



Meteorological drought monitoring in Kızılırmak Basin, Türkiye

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Abstract

Drought, a major phenomenon impacting water resources, viability, sustainability, and the economy, has been one of the most important hydrological concerns. In the literature, it has been classified into four groups that are meteorological, agricultural, hydrological, and socio-economic. Meteorological drought expresses the precipitation deficits when they are significantly below those recorded normal times. In this study, using the Standard Precipitation Index (SPI) and mean monthly precipitation records of 17 stations which have been obtained from the General Directorate of Meteorology of Türkiye, a drought monitoring analysis has been conducted for Kızılırmak Basin, which is the second largest water basin of the country and water source of many provinces allowing for the time scales of 1, 3, 6, 9, 12, and 24 months considering the cases of “dry” ($SPI \leq -1.5$) and “wet” ($SPI \geq 1.5$). To detect the possible trends in two categories of Severe and Extreme Drought, SED ($SPI \leq -1.5$), and Severe and Extreme Wet, SEW ($SPI \geq 1.5$) of all time scales, a developed form of innovative trend analysis (ITA) is performed by adding two vertical lines. In addition, a traditional the Mann–Kendall test is applied to the SPI series. The findings indicate that dry occurrences tend to outnumber wet occurrences across various time scales. Analysis reveals that a significant majority of results across all time scales exhibit a consistent trend (89%), with a notable increase in the SEW category (62.74%) and a decrease in the SED category (60.78%). Mann–Kendall analysis demonstrates that 67% of the observed trends show a decrease, while 33% show an increase across all time scales.

Keywords Drought · SPI · Mann–Kendall · ITA · Kızılırmak · Türkiye

Introduction

Drought is a natural hazard that is still an attraction of humanity, since it is directly a subject matter of water presence in any part of the world. Usually, drought as a term is defined as the precipitation levels that are below the normal recorded levels. To understand its nature, it is needed to recall some properties of this serious phenomenon from the literature. Droughts are complex events (Shiau and Modarres 2009), the least understood disasters (Kao and Govindaraju 2010), recurrent events with more harmful effects (Ullah et al. 2023), slow evolution process that takes place with

long duration and common impact (Ahmadi and Moradkhani 2019; Sun et al. 2023), most serious and extensive natural catastrophe (Zhou et al. 2023). Besides its properties drought has been classified into four groups meteorological, agricultural, hydrological, and socio-economic (Kheyruri et al. 2023; Deger et al. 2023; Yang et al. 2023; Yuce et al. 2023; Niaz et al. 2023). Meteorological droughts describe precipitation deficits that are significantly below average levels (Akturk et al. 2022).

There are several proposed drought indices for detecting and predicting drought events (Yuce and Esit 2021). Niemeyer (2008) has reported almost 150 indices. However, the Standard Precipitation Index (SPI) that has been proposed by (McKee et al. 1993; McKee 1995) is the most commonly utilized (Akturk et al. 2022). Besides, the World Meteorological Organization recommends the SPI for tracking meteorological droughts (Hayes et al. 2011). Esit and Yuce (2023) have stated that because of its simplicity in the determination of multiple time scales, SPI is widely accepted all over the world.

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Trend analysis means that the techniques needed to put forth the behavior of the data. From this point of view, besides analyzing the drought events by indices, analyzing the behavior of these events is also important for water resources management and operation (Simsek 2021). The Mann–Kendall test (Mann 1945; Kendall 1975) is of widespread practice for the investigation of trends (Alam et al. 2023). The method has been employed by several researchers (Ashraf et al. 2023; Suhana et al. 2023; Dufera et al. 2023; Thi et al. 2023) in the detection of trends. Innovative trend analysis (ITA) which has been developed and assessed by Şen (2012) and Şen (2017) is the method employed by many researchers (Alam et al. 2023; Achite et al. 2023; Yuce et al. 2023; Soylu Pekpostalci et al. 2023) for detecting the behavior of different drought types. Besides it has been stated by Ahmed et al. (2022) that ITA is utilized for analyzing the trends of many river basins of the world. It has been stated by Şen (2012) that, unlike the well-known trend methods, ITA does not have considerations such as independent structure of the time series, normality of distribution, and length of data. Mallick et al. (2021) reported that ITA can overcome all of the above limitations.

Previous literature studies have shown that there has been a huge interest in drought evaluation and investigation from researchers in the world and Türkiye. For example, in the world, Bhunia et al. (2020) have performed a meteorological drought study for Purulia, Bankura, Midnapore districts in India using SPI and trend of SPI series has been evaluated by Mann–Kendall test, Achite et al. (2023) have made a study about meteorological and hydrological drought in Wadi Ouahrane Basin, Algeria using SPI and Standardized Runoff Index (SRI) for 1, 3, 6, 9, 12, and 24 months, and then, they also test these series by Theil–Sen estimator, the Mann–Kendall test, the Modified Mann–Kendall test and the Innovative Trend Analysis, Muse et al. (2023) have made meteorological drought assessment and Trend analysis study for Puntland Region in Somalia using six drought indices of the normal Standardized Precipitation Index (normal-SPI), the log normal Standardized Precipitation Index (log-SPI), the Standardized Precipitation Index using the gamma distribution (Gamma-SPI), the Percent of Normal Index (PNI), the Discrepancy Precipitation Index (DPI), and the Deciles Index (DI) and trends in precipitation and temperature series are evaluated the Mann–Kendall test, Spearman’s rho test, Sen trend test, Pettitt test, and Thiel–Sen method. Ullah et al. (2023) have performed a study to evaluate spatiotemporal characteristics of meteorological drought and trends. They used the Standardized Precipitation Evapotranspiration Index (SPEI) for annual and seasonal timescales and Sen’s Slope estimator and modified the Mann–Kendall test for the estimation of trends. When it comes to Türkiye; Dabanlı et al. (2017) have analyzed the droughts over Türkiye using SPI and data from 250 station records, Gumus and Algin (2017) have made a study for meteorological and

hydrological drought analysis for Seyhan and Ceyhan Basins using SPI and Streamflow Drought Index (SDI) for the time scales of 3, 6 and 12 months, Yuce and Esit (2021) have made drought monitoring study for Ceyhan Basin using 10 indices including SPI for the time scales of 3, 6, 9 and 12 months. Gumus et al. (2021) have performed a spatio-temporal trend analysis of droughts for GAP Region that includes south part of Euphrates and Tigris Basins in Türkiye using SPI for the time scales of 3, 6, and 12 months and they used Mann–Kendall and Mann–Kendall Rank correlation tests for determining the monotonic trends of drought indices and its year of start, Sen’s slope method have been utilized for linear slope of the trends, Katipoğlu et al. (2021) have made a spatio-temporal assessment of meteorological and hydrological droughts in the Euphrates Basin, Turkey using five indices including SPI for the time scales of 1, 3 and 12 months, Topçu et al. (2022) have performed a meteorological drought analyses by Aggregate Drought Index (ADI) for Mediterranean, Seyhan, Ceyhan and Asi Basins, Soylu Pekpostalci et al. (2023) have made a study about spatiotemporal variations in meteorological drought for Mediterranean Region of Turkey using SPI-3, SPI-6 and SPI-12, fuzzy c-means and ITA, Simsek et al. (2023) have made a meteorological drought analysis for Black Sea Region using SPI and Reconnaissance Drought Index (RDI) methods at 3-, 6-, and 12-month time scales. Particularly for the Kızılırmak Basin. Akturk et al. (2022) have made a study for meteorological drought analysis using SPI for the time scales of 1, 3, 6, 12, and 24 months, Deger et al. (2023) have made hydrological drought assessment considering SDI for the time scales of 1, 3, 6, 9, and 12 months and ITA has been utilized for investigation of trends considering dry and wet conditions as well.

This study aims to perform a general drought assessment of the Kızılırmak Basin Türkiye using monthly mean precipitation records of 17 stations. To achieve this (i) monthly mean precipitation records during different time ranges have been obtained from the General Directorate of Meteorology of Türkiye (MGM), (ii) the time series of drought events have been produced by SPI for the time scales of 1, 3, 6, 9, 12, and 24 months, (iii) Mann–Kendall test and ITA which is developed by adding two vertical lines have been applied to series. The novelty of the study comes from analyzing drought trends by ITA as graphically by adding vertical lines to -1.5 and 1.5 points for the Kızılırmak Basin of Türkiye. The results of this study are expected to be beneficial for drought action plans and water resources management.

Methodology

Standard Precipitation Index (SPI)

SPI was developed by McKee et al. (1993) and McKee (1995) and it has been stated by Suhana et al. (2023) that

because SPI needs only monthly precipitation data it is simple to apply. SPI enables researchers to track droughts in different time scales. For the different time scales, for the calculation of SPI, the gamma distribution is applied for fitting the precipitation series (Eslamian and Jahadi 2019). The probability distribution function of the gamma distribution is computed from the following equation:

$$g(x) = \frac{1}{\beta^a \Gamma(a)} x^{a-1} e^{-\frac{x}{\beta}} \tag{1}$$

where $\Gamma(a)$ is the gamma function and it is computed by Edwards (1997):

$$\Gamma(a) = \int_0^\infty y^{a-1} e^{-y} dy \tag{2}$$

For maximum likelihood method estimation, shape (α), scale (β) that are parameters can be calculated by Thom (1966) as follows:

$$a = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right) \tag{3}$$

$$\beta = \frac{\bar{x}}{a} \tag{4}$$

In addition, where A is determined (Thom 1966; Eşit and Yüce 2022):

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \tag{5}$$

where n is the number of rainfall records and \bar{x} is the mean of x .

Then cumulative distribution function is computed by (Thom 1966)

$$H(x) = q + (1 - q)G(x) \tag{6}$$

where q represents the probability of zero and $G(x)$ shows the cumulative distribution for the selected month and time scale. If m is shown as the number of zeros, then q can be calculated from $q = m/n$ (Thom 1966). After these calculations, $H(x)$ is converted to the standard normal variable Z which has 0 mean and 1 as variance and represents the SPI value as it is given by the following equation:

$$SPI = \frac{X_{ij} - \bar{X}_{im}}{\sigma} \tag{7}$$

where X_{ij} , \bar{X}_{im} and σ show the total monthly precipitation, the mean and standard deviation of precipitation assessed from monthly time series, respectively (Yuce and Esit 2021). Then, SPI values in a month and desired time scale are associated with a drought class based on its value according to drought classifications in Table 1.

Table 1 Dry and wet classifications

SPI values	Dry/wet classification
≥ 2	Extremely wet
1.50~1.99	very wet
1.00~1.49	Moderately wet
0.99~0	Normal
0~-0.99	Normal dry
-1.00~-1.49	Moderately dry
-1.50~-1.99	Severe dry
≤ -2	Extreme dry

Drought trend analysis

Mann–Kendall test (M–K test)

As a rank-based non-parametric test (Mann 1945; Kendall 1975; Ashraf et al. 2023), applying the Mann–Kendall test is popular in the analysis of hydrological and meteorological data. The following equation is employed to determine S which is the statistics of the Mann–Kendall test (Berhail et al. 2022):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n sgn(x_j - x_k) \tag{8}$$

where n indicates the data length and x_j and x_k are data points are in the years of j and k ($j > k$) and function of $sgn(x_j - x_k)$ considers following conditions in Eq. 9.

$$sgn(x_j - x_k) = \begin{cases} 1 & (x_j - x_k) > 0 \\ 0 & (x_j - x_k) = 0 \\ -1 & (x_j - x_k) < 0 \end{cases} \tag{9}$$

The variance of S in case there may be ties can be calculated from Eq. 10.

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_i t_i(t_i-1)(2t_i+5)}{18} \tag{10}$$

where r is the number of groups of tied ranks, each with t_i tied observations.

Finally, the Z value of the test is calculated from Eq. 11.

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \tag{11}$$

The sign of Z value states the case of the trend. If Z is negative a decreasing trend exists, while an increasing trend is observed when the Z value is positive. Both

interpretations can be thought of as having a significant trend and the null hypothesis (H_0) is rejected if and when the data's p value is less than the significance level (in this case, $5\% = 0.05$). The trend is not significant if the p value is higher than the level of significance, and H_0 is accepted.

Innovative trend analysis (ITA)

As proposed by Şen (2012), ITA has been utilized due to its simplicity and efficiency (Elouissi et al. 2021; Yuce et al. 2023). In addition to this, ITA enables researchers to investigate trends graphically. According to Şen (2012) and Esit (2022), in order to apply this method to a dataset, (i) the whole data is divided into two equal parts which must be ranged in ascending order, (ii) the First part is plotted in the x -axis and the second part is in the y -axis, (iii) 1:1 line (45°) which is no trend line is drawn as it is shown in Fig. 1. Figure 1a shows any point below the 1:1 line describes a decreasing trend while any point above the 1:1 line shows an increasing trend case. Since ITA provides a chance to evaluate trends graphically, as a novelty ITA has been developed by adding two vertical lines to ($SPI \leq -1.5$) which is a combination of Severe and Extreme Drought classes (SED) and ($SPI \geq 1.5$) that is a combination of Severe and Extreme Wet classes (SEW) as it has been visualized in Fig. 1b. Dividing the ITA graph by certain lines also provides information regarding monotonic and non-monotonic cases of trend behaviors of dry and wet classes.

Study area

The Kızılırmak Basin which is situated in the coordinates of 32.80° – 38.35° East longitudes and 35° – 41.75° North latitudes has a surface area of 82,082 km ($\sim 10\%$ of Türkiye's surface area) (Akturk et al. 2022). The basin area covers a wide area that includes either all or a part of Sivas, Kayseri, Sinop, Samsun, Kastamonu, Aksaray, Niğde, Tokat, Yozgat, Amasya, Erzincan, Ankara, Konya, Çankırı, Nevşehir, Kırşehir, Çorum, Kırıkkale provinces of Türkiye. The Kızılırmak River which has a length of 1355 km is the longest and spills its water to the Black Sea. It has been reported by Khorrami et al. (2023a) and Khorrami et al. (2023b) that the mean annual precipitation and temperature are about 461 mm and 10.5°C , respectively, and while in internal parts, semi-arid climatic type is seen, and the coastal regions near the Black Sea have humid-to-semi-humid climatic conditions. In this study, precipitation data from 17 stations have been taken from the General Directorate of Meteorology of Türkiye. The details of these stations are given in Table 2, and their locations are shown in Fig. 2.

Results and discussion

To evaluate meteorological drought in the Kızılırmak basin, SPI values for the different time scales (1, 3, 6, 9, 12, and 24) are assessed and trend analysis is performed on SPI values through the application of the ITA and Mann–Kendall approaches. For ITA graphical analysis, two categories are

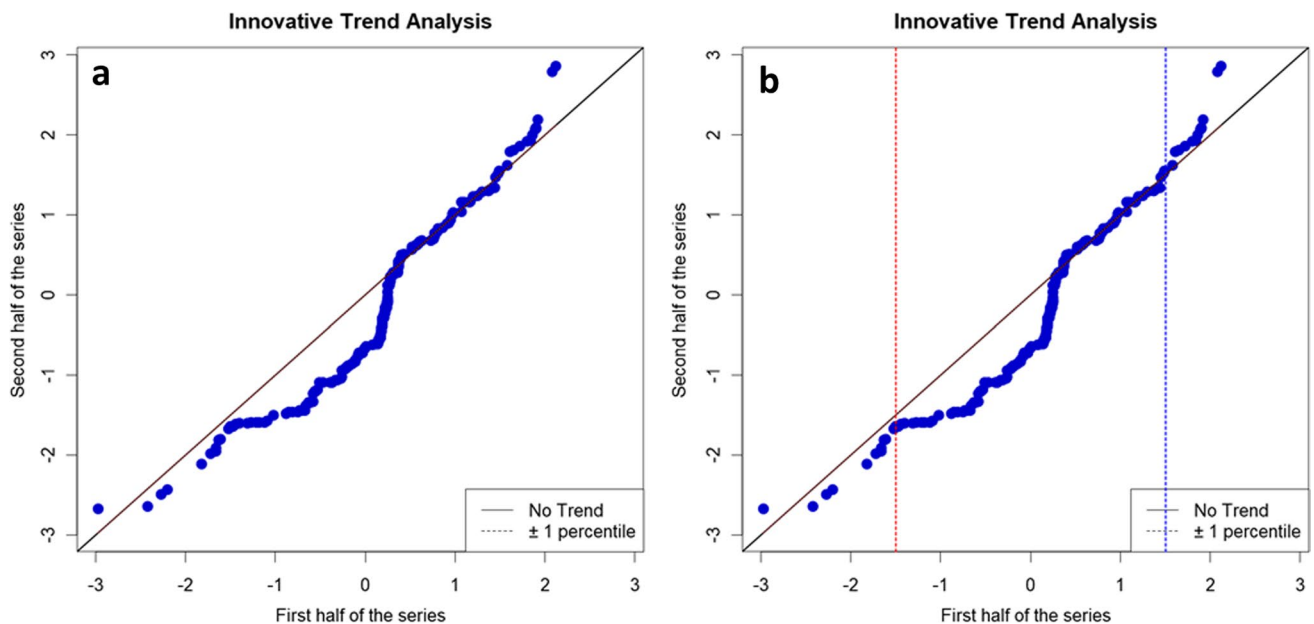


Fig. 1 Graphical representation of **a** ITA by Şen (2012) and **b** Developed ITA

Table 2 Properties and locations of selected stations

Station	Station name	Latitude	Longitude	Elevation (m)	Date interval	Max. Rainfall (mm)	Average rainfall (mm)
17074	Kastamonu	41.371	33.775	800	1930–2021	278.7	40.1
17135	Kirikkale	39.843	33.518	751	1963–2021	172.7	32.2
17137	Elmadag	39.798	32.971	1796	2005–2021	257.8	39.8
17160	Kirsehir	39.163	34.156	1007	1939–2021	161.4	32.3
17193	Nevsehir	38.616	34.702	1260	1959–2021	148.8	34.9
17196	Kayseri	38.687	35.500	1094	1939–2021	164.7	32.3
17618	Devrekani	41.599	33.834	1050	1977–2021	199.0	45.0
17620	Boyabat	41.463	34.785	350	2005–2021	141.2	32.6
17647	Yaprakli	40.758	33.772	1253	2005–2021	152.6	37.2
17648	İlgaz	40.915	33.625	885	1969–2021	216.6	39.5
17650	Tosya	41.013	34.036	870	1959–2021	171.7	39.5
17729	Bala	39.554	33.108	1248	2005–2021	128.6	29.7
17732	Cicekdagi	39.606	34.423	900	1971–2021	171.1	29.0
17756	Kaman	39.365	33.706	1075	1966–2021	253.6	38.6
17758	Mucur	39.061	34.341	1097	2005–2021	165.2	30.3
17833	Avanos	38.722	34.856	950	1986–2021	115.7	25.2
17836	Develi	38.374	35.479	1200	1965–2021	159.6	30.6

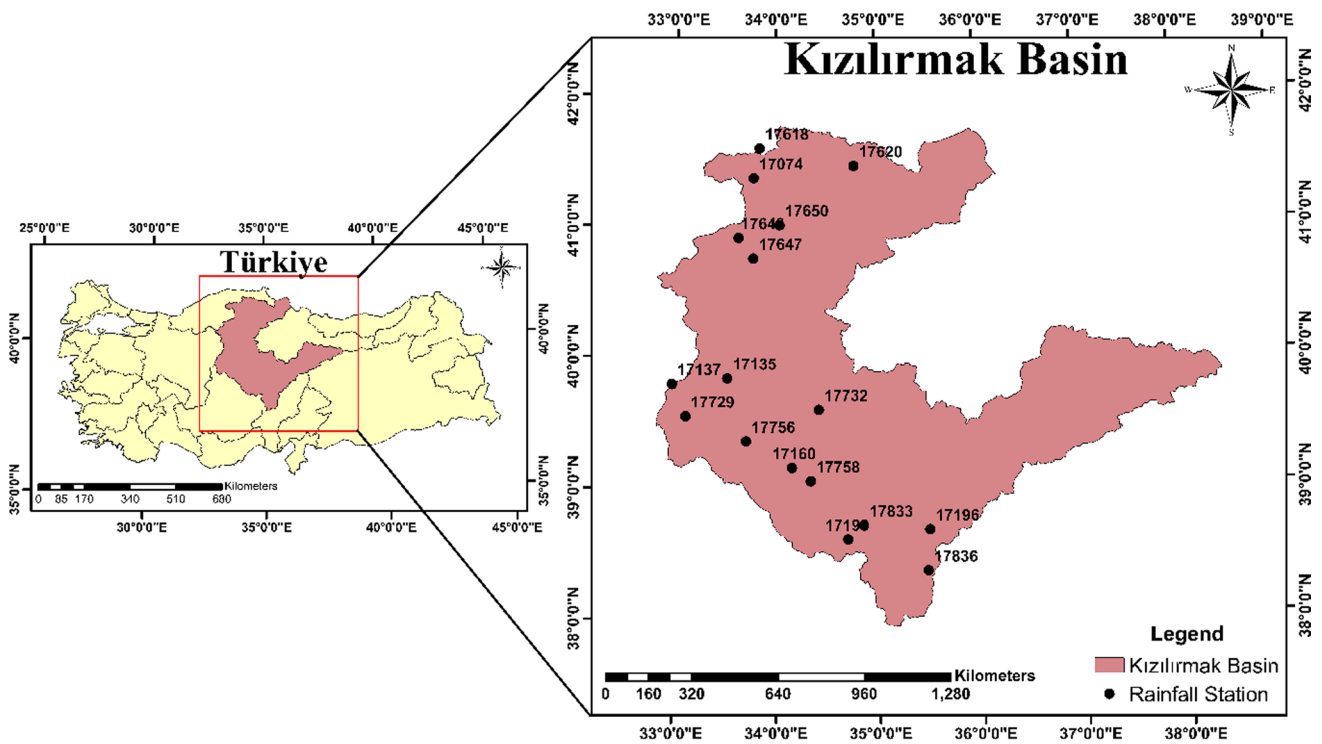


Fig. 2 Illustration of Kızılırmak Basin and selected rainfall stations

determined: wet and dry categories. The wet category is represented by $SPI \geq 1.5$ whereas the dry category is represented by $SPI \leq -1.5$. Numerical inspection is employed to detect trend types in the Mann–Kendall method.

Assessment of meteorological drought in Kızılırmak basin

SPI values are obtained for 1-, 3-, 6-, 9-, 12-, and 24-time scales for meteorological drought analysis of the Kızılırmak basin. Percentages of frequencies are determined by:

$f = \frac{n}{N}$, where n is the number of months in each category and N represents total months (See Appendix 1).

Figure 3 shows the comparison between the two categories using SPI-1, ($N = 826 \text{ years} \times 12 \text{ months/year} = 9912 \text{ months}$; 100%). It is obvious that the number of months with dry conditions (707 months or 7.1%) is higher than those with wet conditions (573 months or 5.8%). The difference between the two categories in percentage is 1.3%. For dry situations, frequencies (the number of months) fluctuate between a minimum of 11 months (station 17758) and a maximum of 77 months (station 17074). In contrast, the number of months showing wet conditions is between 9 months (station 17729) and 68 months (station 17196).

Using the SPI-3-time scale shown in Fig. 3, the first 2 months for each station are not counted so the total frequency (total number of months for 17 stations) is 9878 months ($N = 9912 - 2 \times 17 = 9878 \text{ months}$; 100%), the months representing severe or extreme dry situations (699 months or 7.1%) are still higher than those showing severe or extreme wet conditions (564 months or 5.7%). Interestingly, the difference between the two conditions is strongly closer to SPI-1 results (1.4% and 1.3%, respectively). The number of dry months outperforms those of wet months except for stations: 17137 (12 dry months against 15 wet months), 17196 (55 dry months against 64 wet months), and 17647 (12 dry months against 14 wet months). The quantity of dry months varies between a minimum of 12 months (stations 17137, 17647, and 17758) and a maximum of 73 months (station 17160) whereas for wet conditions SPI-3 frequency ranges between 3 and 64 months (station 17620 and 17196), respectively.

Using SPI-6, the percentage dissimilarity between dry and wet frequencies remains slightly the same as SPI-1 and SPI-3. The number of months with severe or extremely wet conditions (553 months or 5.6%) is smaller than those with severe or extremely dry conditions (670 months or 6.8%). All stations indicated dry conditions (dry frequencies are more than wet frequencies), except for stations: 17647 (11 against 12 wet months), 17648 (30 against 37 wet months or 4.2% against 6.3%), and 17729 (9 against 10 wet months). Over the basin, the minimum and maximum numbers of

dry months have been observed as 9 and 76 months, respectively, while wet has been noted with 4 months as minimum and 58 months as maximum.

For dry and wet conditions for SPI-9 values, 8 months for each station are not counted, so the total frequency is 9824 months ($N = 9912 - 8 \times 17 = 9824 \text{ months}$; 100%). The difference, in percentage, between categories of dry frequencies (660 months or 6.7%) and categories of wet frequencies (559 months or 5.7%), becomes decreasing (1.0%). Consequently, wet conditions start to increase. It is obvious that from this scale the establishment of balance between the categories has begun. In this time scale, the dry months have been detected with 12 months as minimum and with 78 months as maximum. The wet months have been seen as minimum with 7 months and 66 months as maximum.

In the long-term scale (SPI-12), the frequency (total number of months) is 9725 months ($N = 9912 - 11 \times 17 = 9725 \text{ months}$). The difference between dry categories and wet categories continues to decrease and it becomes 0.90%. Indeed, the number of wet months started to rise more rapidly than dry months compared to the results of SPI-9 (587 months or 6.0% against 675 months or 6.9%, respectively). In addition, dry months have been ranged as 11–80 months, while for wet months, the range has been noted as 5–60 months.

The 24-month SPI (Fig. 3) showed a different result than those 1, 3, 6 and 9 SPI values. The dry and wet categories are getting significantly close together. Amazingly, the difference between the categories reaches zero (0.02%). The number of months showing severe or extreme wet and dry conditions gets too close together (602 against 600 months, respectively). In this time scale the minimum and maximum of dry months have been obtained as 9 and 67 months, respectively, and the wet months have been detected as a minimum of 5 months and a maximum of 87 months.

SPI can be used as an indicator for immediate effects such as decreased soil moisture, snowfall, and flow in smaller creeks when it is computed for shorter accumulation periods for example, 1–3 months. Furthermore, the 6-month SPI and 9-month SPI are semi-annual and medium-term scales, respectively. They can be utilized as a predictor of agricultural drought. A wide indirect indicator of water resource management is the 12-month SPI (Caloiero 2018). Not only those but also, SPI can be utilized as a sign of decreased reservoir and groundwater recharge when it is computed over longer accumulation periods (such as 12–48 months). Analysis of SPIs from 1 to 9 months shows that since 1930 Kızılırmak basin has been experiencing severe and extreme drought for short-scale SPIs, monthly (SPI-1), seasonal (SPI-3), semi-annually (SPI-6) and also in SPI-9. It is a meteorological drought that spans 9 months. It may take an agricultural form and impact plants. In the long term, the annual drought SPI-12 does not affect the basin, and

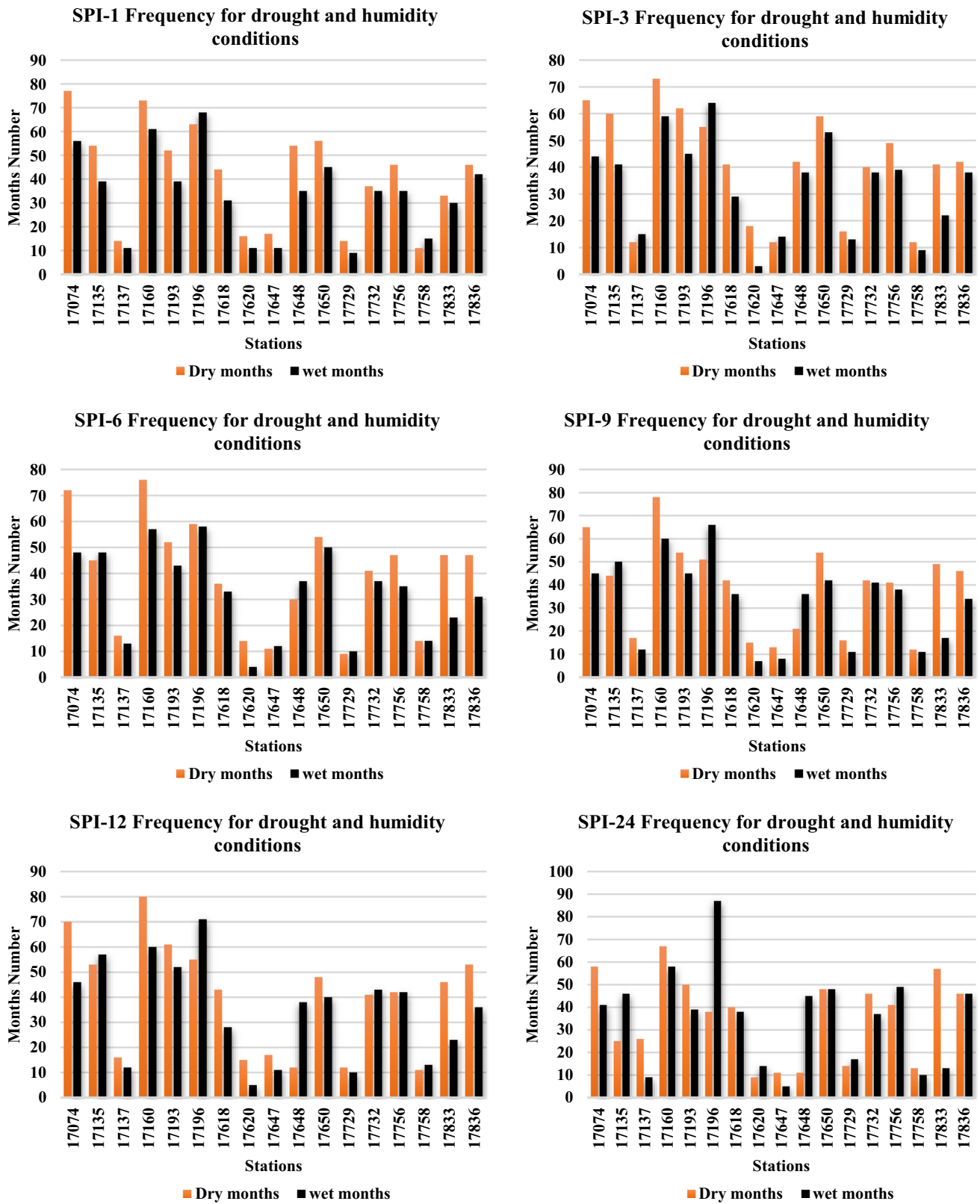


Fig. 3 SPI frequencies for drought and wet conditions

a balance is established between dry and wet episodes. In general, the dry episode frequencies dominate those wet.

Identification of trend analysis by ITA method

ITA is applied to 1-, 3-, 6-, 9-, 12-, and 24-month SPI series, and trend types are identified graphically. To indicate the trend of each SPI at each station, the symbols +, - and 0 have been employed. SPI series having decreasing trend type are shown by “-”, those having increasing trend denoted by “+” and the series that do not have any trend, in which trend slope is equal to 0, are described by “0”. For each SPI, the trends both of Severe and Extreme Drought (SED) and Severe and Extreme Wet (SEW) have been analyzed. Table 3 shows the trend types of the SPI series of all stations. The graphs for ITA results have been given in Appendix 2. In SPI-1 13, SPI-3 8, SPI-6 11, SPI-9 11, SPI-12 11 and SPI-24 8 stations have shown a negative trend for Severe and Extreme Drought (SED) category While in SPI-1 9, SPI-3 11, SPI-6 10, in SPI-9 11, in SPI-12 11 and SPI-24 12 stations have shown an increasing trend for and Severe and Extreme Wet (SEW) category.

In general, the main result obtained for the SPI-1 values was a negative trend for the Severe and Extreme Drought class (SED) and a positive trend for the Severe and Extreme Wet class (SEW), which is related to heavier droughts and heavier wet periods. In fact, in eight stations, a positive trend for the SEW class and a negative trend for the SED class has been detected. These stations are:

17135, 17137, 17193, 17196, 17618, 17732, 17756, and station 17833. Stations 17074 and 17729 have both experienced no trend in the SED category but with different behavior for the SEW class. They showed a positive trend and a negative trend for the SEW category, respectively. Differently from previous stations, four stations showed no trend for the SEW class and a negative trend for the SED category. They are 17620, 17650, 17758, and 17836 stations. Moreover, stations 17647 and 17648 have experienced a negative trend and a positive trend for the SED class, respectively. However, both of them showed a negative trend for the SEW class. The results of ITA methods on station 17160 did not display a clear tendency for the SEW and SED categories.

As regards the 3-month SPI, results are similar to the ones obtained for SPI-1, with a spreading positive trend for the SEW class highest values. Similar results to SPI-1 have been obtained in 17135, 17618, 17756, and 17833 stations. Stations 17074 and 17836 evidenced positive trends for the SEW class and negative trends for the SED class, respectively. In contrast, they showed no trend for the SED class and no trend for the SEW class, respectively. Stations 17160, 17193, 17647, and 17758 have evidenced results different from the ones obtained for SPI-1. They all experienced a positive trend for the SED class but with different trends for the SEW class. Stations 17160 and 17647 have experienced a positive trend for the SEW class (heavier wet periods) whereas a negative trend for the SEW class (weaker wet periods) has been detected in stations 17193 and 17758. A negative trend

Table 3 Innovative trend analysis of selected in Kızılırmak basin

Station	SPI-1		SPI-3		SPI-6		SPI-9		SPI-12		SPI-24	
	SED	SEW	SED	SEW	SED	SEW	SED	SEW	SED	SEW	SED	SEW
17074	0	+	0	+	+	+	+	+	+	+	+	+
17135	-	+	-	+	-	+	-	+	-	+	-	+
17137	-	+	+	+	-	+	-	+	-	+	+	+
17160	0	0	+	+	-	+	+	+	+	+	+	-
17193	-	+	+	-	0	-	+	-	+	0	0	-
17196	-	+	0	+	-	-	-	+	-	+	+	+
17618	-	+	-	+	-	+	-	+	-	0	-	+
17620	-	0	-	-	-	-	-	+	-	+	-	+
17647	-	-	+	+	+	+	+	+	+	+	+	+
17648	+	-	-	-	-	-	-	-	-	-	-	-
17650	-	0	-	+	-	0	-	+	-	+	-	+
17729	0	-	+	-	+	-	+	-	-	-	-	-
17732	-	+	+	+	0	+	-	-	-	-	+	-
17756	-	+	-	+	-	+	-	0	-	0	-	+
17758	-	0	+	-	-	0	+	-	+	-	-	-
17833	-	+	-	+	-	+	-	-	-	-	-	-
17836	-	0	-	0	-	0	-	0	-	+	-	+

SEW Severe and Extreme Wet, SED Severe and Extreme Drought, +: Increasing Trend, -: Decreasing Trend, 0: No Trend.

of both SEW and SED categories has been observed in stations 17620 and 17648, thus evidencing heavier droughts and weaker wet periods. In contrast, stations 17732 and 17137 have both experienced a positive trend for both SEW and SED categories. At the same time, stations 17650 and 17729 showed different trends. Station 17650 showed heavier wet periods (a positive trend in the SEW class) and heavier droughts (a negative trend in the SED class) while station 17729 showed the opposite (weaker wet periods and weaker droughts). Finally, a positive trend for the SEW class and no trend for the SED class have been detected in station 17196, thus demonstrating heavier wet periods.

Considering the 6-month SPI, ITA results show the same results as SPI-1 and SPI-3 with a spreading negative trend for the SED class. In general, results in 7 stations show a negative trend for the SED class and a positive trend for the SEW class. These stations are 17135, 17137, 17160, 17196, 17618, 17756 and 17833. By contrast, stations 17193 and 17,729 have both evidenced weaker wet periods (a negative trend for the SEW class), with a concomitant positive trend for the SED class (weaker droughts) in station 17729 and with no clear tendency in station 17193. At the same time, a negative trend for SEW and SED categories has been detected in stations 17620 and 17648, whereas stations 17074 and 17647 have experienced a positive trend for the two classes. Moreover, no trend has been detected for the SEW class in stations 17650, 17758, and 17836 with different results for the SED category. While weaker droughts (the positive trend for the SED class) have been identified in station 17758, all other stations indicated a tendency through heavier droughts (a negative trend for the SED class). Finally, in station 17732, a positive trend for the SEW class has been detected and they did not show a clear tendency for the SED class, thus indicating heavier wet periods.

ITA analysis results of SPI-9 confirm the same results as SPI-1, SPI-3, and SPI-6. The main results show a tendency through heavier wet periods and heavier droughts. A positive trend in the SEW class and a negative trend for the SED class have been detected in 8 stations namely: 17135, 17137, 17196, 17618, 17620, 17650, 17732, and 17833. By contrast, a positive trend for the SED class and a negative trend for the SEW class have been evidenced in stations 17193, 17729, and 17758. At the same time, a negative trend for the two categories (SED and SEW) was noticed in 17,648. Whereas, a positive trend in the two categories (SED and SEW) has been detected in stations 17074, 17160, and 17647. They are exposed to heavier wet periods and weaker droughts. Finally, stations 17756 and 17836 have experienced a negative trend for the SED class has shown no trend for the SEW category.

According to a long-term 12-month SPI analysis, the ITA trend analysis main results have given a tendency through heavier droughts and wet periods. A positive trend for the SEW class and a negative trend for the SED class have been detected in 8 stations namely: 17135, 17137, 17196, 17620, 17650, 17732, 17833, and 17836. On the contrary, a positive trend for the SED class and a negative trend for the SEW class have been evidenced in stations 17729 and 17758. At the same time, a negative trend for the two categories (SED and SEW) has been noticed in station 17648. Whereas, a positive trend for SED and SEW classes has been detected in stations 17074, 17160, and 17647. Finally, no trend for the SEW class has been detected in 3 stations (17193, 17618, and 17756) but with different trends for the SED category. Stations 17618 and 17756 have shown a negative trend while station 17193 has shown a positive trend for the SED category.

As regards SPI-24, the ITA trend analysis main results showed the same results as SPI-12. A positive trend for the SEW class and a negative trend for the SED category have been identified in 7 stations. These stations are 17135, 17618, 17620, 17756, 17650, 17833 and 17836. Different from previous results, a positive trend for the SED class and a negative trend for the SEW category have been evidenced in stations 17160, 17729, and 17758. At the same time, a negative trend for the two categories (SED and SEW) has been detected in station 17648, thus signifying heavier droughts and weaker wet periods. Whereas, a positive trend for SED and SEW classes has been noticed in stations 17074, 17137, 17196, 17647, and 17732, thus indicating a clear tendency toward heavier wet periods and weaker droughts. Finally, station 17193 did not show a clear tendency.

As a result, this research has proved that the majority of ITA trend analysis applied to SPI time scale values for SED ($SPI \leq -1.5$) and SEW ($SPI \geq 1.5$) categories is a positive trend and a negative trend, respectively. Looking at Table 3, it can be observed that in the majority of the cases, a trend is present. Among 204 analyses ($6 \times 2 \times 17 = 204$), 88.73% of analyses have either an increasing or decreasing trend. The percentage of the increasing trend in the SEW class is 62.74% and the percentage of the decreasing trend in the SED class is 60.78%. Some studies proved the results found in this research. A previous study showed that a decreasing trend dominates the majority of 7 stations located in the Kızılırmak basin (Deger et al. 2023). Another study of trend analysis of monthly average flows of 3 stations located in the Kızılırmak basin showed that 2 stations experienced a decreasing trend (Minarecioglu and Çitakoglu 2019).

Table 4 Mann–Kendall analysis of selected in the Kızılırmak basin

Stations	Z value						Trend type					
	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24	1	3	6	9	12	24
17074	2.8297	6.1841	9.1812	10.601	11.341	14.377	+	+	+	+	+	+
17135	-0.19357	0.46034	0.96281	1.1253	1.5495	2.7024	-	+	+	+	+	+
17137	0.60859	0.65399	0.36933	0.3632	1.162	3.6369	-	+	+	+	+	+
17160	-0.43825	-0.11842	-0.48703	-1.2526	-1.7594	-1.8808	-	-	-	-	-	-
17193	0.99601	0.8454	0.81927	0.84555	0.80357	1.9878	+	+	+	+	+	+
17196	2.7045	4.6285	6.9819	8.3525	9.5185	12.517	+	+	+	+	+	+
17618	-1.3604	-1.223	-1.1687	-1.0538	-1.0833	0.18603	-	-	-	-	-	+
17620	-0.37301	-0.52271	-1.3632	-1.6258	-1.8049	-1.5239	-	-	-	-	-	-
17647	0.55092	0.15215	-0.35705	-0.37914	-0.18651	1.3202	+	+	-	-	-	-
17648	-2.9255	-4.3124	-5.3195	-5.5403	-5.7701	-5.964	-	-	-	-	-	-
17650	-0.66735	-0.95836	-1.5105	-1.9226	-2.0655	-1.2802	-	-	-	-	-	-
17729	0.35706	-0.38528	-0.99019	-1.1264	-1.281	-0.26871	+	-	-	-	-	-
17732	-0.80489	-0.42215	-0.74787	-0.85121	-0.55231	-0.25111	-	-	-	-	-	-
17756	-1.1726	-1.1047	-1.1489	-1.2899	-1.4275	-1.59	-	-	-	-	-	-
17758	-0.79635	-1.5411	-1.9988	-1.8687	-1.4957	-0.16196	-	-	-	-	-	-
17833	-4.6804	-6.4616	-7.3434	-7.3197	-7.6116	-8.3532	-	-	-	-	-	-
17836	-0.68982	-0.84093	-0.98729	-1.2694	-1.6648	-3.4114	-	-	-	-	-	-

Identification of trend by using the Mann–Kendall

The Mann–Kendall method has been used to investigate trend analysis of each SPI series (1-, 3-, 6-, 9-, 12-, and 24-month SPI) and to detect trend type by a numerical inspection. Table 4 shows the trend types of the SPI series of all stations based on the Mann–Kendall method.

The results in Table 4 showed that most of the stations experienced a decreasing trend for all SPI series. The percentage of decreasing trend and increasing trend is 67% and 33%, respectively. Some stations showed a monotonic trend for all SPI series, either increasing or decreasing. Stations 17074, 17137, 17193, and 17196 showed an increasing trend for all SPI series. In contrast, stations 17160, 17620, 17648, 17650, 17732, 17756, 17758, 17833, and 17836 displayed a decreasing trend for all SPI series. In addition, station 17135 showed a decreasing trend only for SPI-1 whereas station 17618 experienced an increasing trend only for SPI-24.

Conclusion

In this study, a meteorological drought monitoring study has been examined by SPI and mean monthly precipitation records of 17 stations over different years in Kızılırmak Basin. for various time scales (1, 3, 6, 9, 12 and 24

months). The number of months with severe and extreme dry or wet conditions have been detected for each SPI. Severe and Extreme Dry (SED) categories are considered as $SPI \leq -1.5$ and Severe and Extreme Wet (SEW) categories as $SPI \geq 1.5$. Finally, the SPI series was then subjected to a graphical approach based on the Innovative Trend Analysis (ITA) developed by adding 2 vertical lines and a numerical approach based on the Mann–Kendall method. According to SPI results, for all time scales, the number of months showing dry conditions is higher than the ones showing wet conditions. In stations 17074, 17160, 17193, 17618, and 17833; the number of months with severe and extreme dry conditions outperform those of wet conditions for all time. By developed ITA, the possible trends are composed of three cases: an increasing trend, a decreasing trend, and no trend. For each SPI, the trends both of Severe and Extreme Drought (SED) and Severe and Extreme Wet (SEW) are examined. For ITA graphical analysis, the majority of results for all time scale showed a trend (89%). While a negative trend of SPI value under the dry categories indicates the presence of heavier drought, a positive trend shows no drought. In contrast, an increasing trend of SPI value under the wet category demonstrates the presence of wet significantly, whereas a decreasing trend means weaker wet periods. The main result obtained was a negative trend for the Severe and

Extreme Drought class (SED) and a positive trend for the Severe and Extreme Wet class (SEW), which is related to heavier droughts and heavier wet periods. It is also worth stating that some stations have demonstrated a decreasing trend in the majority of the time scale whereas other stations have shown an increasing trend in the majority of the time scale. Among all stations; stations 17618 (6 cases), 17620 (8 cases), 17648 (11 cases), 17650 (6 cases), 17729 (6 cases), 17756 (6 cases), and 17836 (6 cases) have shown a negative trend in time scales (1, 3, 6, 9, 12 and 24) of SPI values. In contrast; stations 17074 (12 cases), 17137 (8 cases), 17160 (8 cases), 17196 (7 cases), 17647 (10 cases), and 17732 (8 cases) have shown an increasing trend in all time scales of SPI values for both SED and SEW categories. Station 17074 (12) and station 17648 (11) have the highest number of positive trend cases and negative trend cases which are 12 and 11 cases, respectively. Based on ITA analysis of SEW and SED categories, it has been observed for four stations the positive trend and negative trend are equal. These stations are 17135, 17193, 17758, and 17833. According to Mann–Kendall analysis results, decreasing and increasing trends account for 67% and 33%,

respectively. It is worth noticing that, according to the Mann–Kendall test, some stations displayed a monotonic trend that was either increasing or declining for all time scales. Overall results demonstrate that there is an increase in wet categories in some parts of the basin parts and a large increase in dry conditions in other parts of the basin. In order to protect water supplies from potential future droughts, analyses have suggested that the basin needs an effective drought management plan. Therefore, it is anticipated that the results findings will be helpful for basin and water resources management drought action plans.

Appendix 1.

See Table 5 here.

Appendix 2

See Fig. 4 here.

Table 5 Number of severe and extremely dry and severe and extreme wet months in 17 stations

Station	SPI-1		SPI-3		SPI-6		SPI-9		SPI-12		SPI-24	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
17074	77	56	65	44	72	48	65	45	70	46	58	41
17135	54	39	60	41	45	48	44	50	53	57	25	46
17137	14	11	12	15	16	13	17	12	16	12	26	9
17160	73	61	73	59	76	57	78	60	80	60	67	58
17193	52	39	62	45	52	43	54	45	61	52	50	39
17196	63	68	55	64	59	58	51	66	55	71	38	87
17618	44	31	41	29	36	33	42	36	43	28	40	38
17620	16	11	18	3	14	4	15	7	15	5	9	14
17647	17	11	12	14	11	12	13	8	17	11	11	5
17648	54	35	42	38	30	37	21	36	12	38	11	45
17650	56	45	59	53	54	50	54	42	48	40	48	48
17729	14	9	16	13	9	10	16	11	12	10	14	17
17732	37	35	40	38	41	37	42	41	41	43	46	37
17756	46	35	49	39	47	35	41	38	42	42	41	49
17758	11	15	12	9	14	14	12	11	11	13	13	10
17833	33	30	41	22	47	23	49	17	46	23	57	13
17836	46	42	42	38	47	31	46	34	53	36	46	46
Total	707	573	699	564	670	553	660	559	675	587	600	602

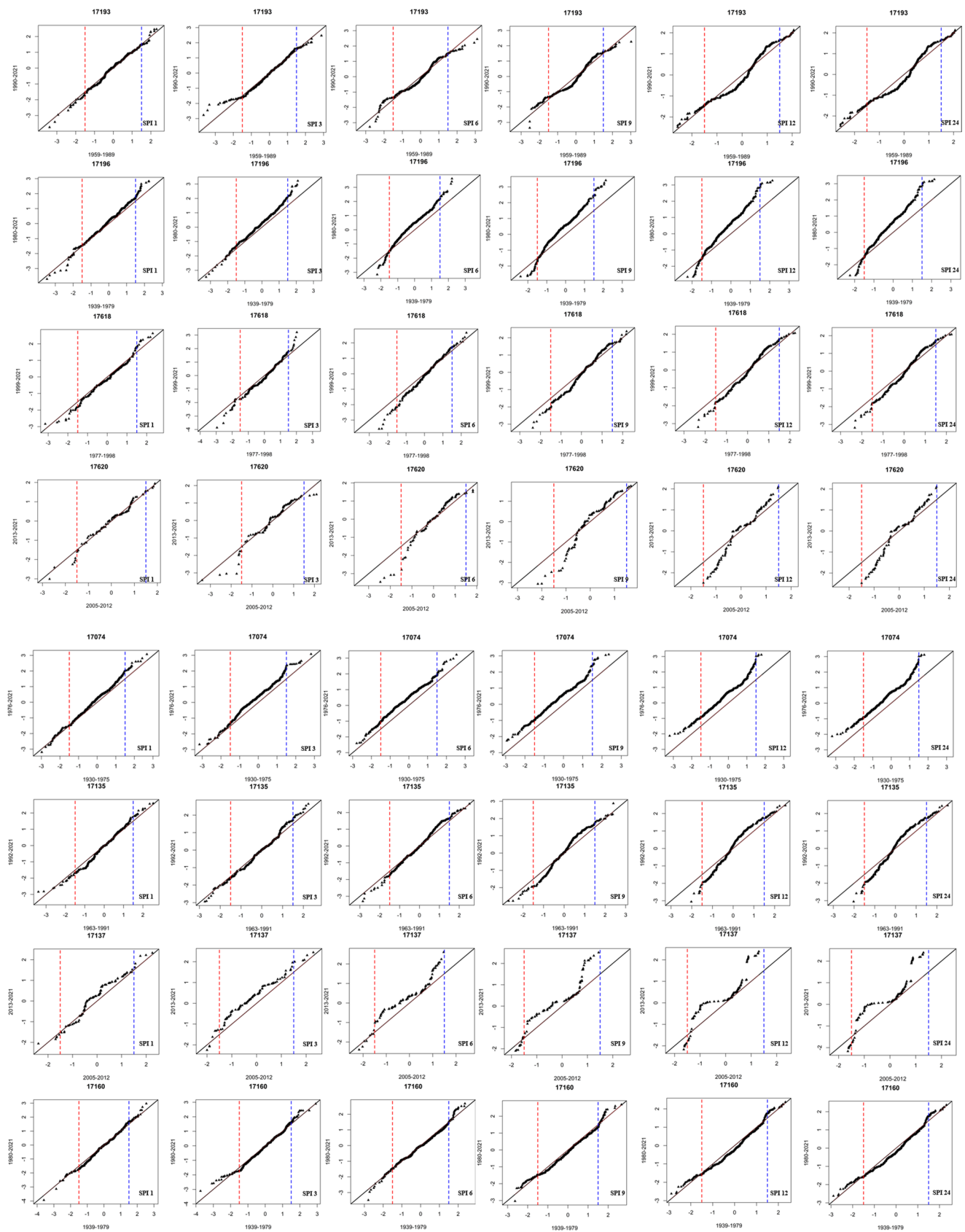


Fig. 4 ITA analysis results of each station 1-, 3-, 6-, 9-, 12-, and 24-month time scale

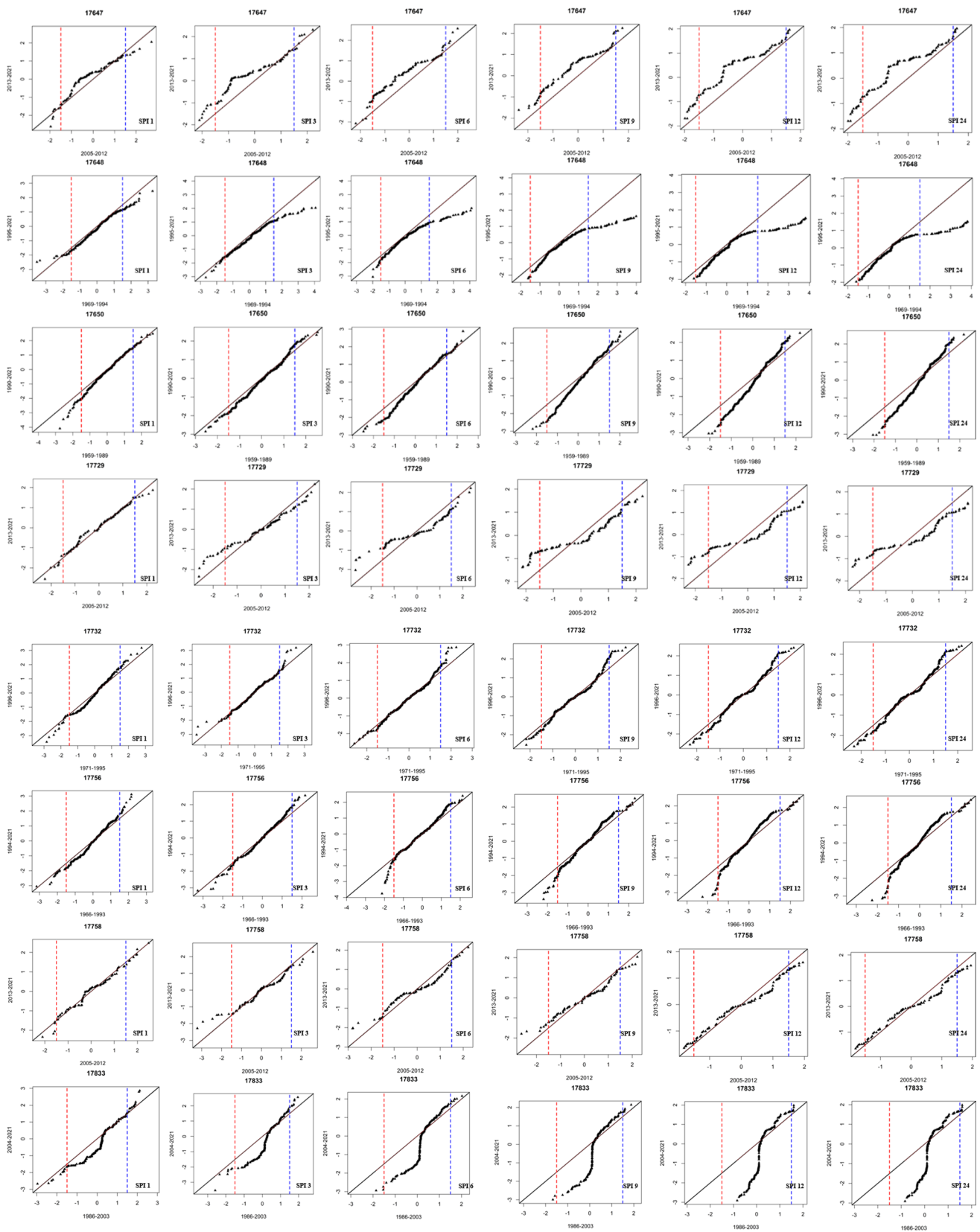


Fig. 4 (continued)

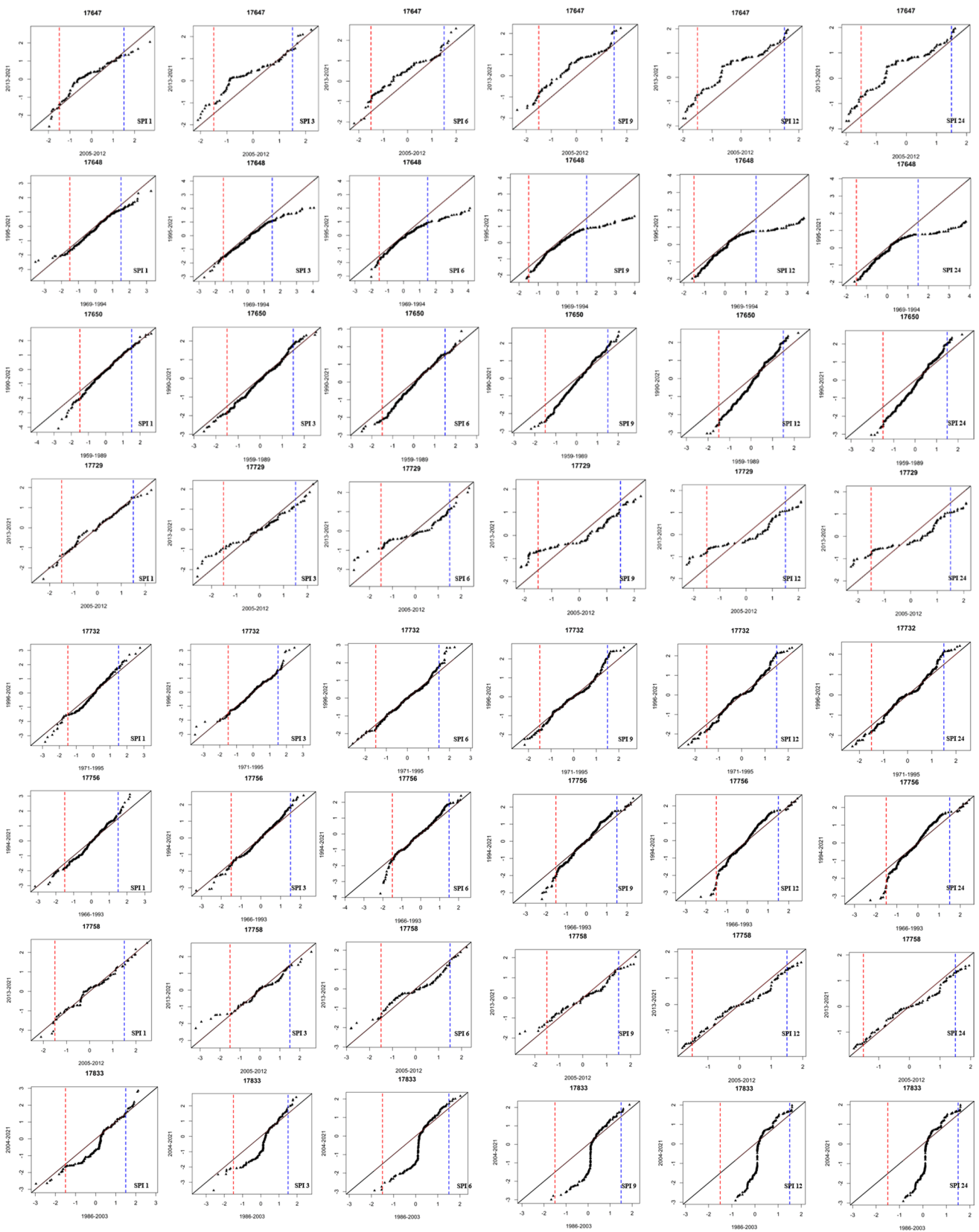


Fig. 4 (continued)

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Data availability All data presented in graphical form is available and can be presented if requested.

Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

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