ORIGINAL PAPER

Trend analysis and change point determination for hydro-meteorological and groundwater data of Kizilirmak basin

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Abstract

Climate change–induced changes in hydro-meteorological parameters such as precipitation, temperature, and evaporation have also altered water cycle components in various parts of the world. Severity of droughts then gradually increases with these changes. In this article, the precipitation, temperature, streamflow, and groundwater data of the stations in the Kizilirmak basin between 1970 and 2017 were studied. Precipitation (P), maximum temperature (T_{max}), minimum temperature (T_{min}), and mean temperature (T_{mean}) data that were taken from 20 meteorology stations were used. For trend analysis, linear regression (LR) and non-parametric Mann–Kendall (MK), modified Mann–Kendall (Hamed−MK), and Spearman's Rho (SRHO) methods were used to find out the trends in time series. Pettit test was used to determine the inception period of the trend. Although increasing trends were observed in maximum and minimum temperatures across the basin, significant trends were not observed in mean temperatures. All significant precipitation trends were in increasing direction, except for the Ilgaz station. In the change point analysis, the directional change that is occurring in maximum and minimum temperatures corresponded to the period between 1993 and 1998. On the other hand, such a period coincided to the period between 1983 and 1997. Generally decreasing trends were observed in flows, except for three stations. Majority of the present stations had increasing trends in groundwater levels. Increasing trends, on the other hand, are thought to occur due to the increase in groundwater consumptions.

1 Introduction

Human activities such as using fossil fuels, increasing industrialization, and deforestation induce climate change. These human activities play a great role in acceleration of climate change. The impact of human activities along with the climate change itself are important factors that can change the routes of the hydrological cycle and affect the characteristics of hydrological drought in river basins (Javadinejad et al. 2019). Under the influence of these factors, changes in the direction of increase or decrease in hydro-meteorological variables are monitored. The significant differences observed in the climate averages over many years are so called as the climate change.

Determining the impacts of climate change on hydrological cycle and making attribute assessments have an essential place in water resources planning and management. Although climate change is a worldwide phenomenon, its impacts are different in each region (Kundzewicz and Robson 2004; Obot et al. 2010; Buishand et al. 2013; Wang and Li 2016). Therefore, the IPCC (Intergovernmental Panel on Climate Change) indicated that it is necessary to examine the impacts of climate change on a national and/ or regional scale. IPCC also stressed the need for more scientific studies on the relationship between climate change and water (Change et al. 2007). Therefore, the determination of changes in hydro-meteorological parameters is one of the most critical issues in evaluating the effects of climate change (Trajkovic and Kolakovic 2009; Va Loon and Laaha 2015). In recent years, several studies have focused on climate change and potential impacts on different sectors (Lu et al. 2008; Rawat 2012; Change 2014; Pratoomchai et al. 2015; Vu et al. 2015; Estévez et al. 2018; Khan et al. 2019; Zhao et al. 2019).

Investigation of hydro-meteorological time series is important in terms of determining behavioral characteristics

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of variables such as precipitation, temperature, streamflow, and drought. Because a strict rule does not bind the changes in the climate system, changes in meteorological parameters such as temperature, precipitation, and snow melting are significantly affected by climate change and, as a result, may cause changes in the basin (Wang et al. 2014; Zarenistanak et al. 2015).

One of the most critical and impacted parameters of global climate change is temperature. Due to its effect on precipitation, changes in temperature are one of the meteorological variables that should be monitored in terms of water resources and water management. For example, as a result of climate change, changes were encountered in temporal and spatial distribution of precipitations between 1906 and 2005. However, about 0.74 °C increase was seen in mean temperatures of the same period. In such a situation, it is possible to see more drought in arid regions (Solomon et al. 2007). Recent national and regional studies presented changes in temperatures (Manley 1946; Steinwand et al. 2006; Franzke 2010, 2015; Liu et al. 2012; Capparelli et al. 2013; Irannezhad et al. 2015; Hadi and Tombul 2018; Fallah-Ghalhari et al. 2019; Sun et al. 2019).

Precipitation and reference evaporation are vital parameters in hydro-meteorological studies and are used for agricultural planning, irrigation system design, and management. Demand for precipitation and evaporation is expected to change under climate change and affect sustainable development. Like temperature, precipitation is a critical component of hydro-meteorological studies in the planning and management of water resources. Determination of spatial–temporal changes in precipitation characteristics is vital in terms of evaluating the effects of climate change. For this reason, many studies have been carried out to investigate the changes encountered in climate components such as precipitation (Bhend and von Storch 2008; Obot et al. 2010; Guo et al. 2012; Hereher 2016; Wang and Li 2016; Jiang et al. 2017; Szwed 2019; Palamalai et al. 2020).

The impact of climate change on the streamflow, along with the effects of hydro-climatic components involved in the hydrological cycle, has significant effects on water resources and river flows. Increases or decreases in river flows, floods, or droughts are issues to be planned and taken into consideration in water resources management (Islam et al. 2012). Studies on this subject have been made, and the changes in the rivers have been examined by scientists from all over the world (Kahya and Kalaycı 2004; Cigizoglu et al. 2005; Mishra et al. 2014; Croitoru and Minea 2015; Dogan et al. 2015; Emadi et al. 2016; Zamani et al. 2017; Nashwan and Shahid 2019).

Groundwater is a valuable water resource. Increasing populations, groundwater use in agricultural areas, and wrong irrigation techniques have led to a decrease in groundwater resources and rapid changes in groundwater levels (Rafiq

and Mishra 2016; Mishra and Rafiq 2017). Groundwater levels and surface runoff are affected by climate change as it changes precipitation patterns (Wang et al. 2016, Salem et al. 2017). Changes in groundwater regeneration have also affected the levels of water resources (Taylor et al. 2013). Many researchers focused on groundwater (Rosenberg et al. 1999, Ge and Chaoying 2001, Kirshen et al. 2005, Chen et al. 2007, Howard and Griffith 2009, Nyenje and Batelaan 2009, Crosbie et al. 2010, Goyal et al. 2010, Taylor et al. 2013, Nyakundi et al. 2015, Rahaman et al. 2016, Wang et al. 2016).

Trend is so defined as the change in values of a random variable either ascending or descending order. Time series of climate parameters must be calculated using statistical methods to determine trend direction (Helsel and Hirsch 1992). Such trends also play an important role in planning, design, and management of water structures. Many researchers have analyzed the effects of climate variables on hydrometeorological variables and water resources.

In a previous study on long-term precipitations of Slovakia (1981−2013), Mann−Kendall test was used to analyze trends in precipitation series and significant changes were reported across the country and rainfall increased significantly especially in July (Zeleňáková et al., 2016). In another study investigating the rainfall trends in China's Yangtze River basin, 36 stations were used to analyze 50-year data. Significant increases were observed in the summer season when rainfall was most intense (Becker et al. 2006). In the study covering an 85,000-km^2 area in Northern Italy, monthly precipitations were examined in terms of a trend for 509 years. In the analysis using Mann−Kendall and Sen's graph test, it was stated that the highest and the lowest precipitation data had different values and different trends. Seasonal analyses revealed negative trends in winter and autumn (Caloiero et al. 2018). In the study, rainfall and river trends were analyzed in Neka basin of Iran over 44 years (1972−2015) on a yearly, seasonal, and monthly basis. A significant increase was observed in the annual maximum daily flow and a decrease was observed in monthly flows. At the same time, it was stated that there was a significant relationship between rainfall and flow. In general, a significant relationship was observed between seasonal precipitation and flow of the basin (Nikzad Tehrani 2019). In a study conducted in Warangal region, annual and seasonal groundwater trends were investigated for 15-year period (2000−2015). Three of the forty wells analyzed on a monthly scale had a significant positive trend, while the other seven wells had a significant negative trend. The seasonal tendency in the pre-monsoon period was reported to be decreasing (Satish Kumar and Venkata Rathnam 2019). In the study of meteorological data in Bangladesh, it was noted that there was an upward trend in temperatures and a downward trend in wind speed. It was stated that the increase in maximum

temperatures was higher than the minimum temperatures (Khan et al. 2019). In another study investigating the trends in the monsoon rain, flow, dam reservoirs, and post-monsoon groundwater (PMGW) levels in Karha Basin, India, a non-significant positive trend was found in the basin after 2003. At the same time, it was stated that there was an increase in groundwater levels (PMGW) in the post-monsoon period (Todmal et al. 2018).

The results of trend analyses in the Cobres River basin covering 40 years (1960−2000) showed that there was no continuous long-term and negative trend. However, there were oscillations from average precipitation and river flow within the basin (da Silva et al. 2015). In Sarawak, 31 stations (1980−2014) were used to determine trends in precipitation and extreme precipitation. Significant changes were detected in annual rainfall with the use of MK and Hamed−MK tests. When seasonal trends were analyzed, increasing rainfall was observed in Northeast monsoons; Southwest monsoon rainfall in some regions indicated a decreasing trend (Sa'adi et al. 2019). In a study, the tendency of precipitation, temperature, and river discharge around the West Caspian Sea were analyzed and the positive trend was observed in annual and seasonal rainfall and temperatures. River flows had a negative trend. The beginning of the changes in river flows and temperature emerged as the 1990s. Rising temperatures and decreasing precipitations were related to changes in river flow (Kazemzadeh and Malekian 2018).

In a study conducted in Kizilirmak basin of Turkey, 111 stations across the country were used to analyze spatial and temporal distribution and the trends in annual and seasonal rainfall. The Kruskal−Wallis test was used to check data homogeneity. Mann−Kendall rank correlation trend coefficient method was used for a trend in total precipitation and precipitation intensity data. Decreases were observed in precipitation of all regions and such decreases were more pronounced in the Mediterranean and the Black Sea regions. While there was a significant decrease in the total rainfall in winter season, there was an increase in the rainfall levels in the other seasons. The rainfall intensity decreased significantly in all seasons. While the decrease in total rainfall was substantial in the Mediterranean region, the rainfall intensity decreased more remarkably in the Black Sea region. Decreases in rainfall intensity have been observed to be more intense since 1950 (Turkes et al. 2007). In another study conducted in Eastern Mediterranean region of Turkey, rainfall data of 11 meteorological stations covering the period of 1975−2006 were used for trend analyses. Linear trend models were obtained for total annual precipitation, rainy days, and precipitation intensities. A decreasing trend was observed in annual rainfall and total annual rainy days (Gönençgil and Gülten 2010).

Kizilelma et al. (2015) conducted a trend analysis for mean, minimum, and maximum temperatures. Linear regression analysis revealed increasing mean and maximum temperatures in the study area. Minimum temperatures tend to increase in general except for a few stations. According to Mann−Kendall trend analysis, annual total rainfall in Central Anatolia decreased in general. While the precipitation generally decreased in the spring and summer seasons, there was an increase in winter and autumn season. However, in general, increases in winter and autumn season were not significant. Significant increases were observed in mean and maximum temperatures in almost all stations. Increases and decreases in minimum temperatures were not significant, except for a few stations.

In the study conducted in Adana sub-region, long-term variability and trends of annual and seasonal number of summer and tropical days were examined. According to the identified trends of 14 meteorological stations (1960−2014), number of annual summer days and the tropical days were generally below the long-term average by the end of the 1980s. In particular, positive anomaly values were observed in all stations between 1993 and 2014. According to the Kruskal−Wallis homogeneity test, the significant turning point for anomalies was 1993. The number of annual summer days and tropical days after this year increased rapidly. In particular, negative trends were monitored from 1987 to 1992. A significant increasing trend was observed at the 0.01 level in the number of tropical days around the coast. Simultaneously, in the summer of 2010, the most considerable anomaly values have recorded increases around the coast. It was shown that the region was exposed to a long-term hot period and thermal conditions due to the increasing temperatures in the Adana Sub-region that is one of Turkey's most important agricultural regions. It is stated that it is seen as a potential risk for human health and economic and crop losses (Bayer Altin and Barak 2017).

A correlation study was conducted on the temperature and rainfall values of six meteorological stations of the Kizilirmak basin and the flow values obtained from the measurement stations from the Kizilirmak river. As a result of the analysis, a reversal relationship at secondary significance was observed between temperature and flow. There was a positive correlation at secondary significance between precipitation and flow values. In the trend analysis, although the temperature trend was an upward direction in all stations, precipitation trend was downward direction except for one station. In the study of the long-term data of the streams, the non-dam section of the river (Divrigi station) was preferred due to the protection of natural conditions. Significant reductions in currents were observed in all current stations, including Divrigi station. It was underlined that the decline accelerated, especially after the 1990s (Bahadir 2011).

In a previous study in the Kizilirmak basin, trends in annual total precipitation and annual mean temperature data were investigated. Mann−Kendall was used as trend analysis in the data set covering 1975−2015 period (40 years) of 36 stations. As a result of the research, no trend was observed in precipitation, but an increasing trend was observed in temperature (Sutgibi 2015).

In this study, both meteorological and hydrological trends were investigated in the Kizilirmak basin, which is fed by many different tributaries and passing through different climate regions. Linear regression and non-parametric Mann−Kendall (MK), modified Mann−Kendall (Hamed−MK), and Spearman's Rho (SRHO) trend tests were used to determine trends. At the same time, the Pettit test was used to determine the change point in the historical series. The relationship between meteorological trends and trends of flow-groundwater levels was also investigated.

2 Material and method

2.1 Study area and data

Kizilirmak basin is the second largest watershed of Turkey. It is located to the east of Central Anatolia between $37°58′ − 41°44′$ north latitudes and $32°48′ − 38°22′$ east longitudes (Fig. 1). The basin, which covers approximately 11% of the country's territory, is generally composed of plains, while only the northern and eastern parts are mountainous. The Kizilirmak river, sourced from near İmranlı,

draws a wide arc after passing through Avanos, flows toward to northwest with a sharp turn from Osmancik and then to the east with a sharper second turn from the south of Kargı (Forestry 2016). All of Kirsehir and Kirikkale provinces, Sivas, Kayseri, Yozgat, Nevsehir, Kastamonu, Cankiri province centers, and a large part of the province; and major parts of Nigde, Ankara, Corum, Sinop, Aksaray, and Samsun are included in the basin. Kizilirmak river with a length of 1151 km is the longest river of Turkey. There is a drainage area of 78,180 km^2 and a water volume of 5.5 billion m^3. Coastal parts of the Kizilirmak basin are dominated by the sea climate and the inland parts by terrestrial climate. The region with the least rainfall is the central part of the basin, which is the pit. The average annual precipitation in these parts of the basin varies between 300 and 400 mm. The Kizilirmak basin covers a large area, including the Kizilirmak river, which is a very long river, and its surroundings. Therefore, meteorologically, the basin area is spread to different geographical regions. It is possible to see different meteorological parameters throughout the Kizilirmak basin, which are very different from each other and are unique to Central Anatolia and Black Sea geographical regions. To generate meteorological data in the Kizilirmak basin, the information about the observation stations of the General Directorate of State Meteorological Affairs within the boundaries of the basin were evaluated.

Of 30 stations in the basin, those with long-term records (at least 40 years) were preferred. The meteorological data (temperature, precipitation) for 1970−2017 period were obtained from the Turkish State Meteorological Service,

Fig. 1 Kizilirmak basin of Turkey, located in the basin precipitation, flow, and groundwater stations
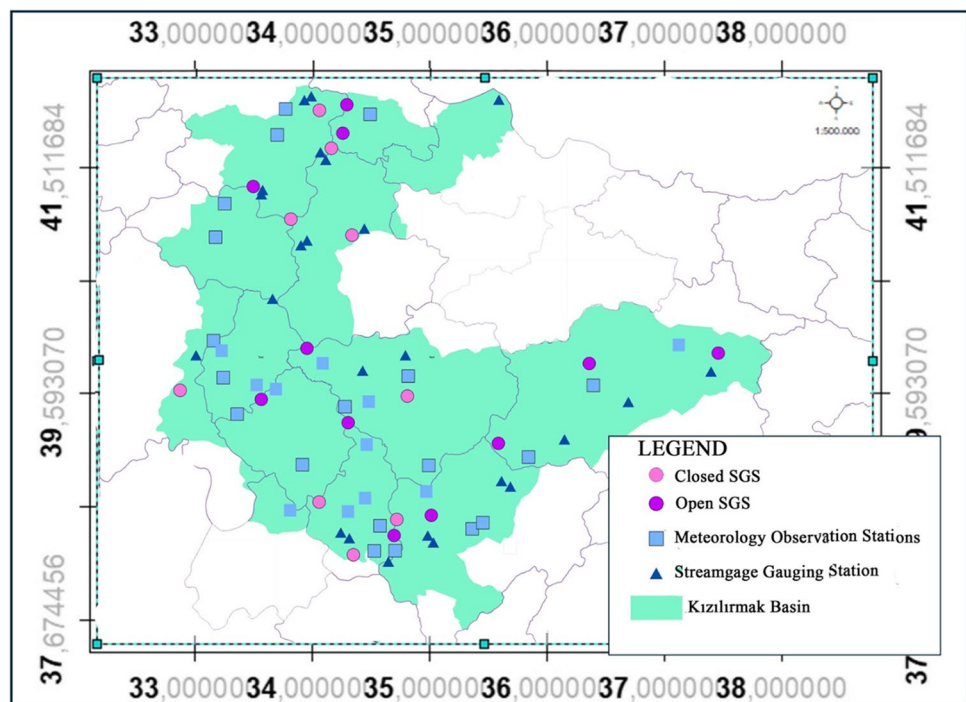
known as DMI in Turkey; streamflow and groundwater levels were obtained from The General Directorate of State Hydraulic Works, known as DSI in Turkey.

2.2 Methodologies

2.2.1 Standard normal homogeneity test

Standard normal homogeneity test (SNHT) (Alexandersson 1986) is one of the important homogenization methods preferred in many hydrological studies. In practice, it is essential to create a composite series with a difference or ratio value of the series according to a reference value whose homogeneity is accepted. After the composite series is standardized, the means of the previous and next series are calculated. If the difference between the mean values reaches the critical value, this indicates a sudden change in the series. In this case, it is determined that the series is not homogeneous; otherwise, the series will be homogeneous (Ducré-Robitaille et al. 2003).

2.2.2 Von Neumann's independence test

In this test proposed by Von Neumann, the test statistic Q is defined as the ratio of the sum of squares of consecutive differences to the variance value and is calculated by the formula below:

$$Q = \sum_{i=1}^{n-1} (x_{i+1} - x_i)^2 \Big/ \sum_{i=1}^{n} (x_i - aax)^2 \tag{1}$$

where aax presents an arithmetic average of series. If the time series is independent from each other, Q is normally distributed with an expected value of 2. Thus, if the tail probability of the standardized variate is greater than half of the critical probability, then the H_0 hypothesis is accepted (Von Neumann 1941).

2.2.3 Autocorrelation test

Serial correlation is an important aspect to be taken into account in the analysis of hydrological time series. Autocorrelation can be defined as the situation in which successive values in time series affect each other. The presence of a serial correlation in a time series increases the possibility of finding a significant trend in the test result even though there is no trend in the analyzed data set and may cause misconceptions about the data group investigated.

With the test used in the study, Student t test, the auto-correlation coefficient t is calculated as $(n-2)$ degrees of freedom as follows:

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

If this coefficient t is lower than the value corresponding to the significance value, it indicates that there is no autocorrelation. Otherwise, it indicates the presence of autocorrelation (Akinsanola and Ogunjobi 2017).

2.2.4 Wald–Wolfowitz's stationary test

To examine the stationarity of the time series, Wald−Wolfowitz, one of the common methods that are used to calculate R statistic, is recommended, and its formula is given below.

$$R = \sum_{i=1}^{n-1} x_i \cdot x_{i+1} + x_1 \cdot x_n \tag{3}$$

In the time series, since R is normally distributed, the tail probability of the standardized variable becomes greater than half the critical probability and this time series is considered as a stationarity series (Helsel and Hirsch 2002).

2.2.5 Mann−Kendall trend test (MK)

Mann−Kendall test is one of the frequently used statistical tests to analyze the tendency in climatological and hydrological time series. Kendall's Tau is a different application of the test. Specifically, it is a suitable test for data with extreme values and non-linear tendencies that do not conform to the normal distribution (Helsel and Hirsch 1992).

In this test, according to the null hypothesis H_0, the data series have time-independent distribution so that there is no trend in the series. However, according to hypothesis H_1, the series has a similar distribution, and there is a trend in the series.

The Mann−Kendall test statistic is defined as

$$S_{M-K} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \tag{4}$$

In this equation, x_i and x_j represent the data in years i and j, and n indicates the length of the data.

$$sign(x_j - x_i) = \begin{cases} 1 & (x_j - x_i) > 0 \\ 0 & (x_j - x_i) = 0 \\ -1 & (x_j - x_i) < 0 \end{cases} \tag{5}$$

In cases where $n \geq 10$, the distribution of the S statistic is entirely appropriate for the normal distribution. In this case, the average of the statistic is zero, and the following equation finds the variance:

$$Var(S) = \frac{n \cdot (n-1) \cdot (2 \cdot n + 5)}{18} \qquad (6)$$

Whether the trend obtained from the test is significant is determined by comparing the normalized z value with the critical z values by calculating the following equation:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \qquad (7)$$

The z values obtained are compared with the $z_{\alpha/2}$ value derived from the standard normal distribution table for α significance level. If $|z| > z_{\alpha/2}$, the hypothesis H_0 is rejected. So, there is a significant trend in the series. Also, there is a decreasing tendency if the Z value is negative and an increasing trend if it is positive. In this study, since the significance level (α) was selected as 5%, and ± 1.96 was used as the critical value (Mann 1945; Kendall 1948).

2.2.6 Spearman's Rho test (SRHO)

Spearman Rho is one of the non-parametric tests used to detect the presence of monotone tendency in hydro-climatic time series (Yenigün et al. 2008). SRHO, which is based on rankings, indicates a significant trend when the correlation between data is significant.

In this test, all data in the time series have an independent and identical distribution according to the null hypothesis (H_0), indicating the presence of increasing or decreasing trends relative to the other hypothesis (H_1). Positive values of S indicate upward trends, while negative S indicates downward trends in the time series.

2.2.7 Modified Mann−Kendall test (Hamed−MK)

An essential issue in trend analysis studies is autocorrelation, which is frequently seen in climatic data. The presence of autocorrelation in a time series causes it to show trend even if there is no trend, rejecting the zero hypothesis that there is no trend. Therefore, modified MK is recommended to be used to determine the trends of data with autocorrelation (Hamed and Rao 1998).

In this improved method, the variance calculation of S statistics is as follows:

$$Var(S') = \left[\frac{n \cdot (n-1) \cdot (2 \cdot n + 5)}{18} \right] \cdot \frac{n}{n_e^*} \qquad (8)$$

In the formula, $\frac{n}{n_e^*}$ represents the autocorrelation correction factor and is calculated as follows:

$$\frac{n}{n_e^*} = 1 + \frac{2}{n \cdot (n-1) \cdot (n-2)} \sum_{i=1}^{n-1} (n-i) \cdot (n-i-1) \cdot (n-i-2) \cdot p(i) \qquad (9)$$

$p(i)$ symbolizes the autocorrelation function of the ranks of the time series.

Whether the trend in the series with autocorrelation is significant is determined by comparing the new z value with the critical z values by calculating the following equation:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \qquad (10)$$

The calculated z values are compared with the $z_{\alpha/2}$ value obtained from the standard normal distribution table for the α significance level. If $|z| > z_{\alpha/2}$, the hypothesis H_0 is rejected. Rejection of the null hypothesis H_0 indicates a significant trend in the series. Regarding the direction of the trend, $Z < 0$ means a decreasing trend and $Z > 0$ means an increasing trend.

2.2.8 Linear regression

Linear regression is the regression analysis used to determine the x-dependent change of the variable y (Atik et al. 2007). The regression equation is $y = ax + b$. The coefficient a denotes the direction and value of the trend. A linear relationship between x and y is expressed according to their distribution in the x–y plane of the observation pairs. To be capable of talk about a relationship between x and y, the distribution must be spread around a line. If there is such a distribution, there is a linear relationship between the observation pairs. For an increasing trend, the coefficient a should be positive. For a decreasing trend, the coefficient a must be negative. The fact that the coefficient a is close to zero indicates that there is no change (Guner Bacanli and Tugrul 2016).

2.2.9 Pettit test

This test is independent of the distribution of the data and is related to their rank in the series. Therefore, it is a test independent of the distribution and does not require acceptance. In this test, the null hypothesis H_0 argues that the time series is homogeneous, whereas the opposite hypothesis is a break in the mean; the data are not homogeneous. This test also determines the change point of the time series (Pettitt 1979).

3 Application and results

Trend analysis of climate variables provides essential information for understanding the impact of climate change on hydrological parameters. In this study, the minimum

temperature (T_{min}), maximum temperature (T_{max}), mean temperature (T_{mean}), and mean precipitation (P) data of 1970−2017 period that is obtained from 20 meteorological stations in Kizilirmak basin were examined to determine trends. In addition to meteorological data, trend research was conducted for flow and groundwater levels. Flows were taken from 14 different observation stations and groundwater levels were taken from 20 different observation stations of the Kizilirmak basin.

Standard normal homogeneity test, autocorrelation test, Wald−Wolfowitz's stationary test, and Von Neumann's independence tests were used to check the homogeneity, autocorrelation, stationarity, and independence of the data in the time series of meteorological, streamflow, and groundwater levels of the Kizilirmak basin. The summary of the tests applied to the meteorological, streamflow, and groundwater levels data are presented in Table 1. According to the results, it was observed that all meteorological stations were homogeneous, non-stationary, independent, and have no correlation. However, some non-homogeneous and autocorrelated distributions were found in some flow and groundwater stations. Since the number of these stations is less than the total stations, trend analysis has been applied.

3.1 Trends of maximum, minimum, and mean temperatures

The time series of meteorological data were analyzed at a 95% confidence level with non-parametric Mann−Kendall (MK), modified Mann−Kendall (Hamed−MK), and Spearman's Rho (SRHO) methods and parametric linear regression (LR) tests. The test statistics demonstrate whether there was a trend when it is less than −1.96 and greater than 1.96. In the maximum temperature series (1970−2017), significant positive trends were observed in 8 stations (40%) among 20 stations across the basin. The other 12 stations did not show a trend in any tests. Among eight stations, except for Kastamonu and Kaman stations, a trend was seen according to all tests. However, a trend was not observed in

tests other than LR and SRHO at Kastamonu station. The distribution of maximum temperature trends in the basin is presented in Fig. 2. As can be seen in Fig. 2, an increasing trend was seen in maximum air temperature along the coast of the Black Sea.

Similarly, a trend was observed in all tests except for Hamed−MK at the stations in Kaman. MK test and Hamed−MK test, one of the tests applied to the maximum temperature variable, showed a harmonious trend in all stations except for Kaman. In the Hamed−MK test, no trend was observed in both Kastamonu and Kaman stations, whereas in the MK test, no trend was observed only in Kastamonu. LR and SRHO tests not only showed trends but also acted harmoniously at all stations. The results of all trend tests were compatible with each other, and additionally, they showed a 100% trend in stations other than Kastamonu and Kaman stations.

While the stations that show trend at minimum temperatures are at different stations than the maximum temperatures, an increasing trend was detected at 6 stations (30%) among 20 stations. The other 14 stations did not show a trend in any tests, and they were not included in this study in order to save space. The distribution of minimum temperature trends in the basin is shown in Fig. 3. As can be seen in Fig. 3, increasing trends in minimum air temperature was concentrated in the southern part of the basin. This is thought to be a result of the decrease in snowfall in the region. Sivas station showed an increasing trend only in the LR test, while the Kaman station showed an increasing trend only in the SRHO test. Although Bafra and Yozgat stations did not show any trends in the Hamed−MK test, they demonstrated a significant increasing trend in SRHO and LR tests. Apart from these stations, Kayseri and Nevsehir stations showed a 100% significant trend for four tests. There is a trend in Nevsehir, Kayseri, and Develi stations and all tests were compatible with each other.

Despite the increasing temperature trends that are occurring at the minimum and maximum temperatures, no significant trend was detected at any stations for average

Table 1 Summary of Von Neumann's independence test (VN) and Wald–Wolfowitz's stationary (WW), standard normal homogeneity test (SNHT), and autocorrelation tests applied on maximum temperature, minimum temperature, precipitation, streamflow, and groundwater level series of Kizilirmak basin with a critical probability level of 5%

Variable	Von Neumann		Wald–Wolfowitz		SNHT		Autocorrelation	
	Independent	Dependent	Stationary	Non-stationary	Accept	Reject	Accept	Reject
T_{max}	20	0	0	20	20	0	20	0
T_{min}	20	0	0	20	20	0	20	0
P	20	0	0	20	20	0	20	0
Streamflow	12	2	4	10	12	2	12	2
Groundwater	5	15	2	18	20	0	20	0

Fig. 2 Display of trend test results of maximum temperature data of different stations of the Kizilirmak basin
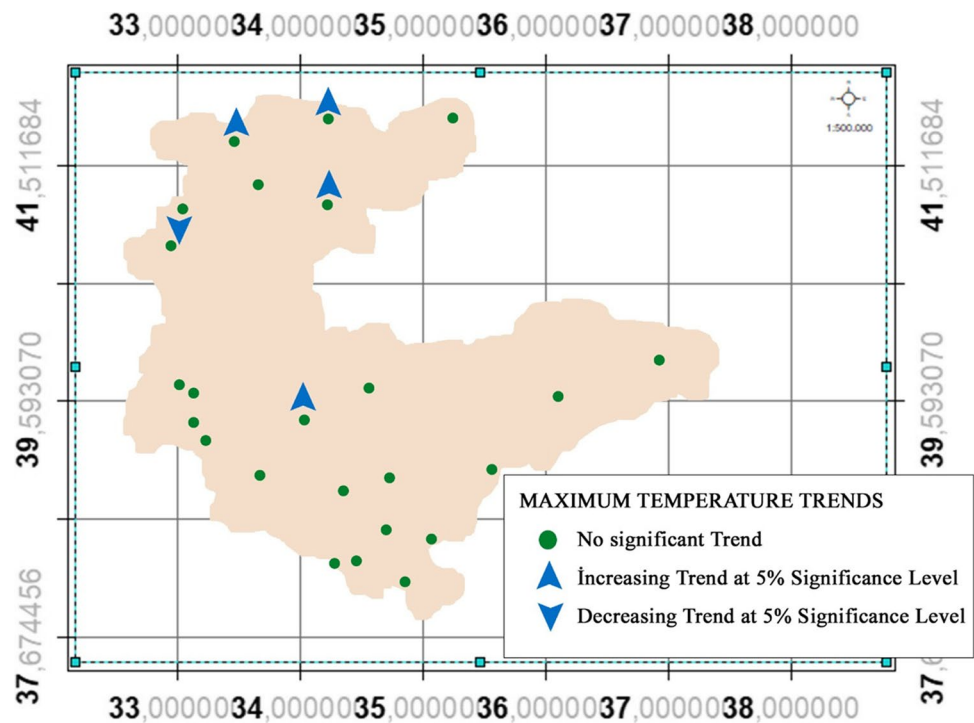
Fig. 3 Display of trend test results of minimum temperature data of different stations of the Kizilirmak basin
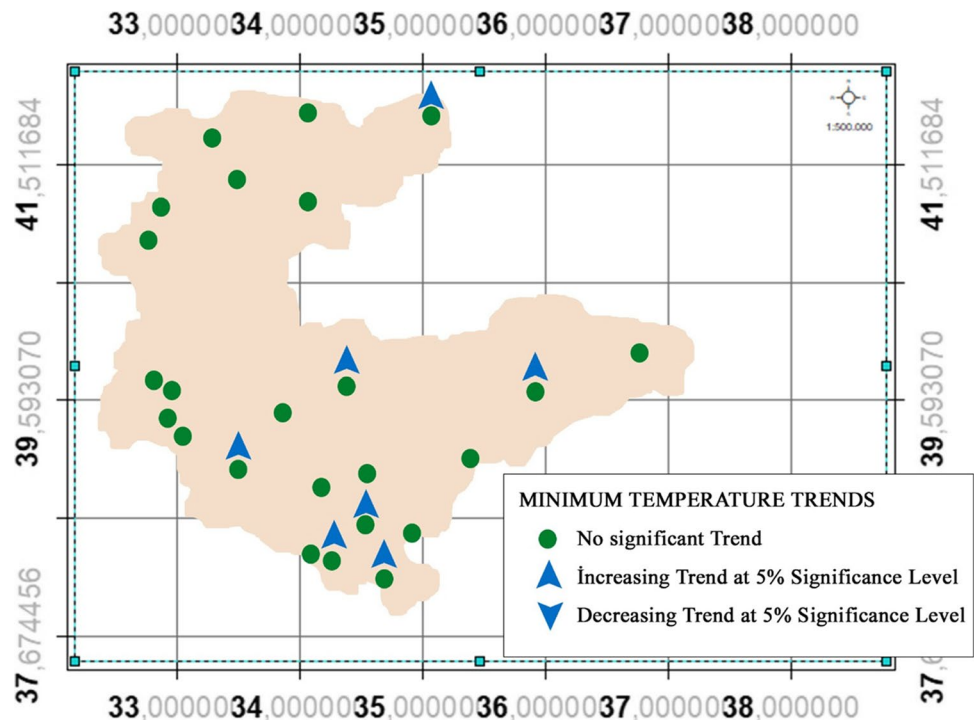
temperatures. Therefore, it is not shown in this paper. However, the increase in temperatures has shown itself up both at maximum temperatures and minimum temperatures. Nevsehir, Yozgat, and Kaman stations were the only stations that had a significant increase in both maximum and minimum temperature variables. In the minimum

temperature trends, there were fewer stations that showed trends when these were compared with the maximum temperature trends. Increase in temperature extremes and the positive progress of warming in the basin caused more trends to be observed at maximum temperatures.
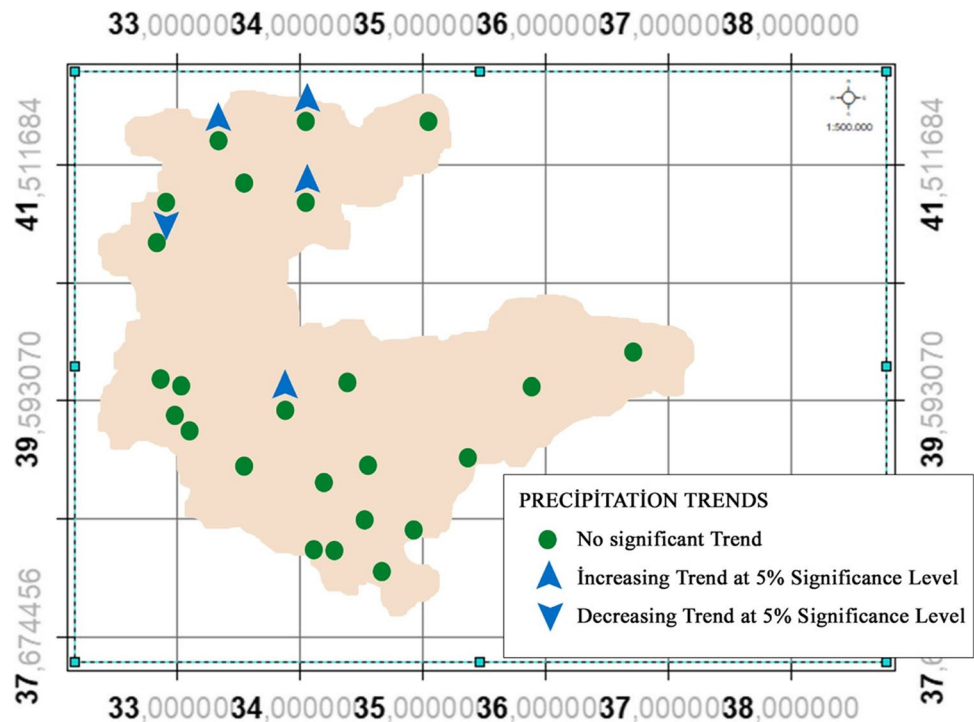
3.2 Trends of precipitations

There was a trend in monthly precipitation series in 5 stations (20%) out of 20 stations. Besides the increases in maximum temperature, the precipitation series had increasing trends in all stations, except for one station in the basin. The distribution of precipitation trends in the basin is shown in Fig. 4. As can be seen in Fig. 4, the increasing trend in precipitation is occurring on the coast of the Black Sea. As shown in Table 2, all stations had an increasing precipitation trend while Ilgaz station had a decreasing trend. Stations without a trend are not shown in Table 2. In Ilgaz station, Hamed−MK, SRHO, and LR tests revealed that precipitations had a decreasing trend since the test statistic value was less than − 1.96. MK test did not have significant trend values. Kastamonu and Osmancik stations showed trends only in the LR test, and they did not show a significant trend in any other trend tests. Boyabat station, on the other hand, had a 100% increasing trend in all trend tests. Ilgaz station showed an increasing trend at maximum temperatures, while

it showed a decreasing trend for precipitation. Kastamonu station had a significant increasing trend in the LR test both in maximum temperature and precipitation series. While Cicekdagi station had no trends in temperatures series, it had an increasing trend in the MK test for precipitation.

3.3 Trends of streamflow

The flow series obtained from the stations at different points of the Kizilirmak basin were passed through four different trend tests mentioned above, and the analysis results are shown in Table 4. For streamflow trends, series were formed by considering the hydrological year. The reflection of the snowfalls occurring in the winter to the river in spring is taken into account in this way (Dai et al. 2010). The locations and distributions of streamflow stations in the Kizilirmak basin are shown in Fig. 5. As seen in Fig. 5, increasing and decreasing trends in streamflow data were concentrated in the central part of the basin.

Fig. 4 Display of trend test results of precipitation data of different stations of the Kizilirmak basin

Table 2 Trends for precipitation series with Hamed−MK, Mann–Kendall (MK) test, linear regression (LR), and Spearman's Rho (SRHO) tests
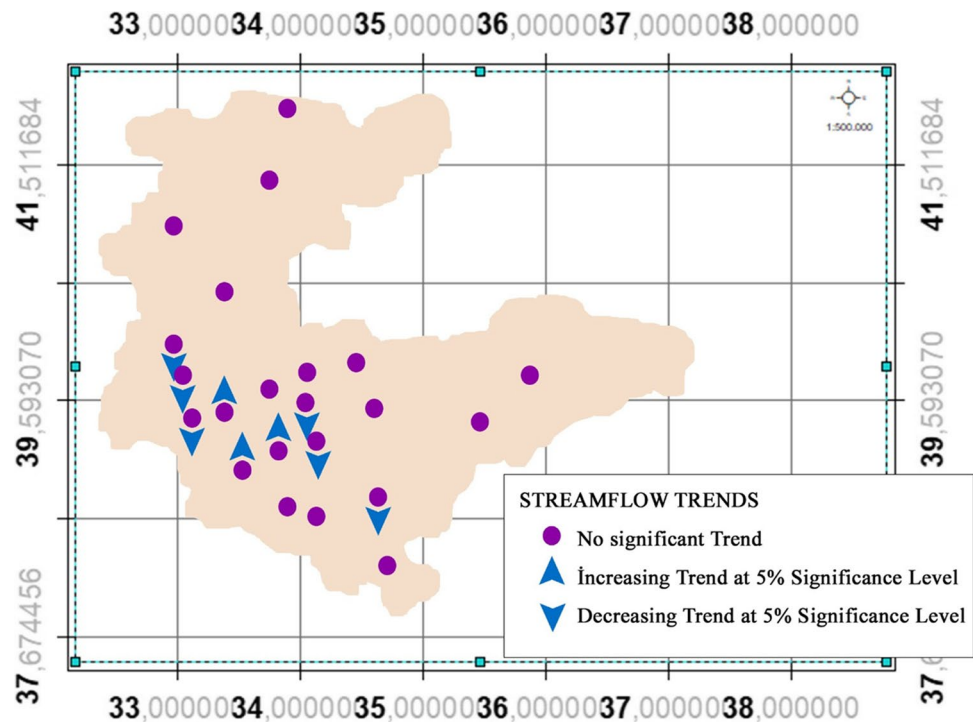
Station	Hamed–MK		MK		LR		SRHO		
P	qMK	Trend	Z	Trend	t_{st}	Trend	Z_{SR}	Trend	% Trend
Kastamonu	0.070	–	1.600	–	2.523	↑	1.470	–	25
Ilgaz	0.026	–	− 2.271	↓	− 3.128	↓	− 1.965	↓	75
Osmancik	0.045	–	1.926	–	2.115	↑	1.742	–	25
Cicekdagi	0.063	–	2.142	↑	1.618	–	1.539	–	25
Boyabat	0.000	↑	3.099	↑	5.878	↑	4.645	↑	100

Of the streamflow gauging stations in the basin, 14 stations with long-term flow series were included in the trend test. Trends were detected in 11 stations (78%) among these 14 stations. While trends were decreasing in eight stations, an increasing trend was observed in three stations. As can be seen in Table 3 and Fig. 5, 15–68 and 15–152 stations had a 100% increasing trend. On the other hand, 15–03, 15–182, and 15–242 stations had a 100% decreasing trend. This situation shows that the tests were compatible with each other. Station 15–01 showed a decreasing trend only in the LR test. The stations 15–108, 15–190, and 15–17 showed a decreasing trend in three different tests. The reason why there were different trends in the basin is that the basin covers different geographical regions because the Kizilirmak river is very

long. The Central Anatolia region and the Black Sea region are two different geographic regions that differ significantly from each other. However, Kizilirmak basin covers certain parts of both regions. Therefore, significant differences are seen in precipitation and temperatures.

MK and Hamed−MK tests showed similar results with a few exceptions. MK test had a trend in 9 stations and Hamed−MK test had a trend in 7 stations among 11 stations. While MK was trending at stations 15–17 and 15–67, Hamed−MK did not show any trends. The SRHO test had a trend at 10 stations out of 11 stations and gave results consistent with the MK test at 9 stations. LR test, on the other hand, is the only non-parametric test. It showed a trend at eight stations in streamflow series. The only test that does

Fig. 5 Display of trend test results of streamflow data of different stations of the Kizilirmak basin

Table 3 Trend results for streamflow series with Hamed−MK, Mann–Kendall (MK) test, linear regression (LR), and Spearman's Rho (SRHO) tests

Station	Hamed–MK		MK		LR		SRHO		
Streamflow	qMK	Trend	Z	Trend	t_{st}	Trend	Z_{SR}	Trend	%
15–01	0.176	–	−1.517	–	−2.673	↓	0.206	–	25
15–03	−5.367	↓	1.902	↓	−2.718	↓	−5.143	↓	100
15–17	−5.564	↓	1.54	–	−4.123	↓	−5.609	↓	75
15–67	2.07	↑	2.448	–	−0.398	–	2.23	↑	50
15–68	5.453	↑	−0.505	↑	2.62	↑	5.418	↑	100
15–108	−8.739	↓	−2.018	↓	0.54	–	−8.867	↓	75
15–152	6.239	↑	0.685	↑	4.688	↑	6.097	↑	100
15–182	−9.088	↓	−2.707	↓	−2.151	↓	−9.025	↓	100
15–190	−5.094	↓	−0.86	↓	−0.164	–	−5.118	↓	75
15–208	−0.988	–	−2.905	–	−2.057	↓	−0.858	↓	50
15–242	−3.62	↓	0.06	↓	−3.88	↓	−3.747	↓	100

not trend at stations 15–108 and 15–190 is the LR test. However, it is the only test that trends at 15–01 station.

3.4 Trends of groundwater levels

A time series was created with groundwater levels obtained from 20 groundwater stations of the Kizilirmak basin. The distribution of groundwater stations in the basin is shown in Fig. 6. Trend tests found that when applied to groundwater time series, all stations had a trend. Although most of the trends are in increasing direction (85%), the decreasing trend (15%) was detected in three stations. The distribution of trends is shown in Fig. 6. As seen in Fig. 6, the increasing and decreasing trend in groundwater levels occurred in the southern part of the basin. Of 20 stations with trends, 15 stations showed trends in all tests. Of 15 stations with a 100% trend, only 54,163 station showed

a decreasing trend. The 55,362 station had decreasing trend in LR and SRHO tests. The 59,667 station had a decreasing trend only in LR. MK and Hamed−MK tests yielded similar results for all stations, except for two stations. MK test (90%), which had a trend in 18 stations, showed a trend in Eskidogan and 54,162 stations, unlike the Hamed−MK test. The SRHO test did not show trends in only one station. Although 59,667 was the only station where SRHO did not show a trend, it had a trend only in the LR test.

The results of the trend tests that performed on meteorological and hydrological parameters in the Kizilirmak basin are summarized and presented in Table 4. The most trending test at the maximum temperature parameter was the LR test, indicating the trend at 8 stations out of 20 stations. The least trending test was the Hamed−MK with 6 stations out of 20 stations. As can be seen in Table 4, the results of the other

Fig. 6 Display of trend test results of groundwater data of different stations of the Kizilirmak basin
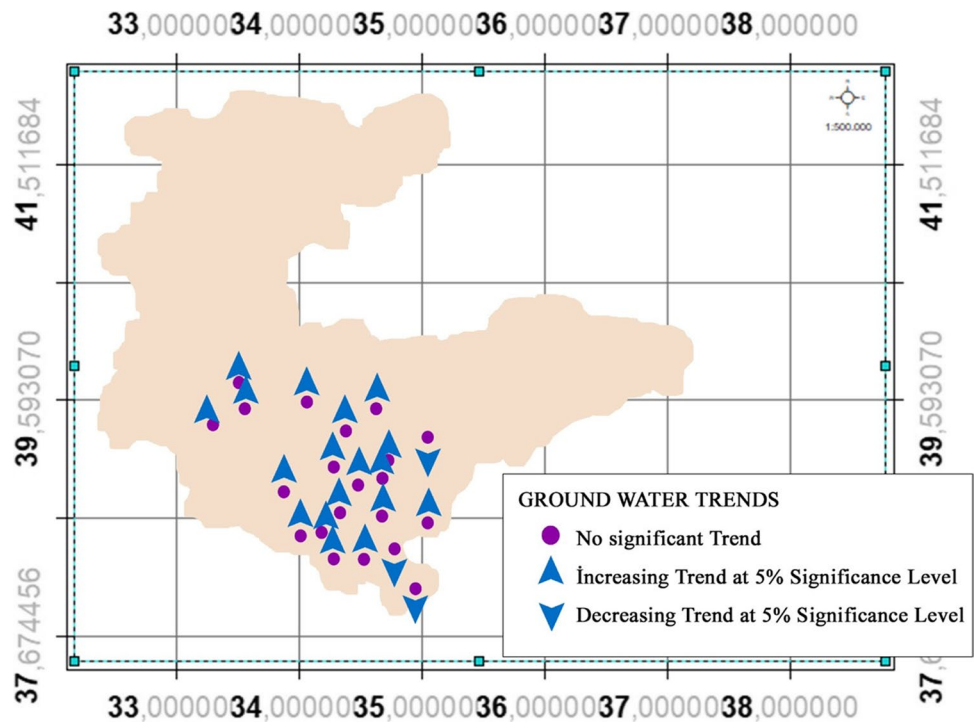
Table 4 Summary of Hamed−MK, Mann–Kendall (MK) test, linear regression (LR), and Spearman's Rho (SRHO) tests applied to maximum temperature, minimum temperature, precipitation, streamflow, and groundwater level series of Kizilirmak basin with a critical probability level of 5%

Variable	mMK			MK			LR			SRHO		
	No trend	↑ Trend	↓ Trend	No trend	↑ Trend	↓ Trend	No Trend	↑ Trend	↓ Trend	No trend	↑ Trend	↓ Trend
T_{max}	14	6	0	13	7	0	12	8	0	13	7	0
T_{min}	15	5	0	17	3	0	14	6	0	14	6	0
P	19	1	0	17	2	1	16	3	1	18	1	1
Stream flow	5	3	6	7	2	5	6	2	6	4	3	7
Groundwater	2	17	1	1	18	1	1	16	3	1	17	2

tests were numerically close to each other. This situation showed that the tests yielded consistent outcomes.

For minimum temperature series, LR and SRHO tests yielded trends the most. Of the present meteorological parameters, precipitation had the least trends. The LR test was the numerically most trending test. It indicated an increasing trend in three stations and a decreasing trend in one station. While the trend in the meteorological data was generally increasing in the basin, there is an increasing and decreasing trend in the flows and groundwater levels. In the SRHO test, in the streamflow series, decreasing trends were observed at 7 stations of 11 stations, while an increasing trend was observed at 3 stations. In both the LR and Hamed−MK tests, the streamflow series had decreasing trend at six stations, while increasing trends were detected at two stations. It is thought that the decreasing trends in streamflow were due to the effects of dams on the Kizilirmak river rather than meteorological changes.

3.5 Change years by Pettit test

As a result of applying trend tests to meteorological data, trends and directions occurring in the time series were determined. Another parameter that is as important as learning trends is to determine when trends start. Knowing the beginning of change is very important to identify the factors that cause the change. The Pettit test consists of a data set sorted on a month-by-month basis from the first year of the time series to the most recent year. The Loc value obtained from the calculations corresponds to the order of the change point as a month. In graphs, the change point is the time at which

the maximum value is in the safe range. The Loc value of the stations referred to the month when the trend started. The corresponding year in the data set for this value is also shown in Table 5.

In this study, the Pettit test was used to determine the change point of the trends of meteorological parameters, streamflow, and groundwater levels in the Kizilirmak basin. Table 5 shows the change point results and directions of the trends for maximum temperature, minimum temperature, and rainfall, respectively. Change years in meteorological and hydrological parameters have similarities with drought events seen before in Turkey. In previous studies, 1971, 1972, 1973, 1974, 1983, 1984, 1989, 1990, 1991, 1992, 1993, 1994, 2001, 2006, 2007, and 2008 were determined as arid years in Turkey (Turkes and Erlat 2003; Ceylan and Komuscu 2007; Turkes and Tatli 2011). The most severe and widely distributed droughts in Turkey occurred in 1971−1974 period and in 1983, 1984, 1989, 1990, 1996, and 2001 (Turkes 2003).

According to the results presented in Table 5, Kastamonu station started to change direction at month 339, and the value of month 339 in the graph showed the maximum point. However, in the maximum temperature time series of Kastamonu station that started in January 1970, this point refers to March 1998. Similarly, the change point in Yozgat, Kirsehir, Nevsehir, and Tosya stations corresponded to the 280th month. Starting from January 1970, this value corresponded to April 1993. The graphics of Nevsehir stations are shown in Fig. 7. Starting from January 1970, this value corresponded to April 1993. According to the results obtained, it was observed that the maximum temperatures in

Table 5 Result of Pettit test for change points (year) in historical series of maximum temperature, minimum temperature, precipitation, streamflow, and groundwater level of Kizilirmak basin

Meteorolojik series				Streamflow series		Groundwater series			
Station	T_{max} Years	T_{min}	P	Station	Years	Station	Years	Station	Years
Kastamonu	1998	–	1997	15–01	2008	Ozbag	2017	Dev-55362	2014
Sivas	–	1998	–	15–03	2000	A-Temirli	2014	Dev-60637	2015
Yozgat	1993	1998	–	15–17	2001	Budak	2014	Dev-54157	2003
Kirsehir	1993	–	–	15–67	1975	Yeniyapan	2014	Dev-54158	1997
Nevsehir	1993	2005	–	15–68	1986	Eskidogan	2013	Dev-54159	2012
Kaybolge	–	1988	–	15–108	1994	Bgz-59666	2013	Dev-54160	2001
Bafra	–	1998	–	15–152	1985	Bgz-59667	2010	Dev-54161	1996
Ilgaz	1993	–	1974	15–182	2000	Bgz-60078	2010	Dev-54162	1999
Tosya	1993	–	–	15–190	1994	Dev-59669	2012	Dev-54163	2006
Osmancik	–	–	1994	15–208	1989	Dev-55350	2015	Dev-60638	2014
Cicekdagi	–	–	1983	15–242	1993	–	–	–	–
Kaman	1997	1997	–	–	–	–	–	–	–
Urgup	1994	–	–	–	–	–	–	–	–
Develi	–	1998	–	–	–	–	–	–	–
Boyabat	–	–	1986	–	–	–	–	–	–
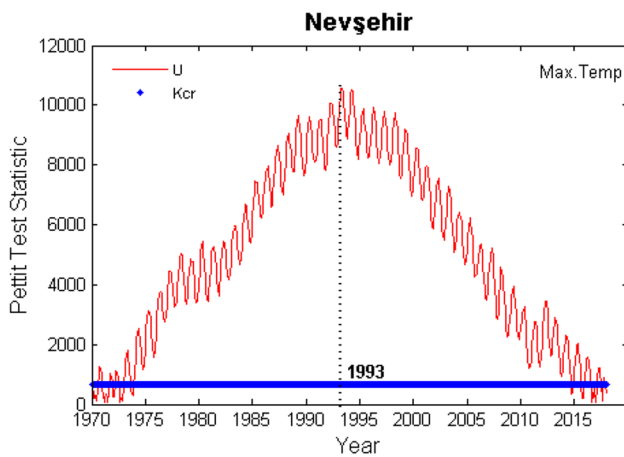
Fig. 7 Pettit test results and change year of Nevşehir station for maximum temperature data

the Kizilirmak basin began to increase since 1993. In the stations in the central Anatolia region, which is an arid region and one of the leading regions of Turkey to be affected by global warming, Yozgat, Kirsehir, Nevsehir, and Urgup started to show an increasing trend in maximum temperatures during the same period, 1993−1994. Only Kaman station has shown increasing trends in maximum temperature since 1997 and Kastamonu station has shown increasing trends in maximum temperature since 1998.

At Sivas, Yozgat, Bafra, and Develi stations, the minimum temperature change point corresponded to the 340th month. In the series starting from 1970, this numerical value corresponded to April 1998. In addition, at the Kaman station, the change point was the 336th month corresponding to November of 1997. The change point graph of the Kayseri station is presented in Fig. 8. In the graph shown, the change point of Kayseri station was the 219th month corresponding
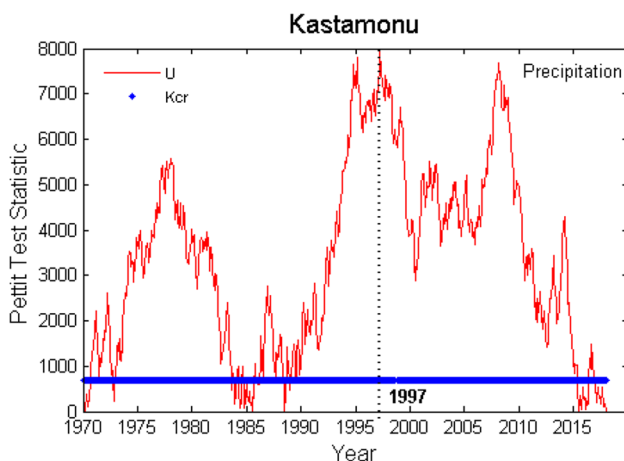
to March of 1988. The starting period of the trend was within the range of the arid-affected period, according to the results of the change point at minimum temperatures. Kaman, Develi, Yozgat, and Sivas stations, which are usually located within the borders of Central Anatolia region, started to show an increasing trend in minimum temperatures during the period 1997−1998. Although Bafra station is not located in the climatically arid region, it followed an increasing trend during 1998. Nevsehir stations followed the direction of increasing minimum temperatures in 2005.

In Kastamonu station shown in Fig. 9 for precipitation series, the change point was seen at the 327th month corresponding to March of 1997. Osmancik station had the change point at the 219th month corresponding to March of 1994. Ilgaz station had the change point at the 60th month (December 1974), and Cicekdagi station had change point at the 145th month (July 1983). The trend in precipitation series in decreasing direction at Ilgaz station began in 1974. This period coincides with the arid season of 1974. Similarly, an increase in precipitation series has been observed in Cicekdagi station since 1983, which was another arid period in Turkey. Increases in precipitation were observed at Boyabat station in 1986.

The time and direction of change points of trends observed at streamflow stations are shown in Table 5. Graph of 15–03 station is presented in Fig. 10. The change point at station 15–108 started to decrease in the 264th month. This value shows April 1994 in the current series starting from 1967. This period coincides with the beginning of the increasing trend in maximum temperatures for Nevsehir station. Station 15–01 shows the change point in the 376th month, and this value shows that the decrease started in May 2008. It is thought that the Yamula Dam, which opened to operation in the area in 2005, might have affected this reduction. A decreasing trend in streamflow for 15–17

Fig. 8 Pettit test results and change year of Kayseri Station for minimum temperature data
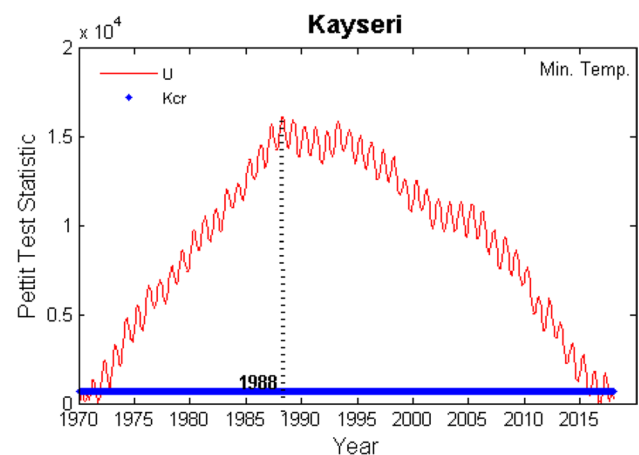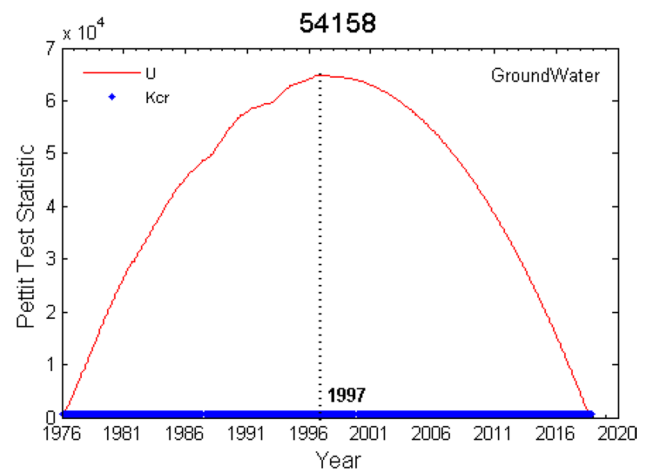

Fig. 9 Pettit test results and change year of Kastamonu station for precipitation data
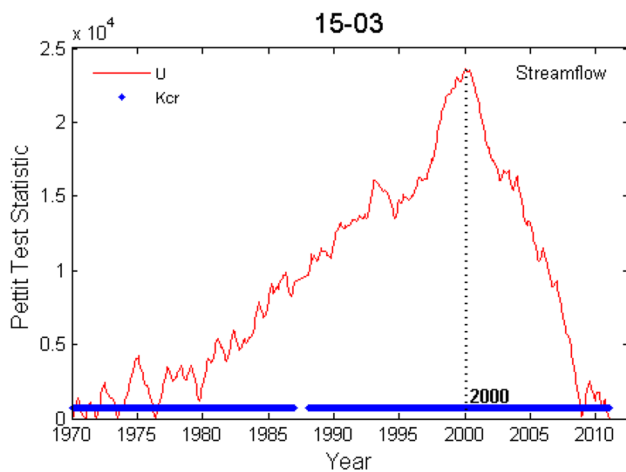
Fig. 10 Pettit test results and change year of 15–03 station for streamflow data

Fig. 11 Pettit test result and change year of 54,158 station for groundwater data

Sefaatli stations has been identified since 2001. The Uzunlu and the Gelingullu dams, which were opened to operation in 1995 and 1997, were thought to influence streamflow at these stations. Decreasing trends were observed in 15–03 Yahsıhan station and 15–182 Kesikkopru station in 2000, 15–190 Cicekdagi station in 1994, 15–208 Kaman station in 1989, and 15–242 Kirsehir station in 1993. When the surrounding dams were examined, it was determined that the decreasing trend in streamflow was at much later dates than the operational dates of the dams. However, extreme arid periods (Turkes and Erlat 2003) occurring throughout Turkey were estimated to contribute to this decreasing trend. In stations where there is no 5% significant trend in precipitation, the effect of dams on the river was thought to be the reason for the decrease in streamflow. In addition, the reason for the declining flows was thought to be the combination of drought and the impact of dams on flow regimes. The flow stations that have an increasing trend were 15–67 and 15–68 stations located in Keskin. They had different results from the other stations with increased streamflow in 1975 and 1986, respectively. Similarly, 15–152 Kirsehir station, the other station showing an increasing trend, had the change of direction in 1985. It was estimated that the reason for the increase was that the Hirfanlı dam left water from the dam in 1985, which is the dry period.

Pettit test results for groundwater levels are shown in Table 5. An increasing trend in groundwater levels were observed in all stations except for three stations. According to the Pettit test, 54,158 station had an increase at the 254th month corresponding to April 1997. Graph of 54,158 station is presented in Fig. 11. The change points for the other increasing stations are as follows: in 54,161 station in the 283rd month and 1996, 54,162 station in the 281st month and 1999, 54,160 station in the 300th month and 2001, and

54,157 station in the 99th month and 2003. One of the most important reasons for the level of increase is the droughts that occurred during that period. The dry periods between 1996 and 2001 in Turkey coincide with the change points of these stations. The beginning time of trends was in 2010 at 60,078 station, in 2012 at 54,159 and 59,669 stations, and in 2013 at 57,515 and 59,666 stations. Similarly, at A-Temirli, Budak, Yeniyapan, and 60,638 stations in 2014 and at 55,350 and 60,637 stations in 2015 are the dates when the change for the trend began. The drought began in parts of Central Anatolia in Turkey in 2012 and continued more effectively in 2013. Then, in the summer of 2013, it turned into agricultural and hydrological drought with the effect of the drought that began to reign all over Turkey. It continued its influence in 2014 (Turkes 2014). The demand for groundwater increased due to the drought. A decreasing trend was observed at three stations. These stations are 54,163, 59,667, and 55,362. The change points for these stations are 2006, 2010, and 2014, respectively. The reason for the decrease was thought to be the proliferation of the number of groundwater wells in the region during the arid periods.

4 Conclusion

Climate change and drought are critical and unhindered situations that have been felt in Turkey since the 1970s. In this study conducted in the Kizilirmak basin, which is the second-largest basin of Turkey, climate change–dependent trends in meteorological and hydrological parameters of the basin were investigated. Trend research is essential to see the extent of the change in meteorological and hydrological components of the climate change in the Kizilirmak basin. The presence of trends in the time series of

maximum temperature, minimum temperature, mean temperature, and precipitation was investigated. Also, river flows and groundwater level data were included in the study. Linear regression (LR) and non-parametric Mann−Kendall (MK), modified Mann−Kendall (Hamed−MK), and Spearman's Rho (SRHO) methods were used to detect existing trends. Pettit test was used to determine the period when the trend started. The homogeneity, autocorrelation, stationarity, and independence of the data were checked by standard normal homogeneity test, autocorrelation test, Wald−Wolfowitz's stationary test, and Von Neumann's independence test. The following conclusions were drawn based on present findings:

- As a result of the homogeneity, autocorrelation, stability, and independence tests performed for the reliability of trend analysis, a regular structure has been observed in most of the time series.
- Significant increasing trends were observed in meteorological parameters. Increasing trends were observed in maximum and minimum temperatures throughout the basin, but no significant trends were observed in mean temperatures. The proportion of stations with the increasing trend was 40% for maximum temperatures and 30% for minimum temperatures. While no trend was observed in mean temperatures, the increasing trends of maximum and minimum temperatures were seen as the expected impact of climate change. Previous studies showed temperature increases. According to the IPCC third assessment report, temperatures have increased since 1980. In the same report, the mean annual temperatures in Turkey were expected to rise between 1 and 3 °C by the year 2050 (Apak and Ubay 2007).
- In change-point analyses, the beginning of the trend at maximum and minimum temperatures coincided with the period 1993−1998. Maximum temperatures, which increased after 1993, continued to rise in recent years (Turkes and Erlat 2018). Although there are apparent differences between the regions in Turkey, a general warming trend is evident after the 1990s, especially after the Cold year in 1992 (Turkes 1996a, b).
- Significant trends observed in precipitation (20%) were in increasing direction, except for Ilgaz station. The beginning of the increasing trends was in the period 1983−1997. Droughts were encountered in Turkey between 1983 and 1997. Only Ilgaz station began to show a decreasing trend in 1974. Previous studies have shown that annual precipitation had decreasing trends in 1970s and the prolongation of dry periods has led to a decrease in rainfall in these years (Turkes 1996a, b). Besides, precipitation has increased between 0.5 and 1% in the middle and high latitudes of the northern hemisphere every decade. In contrast, in a significant part of the subtropical

land, including the Mediterranean Basin, it has decreased by approximately 3% every decade (Turkes et al. 2007).

- It was observed that the change points of meteorological parameters coincided with the droughts that occurred in the semi-arid Kizilirmak basin between 1980 and 2000 (Turkes 2003). It reinforces the foresight that increasing trends in both temperatures and precipitation were primarily due to climate change.
- Streamflow trends have been tested in 14 stations that have long-term data across the basin. Observed trends in streamflow (78%) were in decreasing direction, except for three stations. Previous studies on flow trends in Turkey have seen decreases since the 2000s. A study was conducted in 2004 in which flows were observed in 26 basins of Turkey. A significant decreasing trend has been observed in river flows in the western and southeastern regions. Furthermore, the study stated that decreasing trends may be the effect of climatic processes and climate parameters influenced by temperature increase, rather than climate change (Bayazıt et al. 2002, Kahya and Kalaycı 2004).
- Although the streamflow trends observed at several of stations were consistent with temperature and rainfall data, no significant relationships were determined between meteorological parameters and flows. Streamflow trends were thought to be caused more by environmental and climatic impacts than by meteorological impacts. The most important of the environmental impacts in terms of flows are the dams built on the Kizilirmak river. It is estimated that the impact of dams on the river regime could cause a decrease in flows. However, it is estimated that the decreasing trends that occur at stations that are not in the dam impact area were affected by the arid periods.
- Observed trends in groundwater levels were in increasing direction, except for three stations. Increasing trends were largely (85%) observed in groundwater levels. Fifteen stations out of 20 stations showed 100% trend. Trend tests (MK, Hamed−MK, SRHO, and LR) yielded consistent outcomes for trends in groundwater levels. No relationship was observed between groundwater levels and meteorological parameters, which would cause trends. Changes in groundwater levels were estimated to have resulted from increased consumption in recent years. Water consumption of urban networks and farmlands, irrigated with groundwater, is thought to have caused an increase in groundwater levels, especially in the period following the arid years. It coincides with arid periods when there are increases in many groundwater wells. According to the change point analysis, the dates when the increase in groundwater levels began were 1996, 1999, and 2001. The trends in these wells drilled in 1970s coincide with the 1990−2001 droughts observed

in Turkey. The starting period of the trend for wells drilled in 2000s is the period between 2010 and 2014. Following the arid period in 2008, the agricultural and hydrological drought that occurred in 2012 is thought to have affected these increasing periods. This situation, caused by the increase of urbanization and the orientation of agricultural irrigation to groundwater sources, is accelerating the decline of water resources.

- Previous studies have predicted that climate change will result in regime irregularity in rainfall and increase temperatures (Kadioglu 1997; Turkes 1998). It is also thought that these temperature changes will have effects on streamflows and groundwater. In a country with a moderately arid climate such as Turkey, it is essential to know the effects of climate change. With this study, the trends of meteorological data were determined in the Kizilirmak basin. The flows and groundwater trends that are important in terms of water resources were also included in the study. There was no significant relationship between meteorological trends and flow and groundwater trends.

- As a result, it was estimated that the trends observed in temperature and rainfall values might have been influenced by the impacts of climate change. Similarly, significant trends have been determined in streamflow and groundwater levels. Climate change is likely to have severe consequences in drought-prone countries such as Turkey. With its different climates, it is important to examine the impacts of climate change in Turkey regionally and take the necessary measures to mitigate the potential effects of climate change.

Declarations

Ethics approval The authors paid attention to the ethical rules in the study. There is no violation of ethics.

Consent for publication If this study is accepted, it can be published in the *Theoretical and Applied Climatology* journal.

Conflicts of interest The authors declare no competing interests.

References

Akinsanola A, Ogunjobi K (2017) Recent homogeneity analysis and long-term spatio-temporal rainfall trends in Nigeria. Theoret Appl Climatol 128(1–2):275–289

Alexandersson H (1986) A homogeneity test applied to precipitation data. J Climatol 6(6):661–675

Apak G, Ubay B (2007) First National Declaration On Climate Change In Turkey. Ankara, www.meteor.gov.tr. Accessed 31 March 2015

Atik K et al (2007) Artificial neural networks modeling of meteorological data. KSU J Sci Eng 10(1):2007

Bahadir M (2011) A statistical analysis of the flow changes of Kizilirmak River. J Turk Stud 6:1339–1356

Bayazıt M et al (2002) Trend analysis in Turkish rivers. Turk Eng News 420:4–6

Bayer Altin T, Barak B (2017) Trends and changes in tropical and summer days at the Adana Sub-Region of the Mediterranean Region, Southern Turkey. Atmos Res 196:182–199

Becker S et al (2006) Spatiotemporal analysis of precipitation trends in the Yangtze River catchment. Stoch Env Res Risk Assess 20(6):435–444

Bhend J, von Storch H (2008) Consistency of observed winter precipitation trends in northern Europe with regional climate change projections. Clim Dyn 31(1):17–28

Buishand TA et al (2013) Homogeneity of precipitation series in the Netherlands and their trends in the past century. Int J Climatol 33(4):815–833

Caloiero T et al (2018) Application of the innovative trend analysis method for the trend analysis of rainfall anomalies in southern Italy. Water Resour Manage 32(15):4971–4983

Capparelli V et al (2013) A spatiotemporal analysis of US station temperature trends over the last century. J Geophys Res Atmos 118(14):7427–7434

Ceylan A, Komuscu AU (2007) Many years and seasonal distributions of meteorological natural disasters. Clim Chang Environ 1(1):1–10

Change ICJMM, Chen Z, Marquis M, Averyt KB, Tignor M et al (2007) The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the intergovernmental Panel on Climate Change. Change, IPCC Climate 996: 2007

Change IPoC (2014) Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 151. IPCC

Chen H et al (2007) Historical temporal trends of hydro-climatic variables and runoff response to climate variability and their relevance in water resource management in the Hanjiang basin. J Hydrol 344(3–4):171–184

Cigizoglu H et al (2005) Trends in the maximum, mean, and low flows of Turkish rivers. J Hydrometeorol 6(3):280–290

Croitoru A-E, Minea I (2015) The impact of climate changes on rivers discharge in Eastern Romania. Theoret Appl Climatol 120(3):563–573

Crosbie RS et al (2010) Modelling climate-change impacts on groundwater recharge in the Murray-Darling Basin, Australia. Hydrogeol J 18(7):1639–1656

da Silva RM et al (2015) Rainfall and river flow trends using Mann-Kendall and Sen's slope estimator statistical tests in the Cobres River basin. Nat Hazards 77(2):1205–1221

Dai ZJ et al (2010) Assessment of extreme drought and human interference on baseflow of the Yangtze River. Hydrol Process Int J 24(6):749–757

Dogan M et al (2015) Trend direction changes of Turkish temperature series in the first half of 1990s. Theor Appl Climatol 121(1):23–39

Ducré-Robitaille JF et al (2003) Comparison of techniques for detection of discontinuities in temperature series. Int J Climatol J R Meteorol Soc 23(9):1087–1101

Emadi S et al (2016) Characteristics and multifractal properties of daily streamflow in a semiarid environment. Iran J Sci Technol Trans Civ Eng 40(1):49–58

Estévez J et al (2018) Introduction to the special issue on "hydro-meteorological time series analysis and their relation to climate change." Acta Geophys 66(3):317–318

Fallah-Ghalhari G et al (2019) Impacts of climate changes on the maximum and minimum temperature in Iran. Theor Appl Climatol 138(3–4):1539–1562

Forestry ROTMOAA (2016) The Effect Of Clımate Change On Water Resources Project Project Final Report

Franzke C (2010) Long-range dependence and climate noise characteristics of Antarctic temperature data. J Clim 23(22):6074–6081

Franzke CL (2015) Local trend disparities of European minimum and maximum temperature extremes. Geophys Res Lett 42(15):6479–6484

Ge G, Chaoying H (2001) Climate change and its impact on water resources in North China. Adv Atmos Sci 18(5):718–732

Gönençgil B, Gülten İÇEL (2010) Türkiye'nin Doğu Akdeniz kıyılarında yıllık toplam yağışlarda görülen değişimler (1975–2006). Türk Coğrafya Dergisi 55:1–12

Goyal S et al (2010) Variability analysis of groundwater levels—AGIS-based case study. J Indian Soc Remote Sens 38(2):355–364

Guner Bacanli U, Tugrul AT (2016) A climate impact of dam lake and Recep Yazicioglu Gokpinar dam lake sample. Pamukkale Univ J Eng Sci 22(3):154–159

Guo J et al (2012) Prediction of variability of precipitation in the Yangtze River Basin under the climate change conditions based on automated statistical downscaling. Stoch Environ Res Risk Assess 26(2):157–176

Hadi SJ, Tombul M (2018) Long-term spatiotemporal trend analysis of precipitation and temperature over Turkey. Meteorol Appl 25(3):445–455

Hamed KH, Rao AR (1998) A modified Mann-Kendall trend test for autocorrelated data. J Hydrol 204(1–4):182–196

Helsel DR, Hirsch RM (1992) Statistical methods in water resources (Vol. 49). Elsevier

Helsel DR, Hirsch RM (2002) Statistical methods in water resources. US Geological Survey Reston, VA

Hereher ME (2016) Recent trends of temperature and precipitation proxies in Saudi Arabia: implications for climate change. Arab J Geosci 9(11):575

Howard KEN, Griffith A (2009) Can the impacts of climate change on groundwater resources be studied without the use of transient models? Hydrol Sci J 54(4):754–764

Irannezhad M et al (2015) Interannual variations and trends in surface air temperature in Finland in relation to atmospheric circulation patterns, 1961–2011. Int J Climatol 35(10):3078–3092

Islam A et al (2012) Streamflow response to climate change in the Brahmani River Basin, India. Water Resour Manag 26(6):1409–1424

Javadinejad S et al (2019) The impact of future climate change and human activities on hydro-climatological drought, analysis and projections: using CMIP5 climate model simulations. Water Conserv Sci Eng: 1−18

Jiang R et al (2017) Spatiotemporal variability of extreme precipitation in Shaanxi province under climate change. Theor Appl Climatol 130(3):831–845

Kadioglu M (1997) Trends in surface air temperature data over Turkey. Int J Climatol J R Meteorol Soc 17(5):511–520

Kahya E, Kalaycı S (2004) Trend analysis of streamflow in Turkey. J Hydrol 289(1–4):128–144

Kazemzadeh M, Malekian A (2018) Changeability evaluation of hydro-climate variables in Western Caspian Sea region, Iran. Environ Earth Sci 77(4):120

Kendall DG (1948) On the generalized "birth-and-death" process. Ann Math Stat 19(1):1–15

Khan MHR et al (2019) Detection of changes and trends in climatic variables in Bangladesh during 1988–2017. Heliyon 5(3):e01268

Kirshen P et al (2005) Global analysis of changes in water supply yields and costs under climate change: a case study in China. Clim Change 68(3):303–330

Kizilelma Y et al (2015) Trend analyses of temperature and precipitations in Central Anatolia. Turk Geogr Rev 64:1–10

Kundzewicz ZW, Robson AJ (2004) Change detection in hydrological records—a review of the methodology/revue méthodologique de la détection de changements dans les chroniques hydrologiques. Hydrol Sci J 49(1):7–19

Liu L et al (2012) Hydro-climatological drought analyses and projections using meteorological and hydrological drought indices: a case study in Blue River Basin, Oklahoma. Water Resour Manag 26(10):2761–2779

Lu G et al (2008) Real-time flood forecast and flood alert map over the Huaihe River Basin in China using a coupled hydro-meteorological modeling system. Sci China Ser E Technol Sci 51(7):1049–1063

Manley G (1946) Temperature trend in lancashire, 175–1945. Q J R Meteorol Soc 72(311):1–31

Mann HB (1945) Nonparametric tests against trend. Econometrica: Journal of the Econometric Society 245–259

Mishra AK, Rafiq M (2017) Analyzing snowfall variability over two locations in Kashmir, India in the context of warming climate. Dyn Atmos Oceans 79:1–9

Mishra B et al (2014) Analysis of climatic variability and snow cover in the Kaligandaki River Basin, Himalaya, Nepal. Theor Appl Climatol 116(3):681–694

Nashwan MS, Shahid S (2019) Spatial distribution of unidirectional trends in climate and weather extremes in Nile river basin. Theor Appl Climatol 137(1):1181–1199

Nikzad Tehrani E et al (2019) Trend analysis of hydro-climatic variables in the north of Iran. Theor Appl Climatol 136(1):85–97

Nyakundi RM et al (2015) Impact of rainfall variability on groundwater levels in Ruiru municipality, Kenya. Afr J Sci Technol Innov Dev 7(5):329–335

Nyenje PM, Batelaan O (2009) Estimating the effects of climate change on groundwater recharge and baseflow in the upper Ssezibwa catchment, Uganda. Hydrol Sci J 54(4):713–726

Obot NI, Chendo MAC, Udo SO, Ewona IO (2010) Evaluation of rainfall trends in Nigeria for 30 years (1978–2007). Int J Phys Sci 5(14):2217–2222

Palamalai S, Kumar KK, Maity B (2020) Testing the random walk hypothesis for leading cryptocurrencies. Borsa Istanbul Review

Pettitt AN (1979) A non-parametric approach to the change-point problem. J Roy Stat Soc Ser C (Appl Stat) 28(2):126–135

Pratoomchai W et al (2015) Sharing of people's perceptions of past and future hydro-meteorological changes in the groundwater use area. Water Resour Manage 29(10):3807–3821

Rafiq M, Mishra A (2016) Investigating changes in Himalayan glacier in warming environment: a case study of Kolahoi glacier. Environ Earth Sci 75(23):1469

Rahaman KM et al (2016) Modeling on climate induced drought of north-western region, Bangladesh. Model Earth Syst Environ 2(1):45

Rawat PK (2012) Impacts of climate change and hydrological hazards on monsoon crop patterns in the Lesser Himalaya: a watershed based study. Int J Disaster Risk Sci 3(2):98–112

Rosenberg NJ et al (1999) Possible impacts of global warming on the hydrology of the Ogallala aquifer region. Clim Chang 42(4):677–692

Sa'adi Z et al (2019) Trends analysis of rainfall and rainfall extremes in Sarawak, Malaysia using modified Mann-Kendall test. Meteorol Atmos Phys 131(3):263–277

Salem GSA et al (2017) Impact of temperature changes on groundwater levels and irrigation costs in a groundwater-dependent agricultural region in Northwest Bangladesh. Hydrol Res Lett 11(1):85–91

Satish Kumar K, Venkata Rathnam E (2019) Analysis and prediction of groundwater level trends using four variations of Mann Kendall tests and ARIMA modelling. J Geol Soc India 94(3):281–289

Solomon S et al (2007) Technical Summary, Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 19−91

Steinwand A et al (2006) Water balance for Great Basin phreatophytes derived from eddy covariance, soil water, and water table measurements. J Hydrol 329(3–4):595–605

Sun J et al (2019) Analysis of spatial and temporal evolution of hydrological and meteorological elements in Nenjiang River basin, China. Theor Appl Climatol 137(1):941–961

Sutgibi S (2015) Variations and trends in temperature, precipitation and stream-flow series in the Buyuk Menderes River Basin. Marmara Geogr Rev (31):398−414

Szwed M (2019) Variability of precipitation in Poland under climate change. Theoret Appl Climatol 135(3):1003–1015

Taylor RG et al (2013) Ground water and climate change. Nat Clim Chang 3(4):322–329

Todmal RS et al (2018) Hydro-meteorological and agricultural trends in water-scarce Karha Basin, western India: current and future scenario. Arab J Geosci 11(11):254

Trajkovic S, Kolakovic S (2009) Wind-adjusted Turc equation for estimating reference evapotranspiration at humid European locations. Hydrol Res 40(1):45–52

Turkes M (1996a) Meteorological drought in Turkey: a historical perspective, 1930–93. Drought Network News Univ Nebraska 8:17–21

Turkes M (1996b) Spatial and temporal analysis of annual rainfall variations in Turkey. Int J Climatol J R Meteorol Soc 16(9):1057–1076

Turkes M (1998) Influence of geopotential heights, cyclone frequency and southern oscillation on rainfall variations in Turkey. Int J Climatol J R Meteorol Soc 18(6):649–680

Turkes M (2003) Spatial and temporal variations in precipitation and aridity index series of Turkey. Springer, Mediterranean Climate, pp 181–213

Turkes M (2014) Drought and desertification events of climate change and its significance in Turkey 2013−2014 (?) of drought synoptic climatological/meteorological and atmospheric connections. Hydropolitic Academy Climate Change and Drought Studies, Ankara: 1−12

Turkes M, Erlat E (2003) Precipitation changes and variability in Turkey linked to the North Atlantic Oscillation during the period 1930–2000. Int J Climatol J R Meteorol Soc 23(14):1771–1796

Turkes M, Erlat E (2018) Variability and trends in record air temperature events of Turkey and their associations with atmospheric oscillations and anomalous circulation patterns. Int J Climatol 38(14):5182–5204

Turkes M, Tatli H (2011) Use of the spectral clustering to determine coherent precipitation regions in Turkey for the period 1929–2007. Int J Climatol 31(14):2055–2067

Turkes M et al (2007) Spatial and temporal analysis of the changes and trends in precipitation total and intensity series of Turkey. Turk J Geogr Sci 5:57–73

Van Loon A, Laaha G (2015) Hydrological drought severity explained by climate and catchment characteristics. J Hydrol 526:3–14

Von Neumann J (1941) Distribution of the ratio of the mean square successive difference to the variance. Ann Math Stat 12(4):367–395

Vu MT et al (2015) Ensemble climate projection for hydro-meteorological drought over a river basin in Central Highland, Vietnam. KSCE J Civ Eng 19(2):427–433

Wang R, Li C (2016) Spatiotemporal analysis of precipitation trends during 1961–2010 in Hubei province, central China. Theor Appl Climatol 124(1–2):385–399

Wang X et al (2014) Trend and extreme occurrence of precipitation in a mid-latitude Eurasian steppe watershed at various time scales. Hydrol Process 28(22):5547–5560

Wang X-J et al (2016) Impact of climate change on regional irrigation water demand in Baojixia irrigation district of China. Mitig Adapt Strat Glob Chang 21(2):233–247

Yenigün K, Gümüş V, Bulut H (2008, August) Trends in streamflow of the Euphrates basin, Turkey. In: Proceedings of the Institution of Civil Engineers-Water Management (Vol. 161, No. 4). Thomas Telford Ltd, pp 189–198

Zamani R et al (2017) Streamflow trend analysis by considering autocorrelation structure, long-term persistence, and Hurst coefficient in a semi-arid region of Iran. Theor Appl Climatol 129(1):33–45

Zarenistanak M et al (2015) Trends and projections of temperature, precipitation, and snow cover during snow cover-observed period over southwestern Iran. Theor Appl Climatol 122(3–4):421–440

Zeleňáková M et al (2016) Monthly trends of precipitation in gauging stations in Slovakia. Procedia Eng 162:106–111

Zhao J et al (2019) The evolvement mechanism of hydro-meteorological elements under climate change and the interaction impacts in Xin'anjiang Basin, China. Stoch Environ Res Risk Assess 33(4):1159–1173