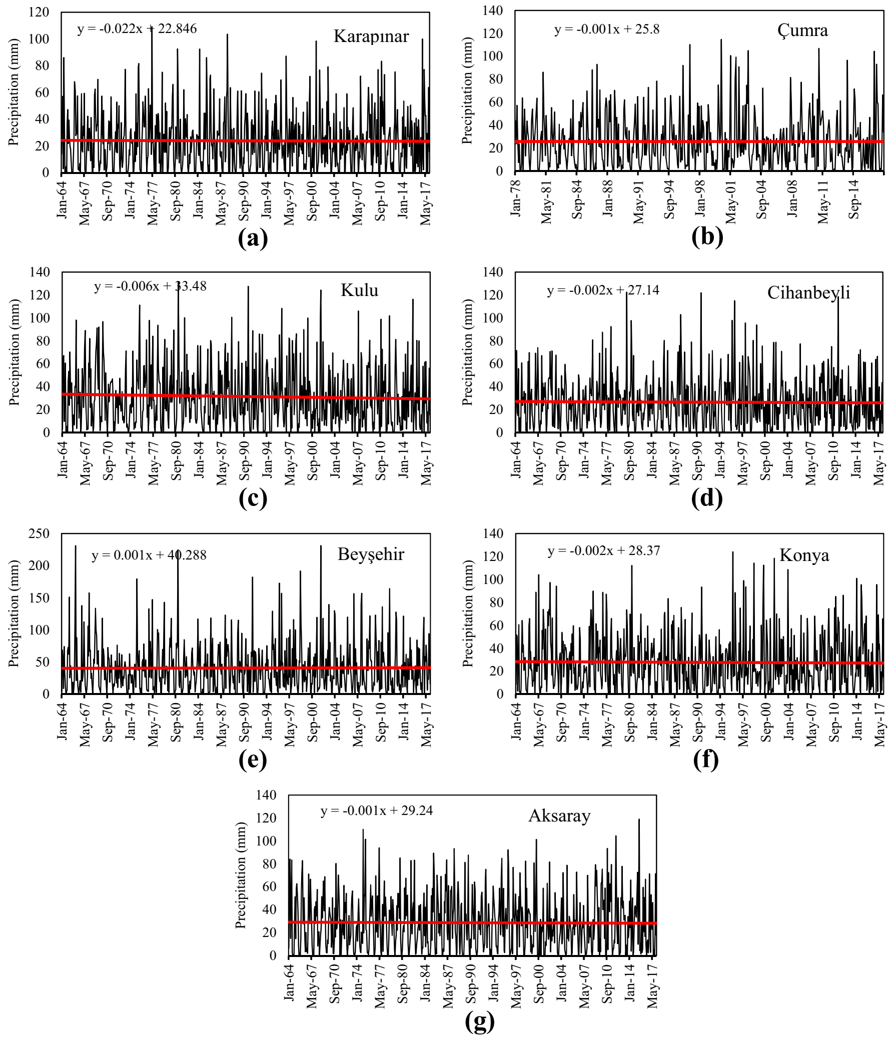



**Fig. 5** Precipitation data time series; **a** Karapınar, **b** Çumra, **c** Kulu, **d** Cihanbeyli, **e** Beyşehir, **f** Konya, and **g** Aksaray station

0.0447, 0.038, 0.0613, and 0.0238 mm/month, respectively. However, these trends are significant only in Beyşehir and Konya stations according to the LT method.

Figure 8 shows a decreasing trend in both lakes and sinkholes. This decrease is 0.0396 m/month for Kızören sinkhole, 0.0488 m/month for Timraş sinkhole, 0.000001 m/month for Lake Tuz, and 0.0032 m/month for Lake Beyşehir.

In Fig. 9, the water levels at Selçuklu (− 0.049 m/month) and Çumra (− 0.0274 m/month) stations show a dramatic decrease, which is statistically significant according to the LT method. According to the linear trend slope equation, it was determined that the groundwater level of Beyşehir (0.0403 m/month), Kulu (0.0044 m/month), and Cihanbeyli (0.0023 m/month) stations increased. However, these trends (0.0403 m/month) are significant only in Beyşehir station according to the LT method.

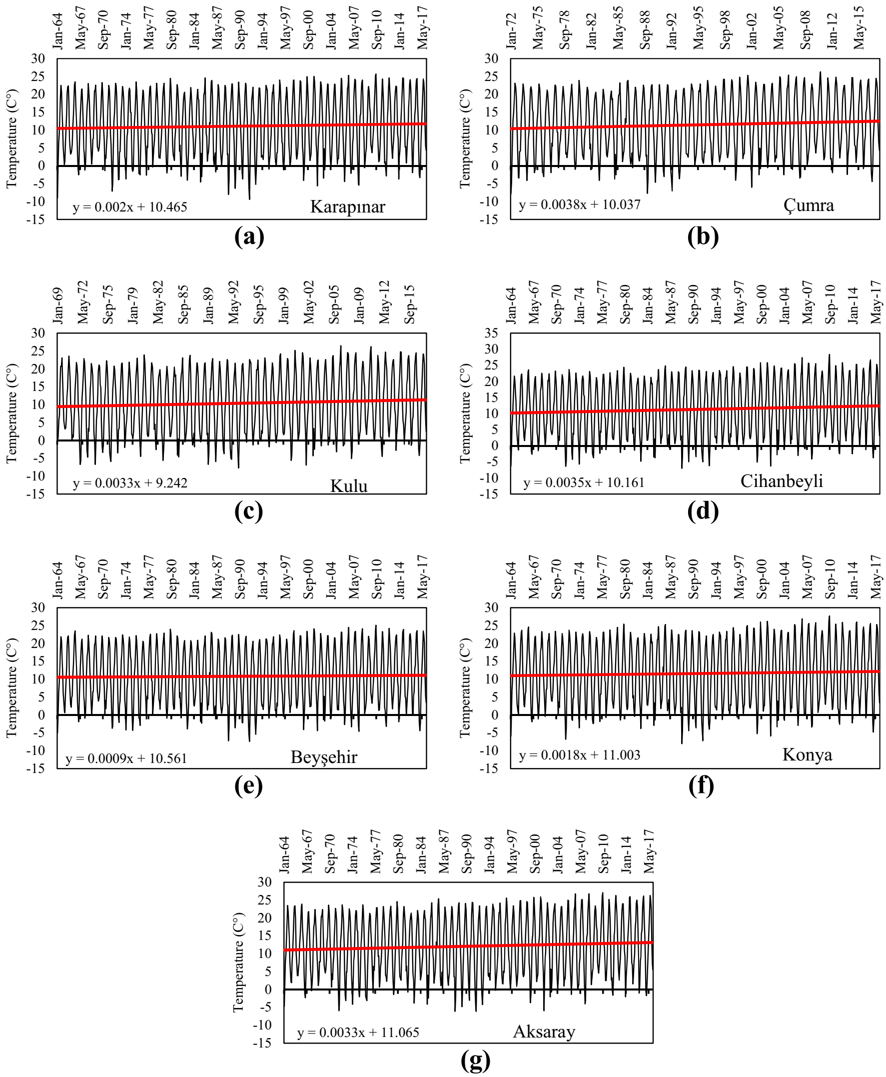



**Fig. 6** Temperature data time series; **a** Karapınar, **b** Çumra, **c** Kulu, **d** Cihanbeyli, **e** Beyşehir, **f** Konya, and **g** Aksaray station

ST graphs on the Cartesian coordinate system are given for precipitation in Fig. 10, the temperature in Fig. 11, evaporations in Fig. 12, lake levels in Fig. 13, and groundwater levels in Fig. 14. If the data are concentrated in the upper triangular region on the 1:1 line (45), this indicates an increasing trend. If the data are concentrated under the 1:1 line, the parameter in the time series is interpreted as showing a decreasing trend.

In the ST graphs in Figs. 11 and 12, the temperature and evaporation data are clearly concentrated in the region above the 1:1 line. This indicates the presence of an increasing trend. Contrary to the general trend in the Karapınar station evaporation data, the fact that the lower-level data is in the decreasing region is considered an indicator of

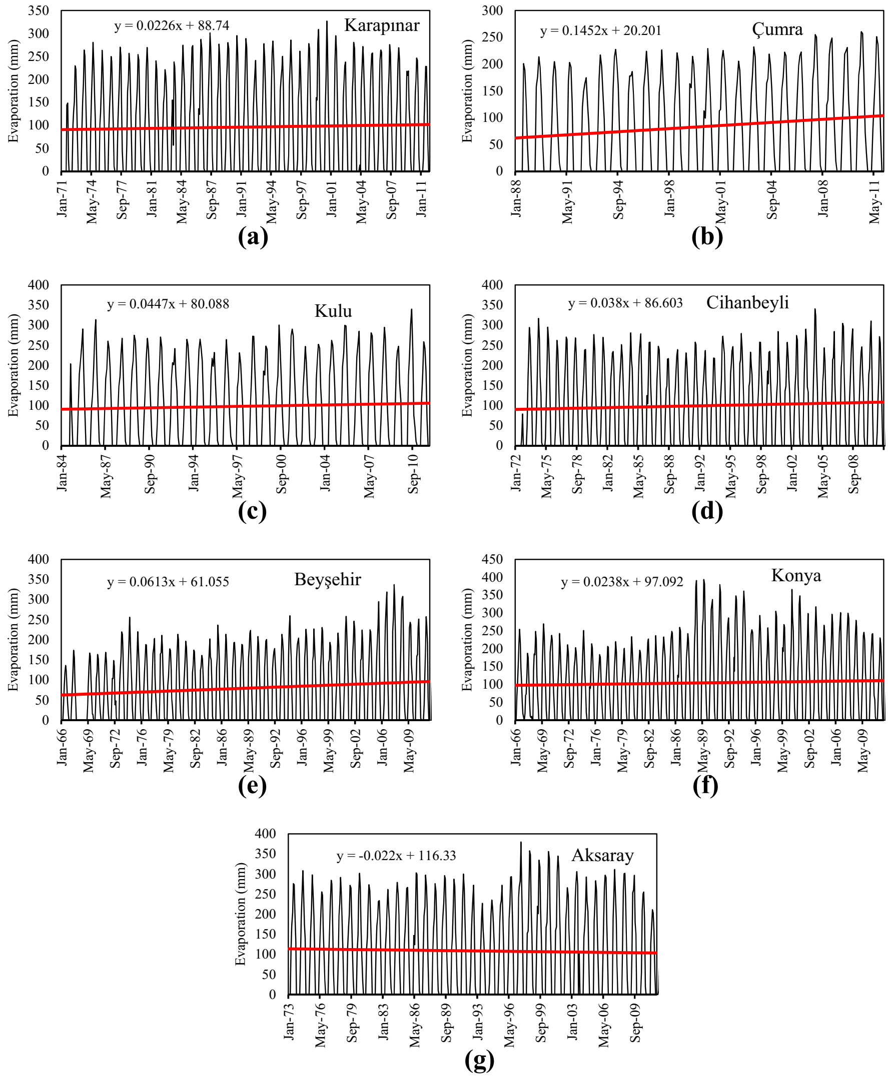



**Fig. 7** Evaporation data time series; **a** Karapınar, **b** Çumra, **c** Kulu, **d** Cihanbeyli, **e** Beyşehir, **f** Konya, and (g) Aksaray station

the meaninglessness in Table 5. In Fig. 10, it could not be exactly determined whether the precipitation data concentrated in the lower or higher triangular regions. This is the limitation of the method (Sen 2012). However, when the averages of the data are analyzed, the results are similar to the ST results in Table 5. In Fig. 13, the data for Lake Beyşehir and sinkholes are concentrated in the lower triangular region. When the graph was analyzed by averaging the data for Lake Tuz, it was determined that the data decreased. In Fig. 14, the Cihanbeyli, Kulu, and Beyşehir stations are concentrated in

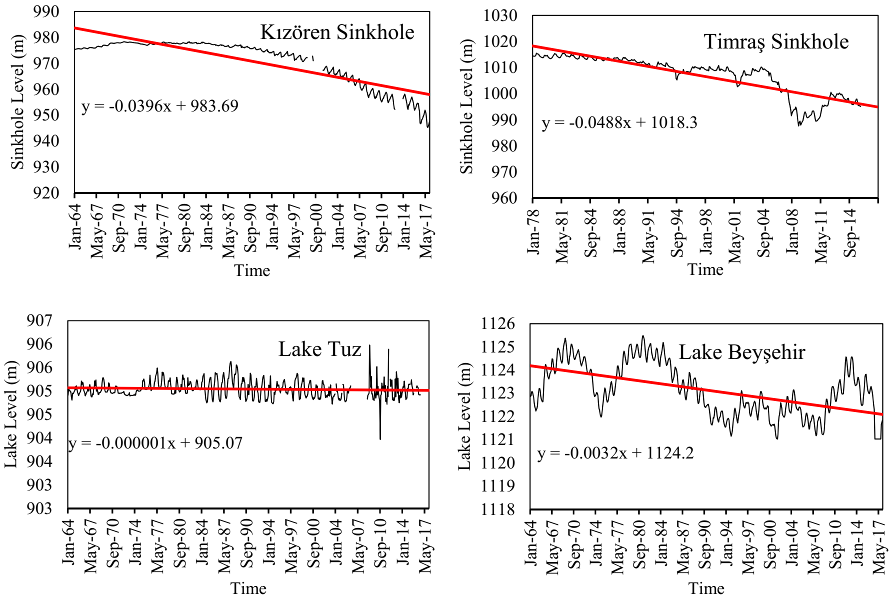



**Fig. 8** Water level data time series; **a** Kızören sinkhole, **b** Timraş sinkhole, **c** Lake Tuz, and **d** Lake Beyşehir station

the upper triangular region and show an increasing trend, whereas other stations show a decreasing trend in the lower triangular region.

### 3.1 Results for the sub-study areas and same period analysis

In this section, data from the same period were used to investigate the effect of changes in meteorological parameters on changes in lakes and sinkhole water levels and groundwater levels. Furthermore, the research region was divided into Thiessen impact polygons and sub-basins. According to the sub-basin and Thiessen polygon analyses (Fig. 1), Lake Tuz is in the polygon belonging to the Cihanbeyli, Kulu, and Aksaray precipitation stations, as well as the Cihanbeyli (53706) and Kulu (53707) groundwater stations. Lake Beyşehir is in the polygon belonging to the Beyşehir precipitation station and the Beyşehir (52770) groundwater station. The Kızören Sinkhole is in the polygon belonging to the Cihanbeyli and Karapınar stations. The Timraş Sinkhole is in the polygon belonging to the Çumra station and the Çumra (181) groundwater station (Fig. 1). Therefore, precipitation has a direct effect on these stations (Thiessen 1911; Demir and Keskin 2020).

#### 3.1.1 Kızören Sinkhole region

Figure 15 shows the groundwater level of the Kızören Sinkhole, as well as the precipitation, temperature, and evaporation data from the Cihanbeyli and Karaman meteorology

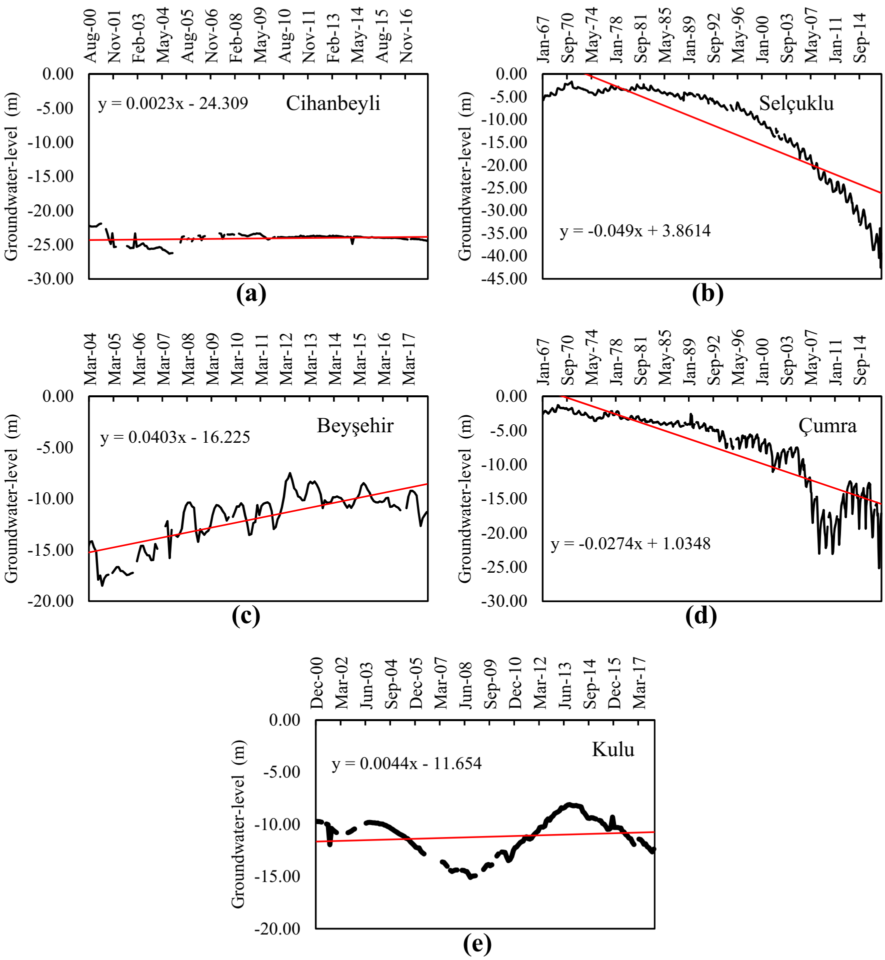



**Fig. 9** Groundwater level data time series; **a** Cihanbeyli, **b** Selçuklu, **c** Beyşehir, **d** Çumra, and **e** Kulu groundwater level observation station

stations. The set period of the evaporation data and the data from the months of the measurements are used in this and the following sections.

The water level in the Kızören Sinkhole shows a decreasing trend. According to the Thiessen polygons, when the graphs of the precipitation data affecting this sinkhole are examined in the same periods, decreasing trends were observed in the Cihanbeyli and Karapınar stations. Since there is no groundwater observation station near the Kızören Sinkhole, the change in the Kızören Sinkhole trend in this section is interpreted only with precipitation data. The increasing trend of the temperatures and related evaporation data may cause a decrease in sinkhole levels. The relationship between the parameters was also examined using correlation analysis. "Appendix 1" shows the correlation results for Kızören Sinkhole region.

There is a positive significant relationship between the Karapınar station precipitation data and the Cihanbeyli station precipitation data, as well as a positive significant

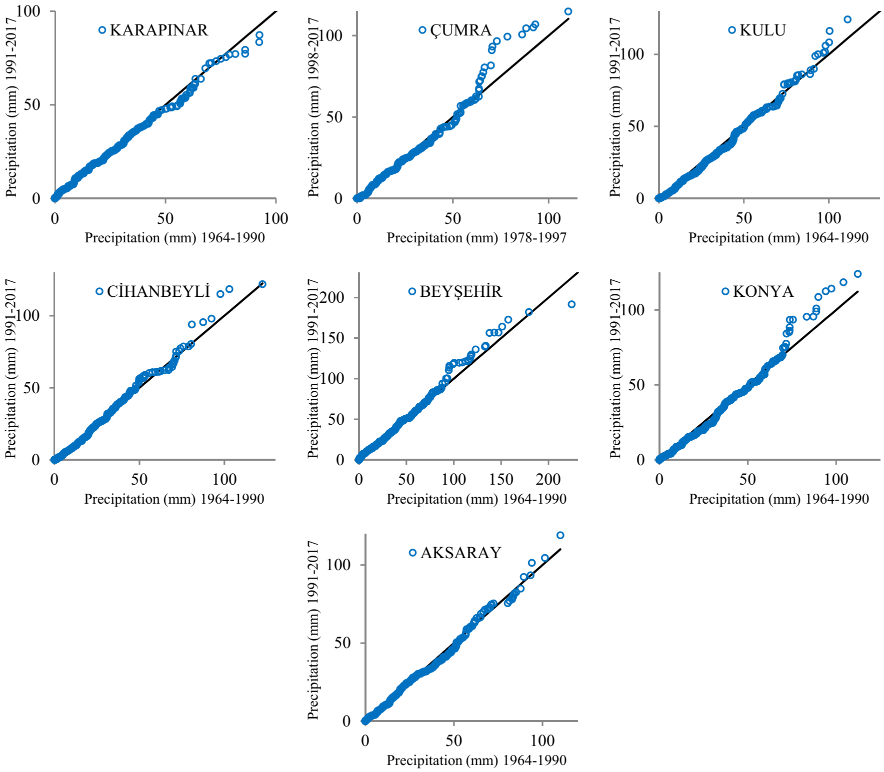



**Fig. 10** ST graphical results for the precipitation observation stations

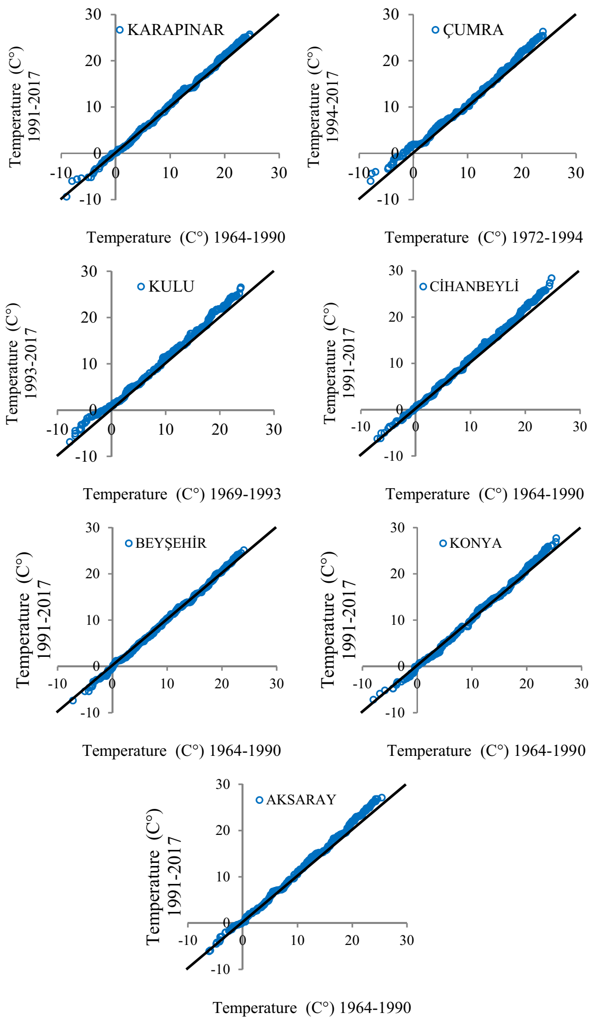
relationship between the Karapınar station temperature data, Cihanbeyli station temperature data, Karapınar station evaporation data, and Cihanbeyli station evaporation data. A moderately significant positive correlation was found between the Kızören Sinkhole water levels and the Karapınar station precipitation data.

### 3.1.2 Konya—Selçuklu groundwater region

Figure 16 shows the groundwater levels at the Selçuklu groundwater level observation station in this section, as well as the precipitation, temperature, and evaporation data from the Konya meteorology station.

Figure 16 shows a decreasing trend in the Konya station precipitation data and the Selçuklu groundwater levels. However, there is an increasing trend in temperatures and evaporation, which may be effective in the decrease in the groundwater level. According to the precipitation data, the decrease in groundwater levels is more pronounced, increasing at a faster rate in recent years. "Appendix 2" shows the correlation results for Konya—Selçuklu region. The positive significant relationship between the temperature and evaporation data, whereas a negative significant relationship was found between the temperature and precipitation data at the Konya station. The relationship between the groundwater levels and other parameters is meaningless and poor.

**Fig. 11** ST graphical results for temperature observation stations




### 3.1.3 Lake Tuz region

Figure 17 shows the water levels of Lake Tuz in this section, as well as the precipitation, temperature, and evaporation data from the Cihanbeyli, Kulu, and Aksaray meteorology stations. "Appendix 3" presents the correlation results for Lake Tuz region.

As shown in Fig. 17, the water levels in Lake Tuz have increased, in consequence of an increase in the precipitation data and groundwater levels and the decrease in the temperature data and evaporation data. In "Appendix 3", the temperature and evaporation data in the region have a strong positive relationship, whereas the precipitation data has a negative relationship. The increase in the water levels of Lake Tuz is significant owing to an increase in the groundwater level at the Cihanbeyli station.

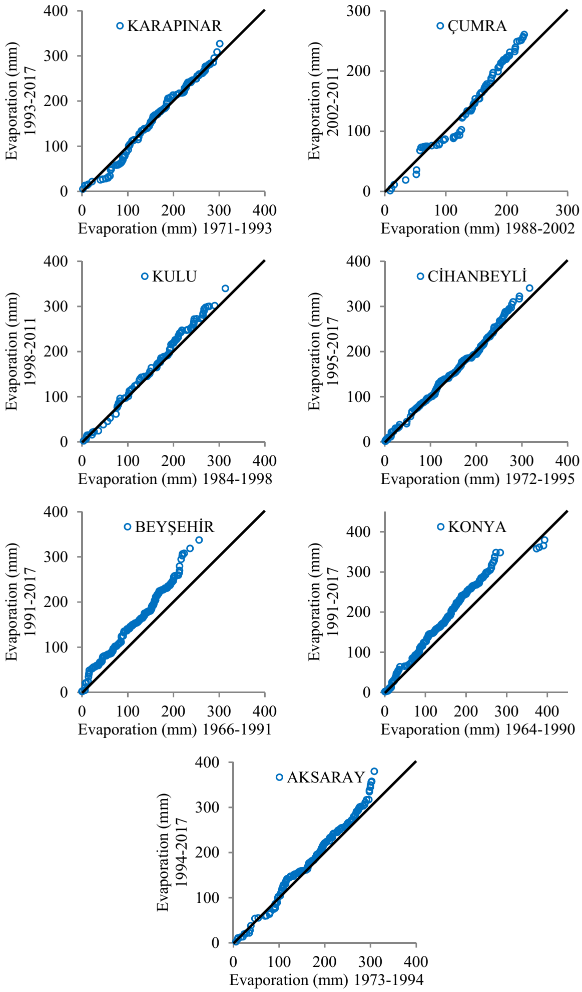



**Fig. 12** ST graphical results for evaporation observation stations

### 3.1.4 Timraş Sinkhole region

In this section, Fig. 18 shows the water levels of the Timraş Sinkhole, as well as the precipitation, temperature, and evaporation data of the Çumra station. "Appendix 4" presents the correlation results for the Timraş Sinkhole region.

Figure 18 shows decreasing trends in Timraş Sinkhole level and Çumra groundwater level observation stations, while increasing trends are observed in the temperature, evaporation, and precipitation parameters. The Timraş Sinkhole and the decreasing trend in the Çumra groundwater-level observation station are in close proximity. In addition, the correlation coefficient between these two data sets is 0.965. This result indicates that although the water levels of the sinkhole and the meteorological parameters produce similar results

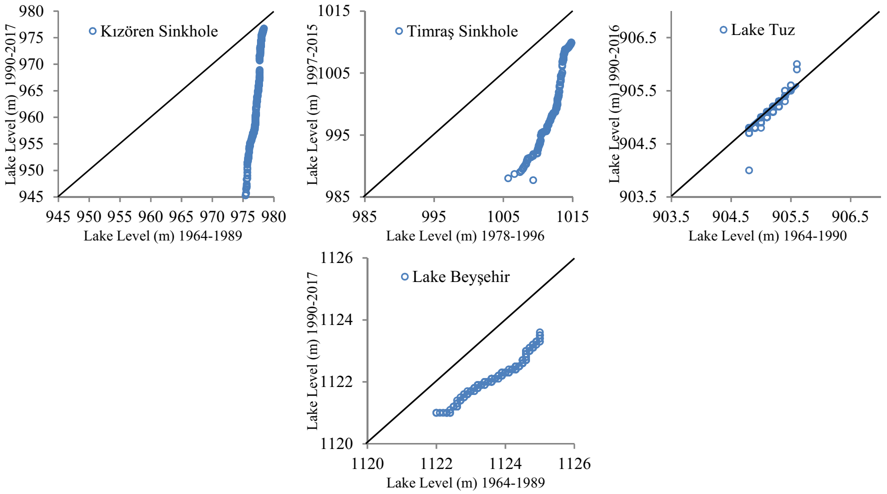



**Fig. 13** ST graphical results for lake and sinkhole stations

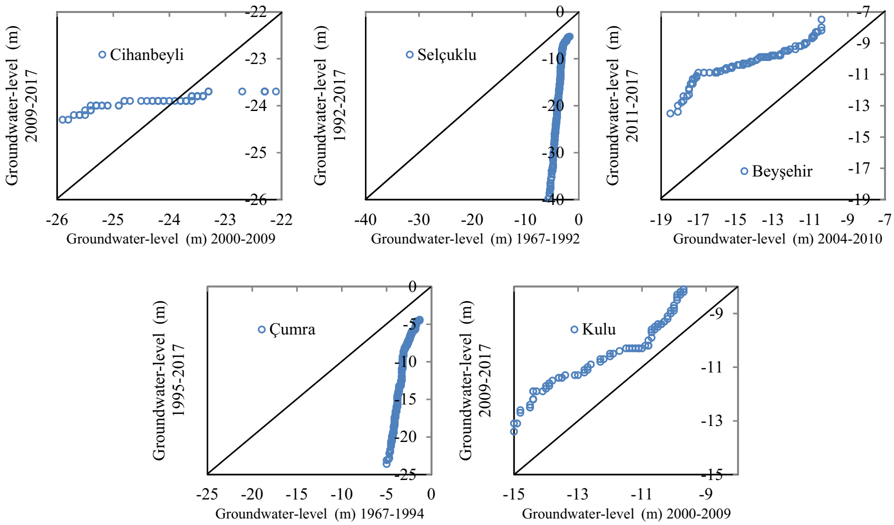



**Fig. 14** ST graphical results for groundwater level observation stations

in terms of the hydrological cycle, the levels of the sinkhole are more related to the groundwater levels.

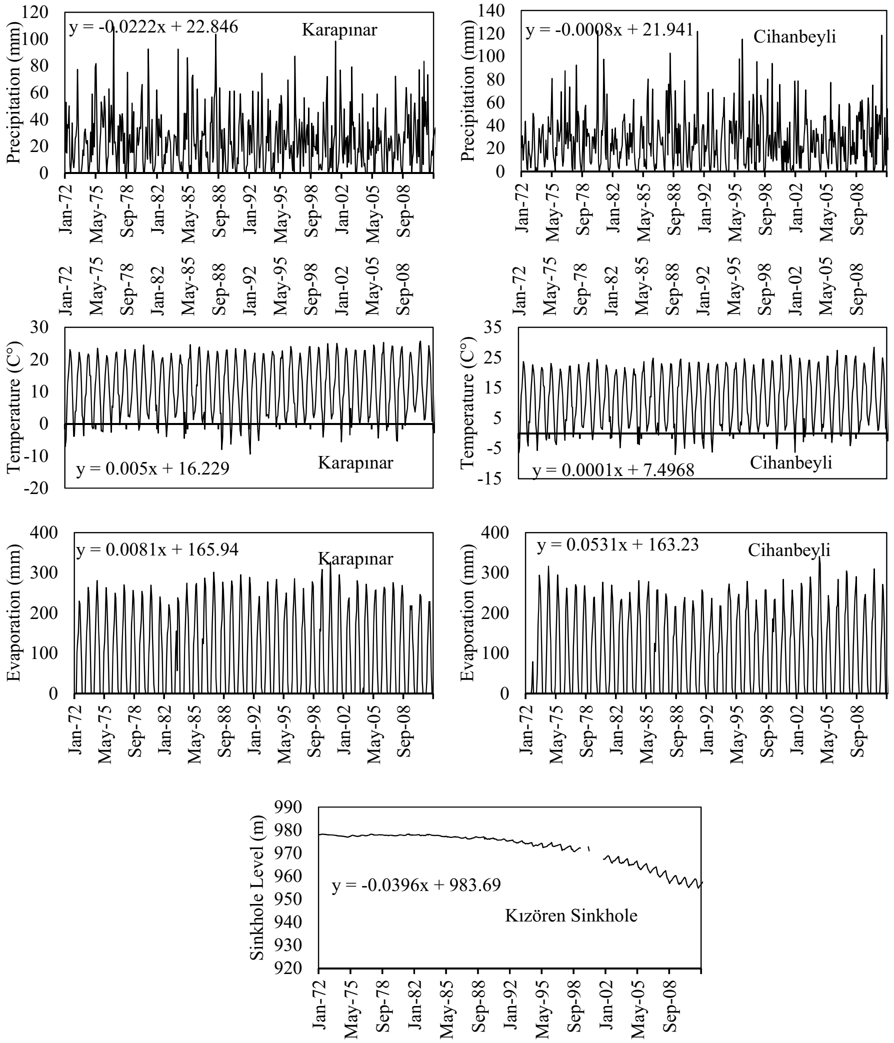



**Fig. 15** The data graph of the Kızören sinkhole, and the Cihanbeyli and Karapınar stations in the same periods

### 3.1.5 Lake Beyşehir region

The water levels of the Lake Beyşehir in this section, precipitation, temperature and evaporation data of the Beyşehir meteorology station and groundwater-level data of the Beyşehir groundwater-level observation station are given in Fig. 19.

In Fig. 19, it is seen that the temperature and evaporation data have decreased, and the lake levels, precipitation and groundwater levels have increased. Although these trend situations among the data are seen to be compatible with the hydrological cycle deficit, when the correlation between the data is examined, the precipitation, the temperature, and the

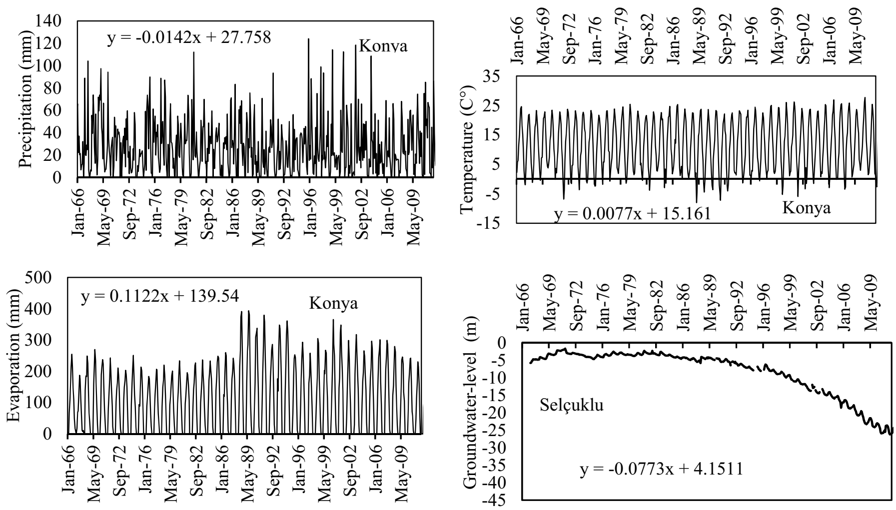



**Fig. 16** The data graph of the Konya meteorology observation station station and Selçuklu groundwater level observation station in the same periods

groundwater levels show a negative relationship different from the expected (expected is an increase in precipitation, a decrease in temperatures and an increase in lake levels). This situation brings to mind that there may be an anthropogenic effect. "Appendix 5" shows the correlation results between other parameters. After examining the meteorological parameters in the time series according to the trend graphs and the slope of the regression line, the trend analysis results are given in Table 6 for the MMK, LT and ST methods.

In Table 6, it was determined that the temperatures increased at Cihanbeyli station, and the water levels decreased in Kızören Sinkhole according to all three methods in Kızören region. In addition, it was determined that evaporation at Cihanbeyli station and temperatures at Karapınar station increased according to the ST method. According to the ST method, precipitation tends to decrease at Karapınar station. In the Konya region, temperatures and evaporation increase and groundwater levels decrease according to all three methods. In addition, precipitation shows a decreasing trend according to the ST method. While no trend could be detected in Lake Tuz region according to the LT method, evaporations decreased at Aksaray station and groundwater levels decreased at Kulu station according to the MMK method.

According to the ST method, temperatures and evaporation increase and precipitation decreases at meteorological stations. While the groundwater level decreases at Kulu station, it increases at Cihanbeyli station. An increasing trend was detected in Lake Tuz. As a result, the increase in Lake Tuz is more compatible with the meteorological parameters and the change in the groundwater levels at the Cihanbeyli station, independent of the groundwater levels at the Kulu station. The results obtained in the Timraş region are the most impressive part of the study. In Timraş Sinkhole, decreasing trends were determined according to all three methods. In addition, decreasing trends were determined at Çumra station, which was determined to be related to these sinkhole water levels. This result revealed that sinkhole water levels were related to groundwater levels rather than meteorological parameters. According to the ST method, it was also determined that precipitation increased and temperatures decreased. In Beyşehir region, it was determined

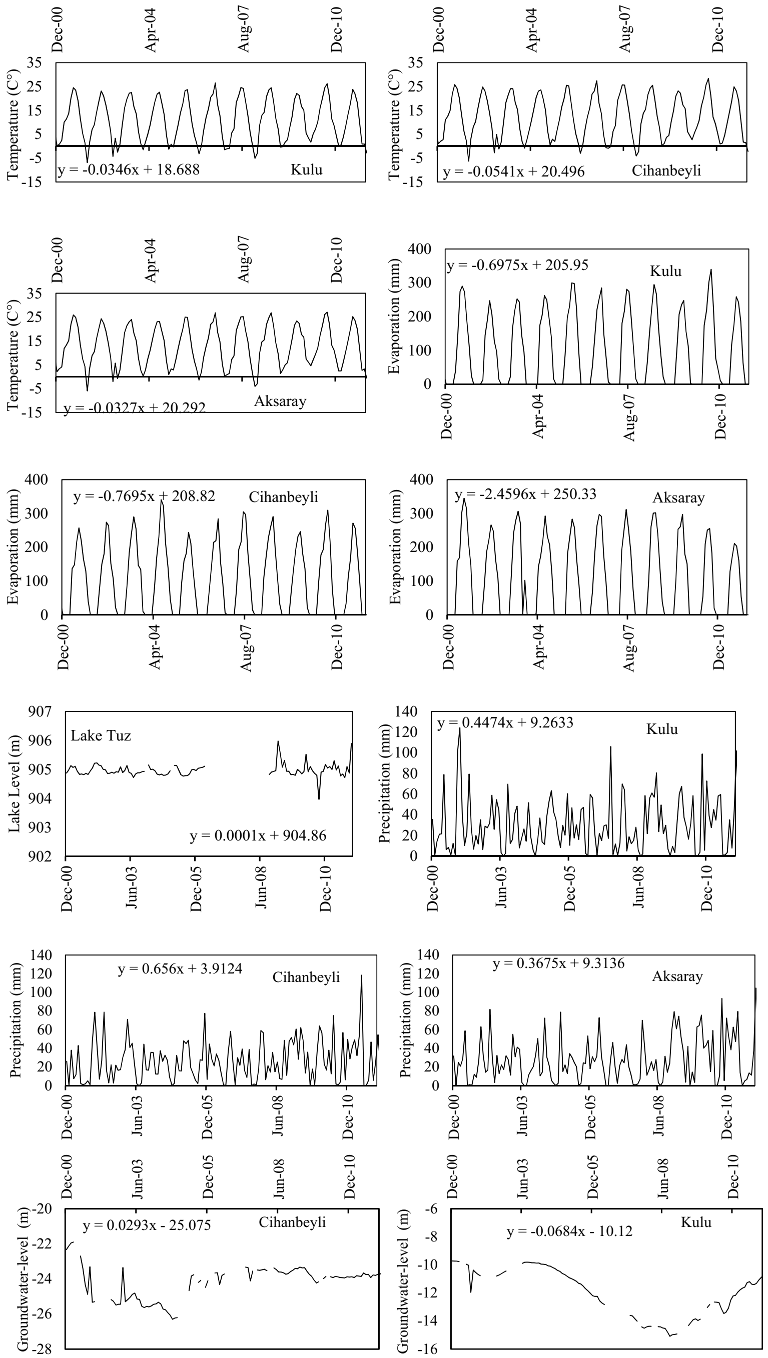



**Fig. 17** The data graph of Lake Tuz, Cihanbeyli, Kulu and Aksaray stations, and the Cihanbeyli and Kulu groundwater level observation station in the same periods

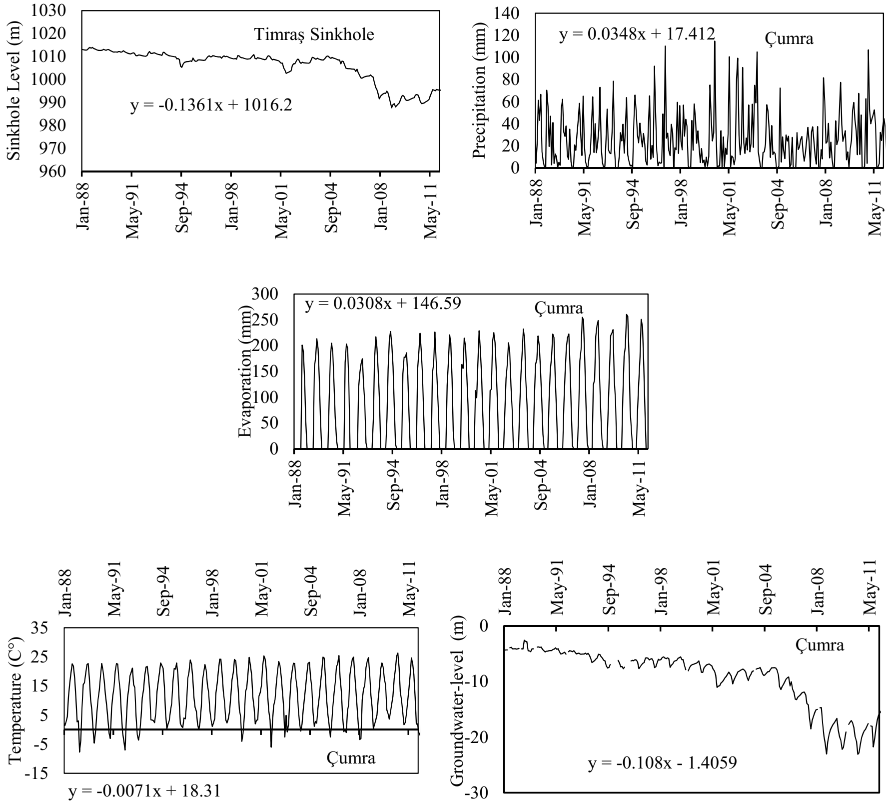



**Fig. 18** The data graph of Timraş Sinkhole, Çumra station in the same periods

that the groundwater levels increased according to all three methods, and the evaporation decreased, and the lake level increased according to the ST method.

## 4 Discussion

According to homogeneity test results, the precipitation data and the temperature data are homogeneous and do not show any trend in the long-term period. However, the lake water level, sinkhole water level and groundwater level data are non-homogeneous and show a trend. In addition, this situation is also seen in the evaporation data of Beyşehir and Konya stations in the long-term period. The opposite relationship between homogeneity and a trend is similar in other studies (Taxak et al. 2014; Demir et al. 2018; Demir and Keskin 2020).

According to trend test results for a long-term period, even though, the analysis results (Table 5) give similar data, they differ from each other at some points. For example, while there is no trend in precipitation stations compared to the MMK and LT methods, decreasing trends are observed compared to the ST method. The LT and ST methods gave similar trends in lake water levels and sinkhole groundwater levels. Alternatively, the MMK

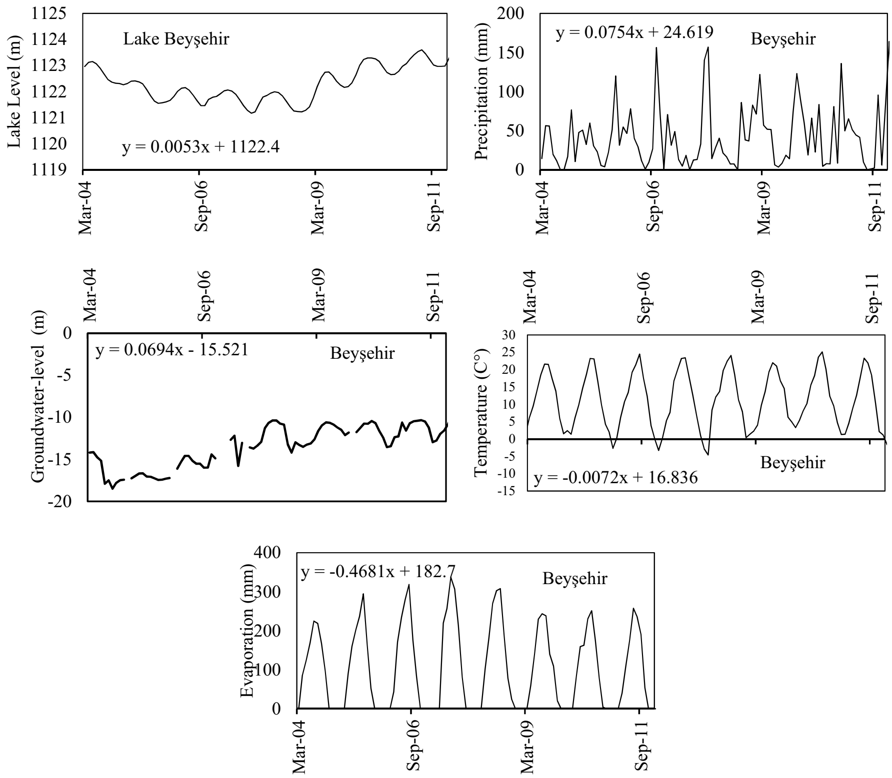



**Fig. 19** The data graph of Lake Beyşehir, Beyşehir meteorology station and Beyşehir groundwater level observation station in the same periods

method did not show a trend in Lake Tuz, Cihanbeyli and Kulu stations, while other methods detected a trend. Again, when Table 5 is examined for the other two stations except Cihanbeyli station, the MMK method gave similar trends with the ST and LT methods. However, these trends are not statistically significant. In other words, just the sign of the MMK test values alone is compatible with the ST and LT methods. The difference in the methods depends on the methodology of obtaining critical account values. While the ST method calculates CL according to one-tail Z distribution, and according to the correlation between data (Eq. 16), the LT method calculates critical values according to t distribution and the MMK method according to the Z distribution (Eq. 8). As a result of the long-term analysis, it can be said that temperatures and evaporation have increased in the region, precipitation has decreased, and the sinkholes groundwater levels and lakes water levels have decreased. As for groundwater levels, they decreased at Selçuklu and Çumra stations, and increased at Cihanbeyli, Beyşehir and Kulu stations. For this reason, analyzes were carried out in the same time periods, which is the second phase of the study, and the results are given in Table 6. In order to better interpret the tabular results, the results are mapped on the study area as in Fig. 20.

The trend analysis results for the same periods shown in Fig. 20 were mapped regionally. Meteorological stations are schematized with circles, while trends in lakes water

**Table 6** Comparison of trend analysis results at the same periods

| Region | Station | Same period | | |
|---|---|---|---|---|
| | | MMK (Z) | LT (t) | ST (s) |
| Kızören | Karapınar (P) | -0.23 | -0.71 | **-0.0231** |
| | Cihanbeyli (P) | -0.46 | 0.04 | 0.0004 |
| | Karapınar (T) | 1.35 | 0.70 | **0.0051** |
| | Cihanbeyli (T) | **2.22** | **1.35** | **0.0102** |
| | Karapınar (E) | 0.16 | -0.02 | -0.0031 |
| | Cihanbeyli (E) | 0.79 | 0.51 | **0.0623** |
| | Kızören Sinkhole (WL) | **-14.13** | **-9.85** | **-0.0809** |
| Konya | Konya (P) | -1.04 | -0.93 | **-0.0103** |
| | Konya (T) | **2.59** | **2.11** | **0.0063** |
| | Konya (E) | **3.71** | **2.13** | **0.1143** |
| | Selçuklu (GWL) | **-7.67** | **-10.36** | **-0.0639** |
| Lake Tuz | Kulu (P) | 0.69 | 0.54 | **0.4378** |
| | Cihanbeyli (P) | 0.86 | 0.73 | **0.7493** |
| | Aksaray (P) | 0.55 | 0.44 | **0.5465** |
| | Kulu (T) | -0.73 | -0.19 | **-0.0539** |
| | Cihanbeyli (T) | -0.98 | -0.30 | **-0.0824** |
| | Aksaray (T) | -1.18 | -0.19 | **-0.0493** |
| | Kulu (E) | -0.83 | -0.24 | **-1.2143** |
| | Cihanbeyli (E) | -1.31 | -0.29 | **-1.6620** |
| | Aksaray (E) | **-2.33** | -0.81 | **-2.7729** |
| | Cihanbeyli (GWL) | 1.05 | 0.84 | **0.0523** |
| | Kulu (GWL) | **-2.08** | -1.17 | **-0.1118** |
| | Lake Tuz (WL) | 0.24 | 0.02 | **0.0016** |
| Timraş | Çumra (P) | 0.47 | 0.81 | **0.0207** |
| | Çumra (T) | -0.45 | -0.47 | **-0.0091** |
| | Çumra (E) | 0.16 | 0.51 | 0.0185 |
| | Çumra (GWL) | **-7.02** | **-6.47** | **-0.1025** |
| | Timraş (WL) | **-6.61** | **-4.66** | **-0.1257** |
| Lake Beyşehir | Beyşehir (P) | 1.15 | 0.56 | -0.0132 |
| | Beyşehir (T) | -0.16 | -0.28 | 0.0025 |
| | Beyşehir (E) | -1.38 | -1.16 | **-0.3263** |
| | Beyşehir (GWL) | **3.37** | **5.20** | **0.1177** |
| | Lake Beyşehir (WL) | 1.33 | 1.13 | **0.0152** |

(+): Increasing trend, (+): Statistically Insignificant Increasing trend,
(-): Decreasing trend, (-): Statistically Insignificant Decreasing trend

levels and sinkhole water levels are shown with arrows pointing upwards or downwards. All trends in the chart are statistically significant trends. In addition, Thiessen polygons and sub-basin boundaries can be seen in Fig. 20. The similarity of the method results and the change of the trends can be seen more clearly in Fig. 20. When the figure is examined with a general view, increases in temperatures and evaporation and decreases in water levels in lakes and sinkholes are seen.

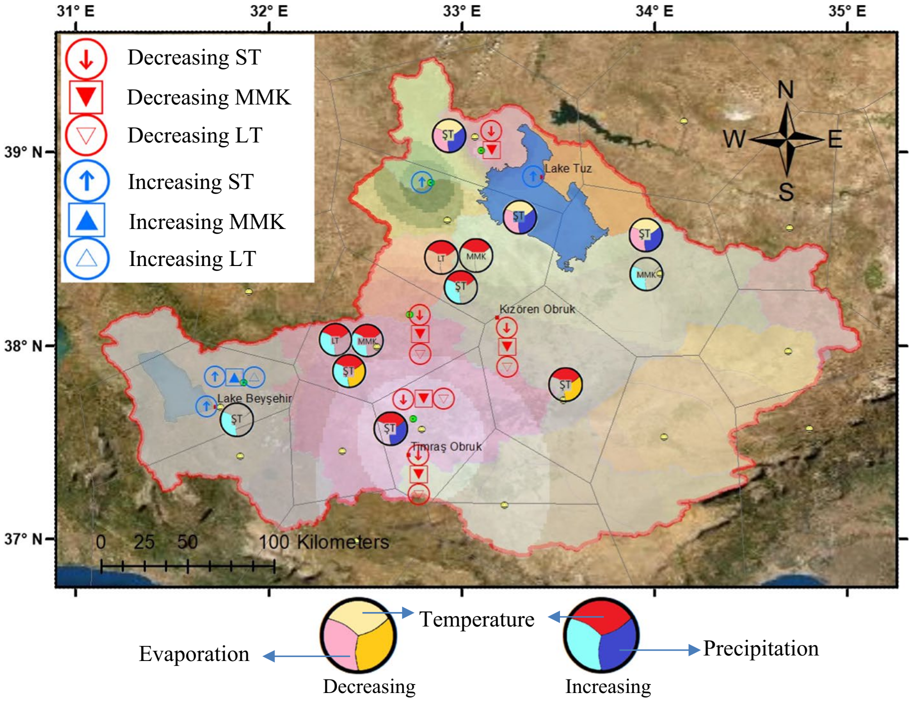



**Fig. 20** Trend test results for same period

Although the precipitation increase and decrease are compatible with lakes water levels and sinkholes water levels compared to other methods, these trends are not statistically significant (Table 5). In addition, Table 6 and Fig. 20 show that trends in lakes and sinkhole water levels are significant with changes in groundwater levels rather than precipitation. Therefore, monitoring groundwater levels is more important for trend studies of lakes. Trends in lake levels are statistically consistent with trends in groundwater levels. While examining trend directions, groundwater level movement, given in Fig. 1 was taken into high consideration. When other studies in the literature are examined, the movement of groundwater levels supports this study (Recep and Tapur 2009; Doğan and Yilmaz 2011; Günay et al. 2011).

Decreases in the groundwater levels cause the formation of many sinkholes in the region. The change in the groundwater level, especially the decreasing trend, causes the soluble rocks at contact with the water to be affected by dissolution, and as a result, to cause the formation of sinkholes. Sinkholes are getting closer to the city centers over time. Sinkholes formed in agricultural areas reduce the capacity, reliability and quality of the agricultural economy in the region (Demir et al. 2021).

In parametric methods, the actual value of the data in the series is important and this value is used in calculations. However, in non-parametric methods, not the actual value of the data, but the number of rows obtained by ordering the data from the smallest to the largest or from the largest to the smallest is used, and the data does not have to comply with the normal distribution (Helsel and Hirsch, 1992). Among the trend methods compared, ST method and MMK method are non-parametric and LT method is parametric. The advantage of the MMK method is that it is simple, takes into account serial correlation, and can be used in missing data. The disadvantage is that instead of the data, it determines the test value dependent on the sing function on the values ordered relative to each other. The advantage of the LT method is that it shows the general slope and uses the t distribution to determine the critical value. In cases where the number of data is less than 120, the t test is a special case of the Z test. When the number of data exceeds 120, the t-distribution can be seen as an advantage in this sense, similar to the Z-distribution (Demir 2018). The disadvantage is that it does not take into account the serial correlation and is useless in case of missing data. The advantage of the ST method is to deduce the overall trend and hidden sub-trends in various categories simultaneously on a furnished 1:1 trend plot. The flexible categorization of observations provides detailed information about the trend characteristics for each cluster. However, analysis of the significance or critical level of the trend attributes it to the distinctive persistence of hydrometeorological data. The ST method compares the test value with the critical value according to the variance methodology. This usually results in test results easily exceeding critical values and giving significant trends (Helsel and Hirsch 1992; Wang et al. 2019; Yagbasan et al. 2020).

## 5 Conclusions

In this study, the changes in the lake water levels and sinkhole water levels in the KCB were investigated by the change of meteorological parameters such as temperature, precipitation and evaporation. In the study, firstly, the homogeneity of the data was performed, and then trend analyzes were conducted. The homogeneity of the data was examined by the SNHT method. In trend analysis, MMK, LT and ST methods were used. All analyzes were performed at 95% of the confidence interval. As for the study period, it was first examined in the long term, which is the entire recording period, and then the parameters were examined in the same time period, and the following results were highlighted.

- As SNHT method was applied to data, it was observed that the precipitation, evaporation (except for Konya and Beyşehir evaporation data) and temperature data were homogeneous, and the lakes, sinkholes water levels and groundwater levels data were nonhomogeneous.
- When long-term trend analyses were performed on precipitation, lake, sinkhole and groundwater level data, the trend has not been determined in the homogeneous precipitation data, except for the ST method. In addition, the trends in nonhomogeneous lakes water levels, sinkholes water levels and groundwater levels were detected. This indicates that the trends are stronger in nonhomogeneous stations.
- The results of the MMK, ST and LT method trend analysis directions are similar. As a result of the recorded a long-term trend analysis, it was observed that the precipitation, lake and sinkhole water levels decreased. Groundwater levels, on the other hand, tend to increase in some stations, and decrease in some others.
- As a result of the above-mentioned analyses, it was determined that it is difficult to accurately determine the changes in lakes water levels and sinkholes water levels according to long-term precipitation. However, this issue can be explained by considering the same period for all data.

- Finally, at the same and last periods, it was observed that the water levels of the Kızören Sinkhole and Timraş Sinkhole water levels decreased, while the water levels of Lake Tuz, and Lake Beyşehir increased. These results are supported by the trends of groundwater level data of stations.

In summary, the trends of the meteorological parameters, lake water levels and sinkholes water levels have significant effects on the country's water resources management, agricultural and socio-economic activities. Serious groundwater level decreases have been detected in the region. These decreases can trigger the formation of many sinkholes in the region. Therefore, measures should be taken to assist lakes and sinkholes with adaptation to changing climatic conditions and reduce the negative effects.

## Appendix 1: Correlation coefficients of the Kızören Sinkhole region

| | Karapınar *P(mm)* | Cihanbeyli *P* (mm) | Karapınar *T* (°C) | Cihanbeyli *T* (°C) | Karapınar *E (mm)* | Cihanbeyli *E (mm)* | Kızören *WL (m)* |
|---|---|---|---|---|---|---|---|
| Karapınar *P (mm)* | 1.000 | | | | | | |
| Cihanbeyli *P* (mm) | **0.711** | 1.000 | | | | | |
| Karapınar *T* (°C) | −0.473 | −0.462 | 1.000 | | | | |
| Cihanbeyli *T* (°C) | −0.491 | −0.499 | **0.992** | 1.000 | | | |
| Karapınar *E* (mm) | −0.467 | −0.467 | **0.942** | **0.930** | 1.000 | | |
| Cihanbeyli *E* (mm) | **−0.502** | **−0.511** | **0.932** | **0.928** | **0.912** | 1.000 | |
| Kızören *WL (m)* | 0.051 | −0.008 | −0.094 | −0.154 | 0.005 | −0.083 | 1.000 |

## Appendix 2: Correlation coefficients of Konya-Selçuklu groundwater region

| | Konya *P (mm)* | Konya *T (°C)* | Konya E *(mm)* | Selçuklu *GWL (m)* |
|---|---|---|---|---|
| Konya *P (mm)* | 1.000 | | | |
| Konya *T (°C)* | **−0.534** | 1.000 | | |
| Konya *E (mm)* | **−0.522** | **0.882** | 1.000 | |
| Selçuklu *GWL (m)* | 0.032 | −0.070 | −0.007 | 1.000 |

## Appendix 3: Correlation coefficients of Lake Tuz region

| | Kulu *P* (mm) | Cihanbeyli *P* (mm) | Aksaray *P* (mm) | Kulu *T* (°C) | Cihanbeyli *T* (°C) | Aksaray *T* (°C) | Kulu *E* (mm) | Cihanbeyli *E* (mm) | Aksaray *E* (mm) | Cihanbeyli GWL (m) | Kulu GWL (m) | Lake Tuz WL (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kulu *P* (mm) | 1.000 | | | | | | | | | | | |
| Cihanbeyli P (mm) | **0.766** | 1.000 | | | | | | | | | | |
| Aksaray *P* (mm) | **0.703** | **0.616** | 1.000 | | | | | | | | | |
| Kulu *T* (°C) | −0.479 | −0.382 | −0.466 | 1.000 | | | | | | | | |
| Cihanbeyli T (°C) | −0.484 | −0.401 | −0.484 | **0.993** | 1.000 | | | | | | | |
| Aksaray T (°C) | −0.463 | −0.369 | −0.478 | **0.995** | **0.994** | 1.000 | | | | | | |
| Kulu *E* (mm) | −0.442 | −0.396 | −0.493 | **0.944** | **0.952** | **0.947** | 1.000 | | | | | |
| Cihanbeyli *E* (mm) | **−0.502** | −0.403 | **−0.523** | **0.911** | **0.919** | **0.902** | **0.882** | 1.000 | | | | |
| Aksaray *E* (mm) | **−0.500** | −0.417 | **−0.517** | **0.860** | **0.872** | **0.866** | **0.868** | **0.829** | 1.000 | | | |
| Cihanbeyli GWL (m) | 0.159 | 0.193 | 0.178 | −0.086 | −0.123 | −0.056 | −0.033 | −0.265 | −0.111 | 1.000 | | |
| Kulu GWL (m) | −0.175 | −0.189 | −0.229 | 0.191 | 0.238 | 0.178 | 0.235 | 0.305 | 0.302 | **−0.570** | 1.000 | |
| Lake Tuz WL (m) | 0.335 | 0.479 | 0.344 | −0.348 | −0.334 | −0.333 | −0.359 | −0.314 | −0.302 | 0.105 | −0.046 | 1.000 |

## Appendix 4: Correlation coefficients of Timraş Sinkhole region

| | Çumra *P* (mm) | Çumra *T* (°C) | Çumra *E* (mm) | Çumra *GWL* (m) | Timraş *WL* (m) |
|---|---|---|---|---|---|
| Çumra *P* (mm) | 1.000 | | | | |
| Çumra *T* (°C) | −0.573 | 1.000 | | | |
| Çumra *E* (mm) | −0.580 | **0.954** | 1.000 | | |
| Çumra *GWL* (m) | 0.019 | −0.027 | −0.099 | 1.000 | |
| Timraş *WL* (m) | −0.070 | 0.102 | 0.030 | **0.965** | 1.000 |

## Appendix 5: Correlation coefficients of Beyşehir region

| | Beyşehir *P* (mm) | Beyşehir *T* (°C) | Beyşehir *E* (mm) | Beyşehir GWL (m) | Beyşehir WL (m) |
|---|---|---|---|---|---|
| Beyşehir *P* (mm) | 1.000 | | | | |
| Beyşehir *T* (°C) | **−0.559** | 1.000 | | | |
| Beyşehir *E* (mm) | **−0.557** | **0.944** | 1.000 | | |
| Beyşehir GWL (m) | 0.086 | −0.030 | −0.088 | 1.000 | |
| Beyşehir WL (m) | −0.141 | 0.035 | −0.022 | −0.032 | 1.000 |

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## Declarations

**Conflict of interest** The authors declare no conflicts of interest.

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