



Visual and statistical inference of hourly and sub-hourly extreme rainfall trends Central Anatolia, Turkey case

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Abstract

The analysis of long-term rainfall data in a changing climate is important because it has many sectoral applications such as agriculture, infrastructure, and water resources management. Statistical analyses of the annual maximum rainfall data were performed using the Mann–Kendall (MK) trend test to evaluate the annual maximum trend characteristics of the rainfall time series, the innovative trend analysis (ITA) method to detect categorical trends, and the ITA indicator to digitize the ITA results. Storm durations of 5, 10, 15, 30 min and 1, 3, 6, 24 h annual maximum rainfall series at 13 central stations in Central Anatolia, Turkey were used. According to the MK test results, there were no significant upward or downward monotonic trend at four stations, whereas the remaining nine stations showed a significant upward or downward monotonic trend. Significant negative and positive trends were identified for the sub-hourly and hourly rainfall, whereas significant positive trends were detected for hourly storm durations. Significant trend results were mostly consistent with the general ITA results. The sub-hourly storm duration data were more consistent in terms of significant trends. Conversely, when evaluated according to low, medium, and high data values in the rainfall series (categories), the high data values showed different trends. Although no trend was detected with the MK test, the ITA results showed an upward or downward trend for 25 rainfall series. 29 of 30 significant MK test results were consistent with the ITA indicator results, compared with 24 of 30 results of the visually inspected ITA results.

Keywords ITA · Trend · Extreme · Annual maximum · Central Anatolia

Introduction

The analysis of long-term rainfall data in a changing climate is important because it has many direct applications. Agriculture, water resources, the design of flood defense systems and other physical environmental factors are affected by the properties of rainfall (Shawul and Chakma 2020). The average properties of rainfall could change and extreme rainfall

may be intensified by climate change (Abbasnia and Toros 2020), which could have long-lasting consequences, both social and economic, for many sectors, in particular agriculture because rainfall is one of the most significant variables for agriculture. (Cogato et al. 2019; Alemu and Bawoke 2019). Changes in seasonality, averages or extremes of rainfall can induce significant unfavorable impact on agricultural production (Cattani et al. 2018). Therefore, monitoring and identifying the temporal and spatial change in rainfall variation are necessary (Joshi and Makhasana 2020).

Nonparametric Mann–Kendall (MK) trend test together with other tests such as linear trend, Sen’s slope, modified MK and regression tests and innovative trend analysis (ITA) have been widely used for the detection of trend tendencies of hydrological variables and time series trends: Saplıoğlu et al. (2014) investigated the monthly and annual river flows into the Western Mediterranean Basin, Wu and Qian (2017) investigated rainfall trends, Hu et al. (2019) analyzed the precipitation, temperature, potential evapotranspiration, and river discharge over the Kamo River basin, Yagbasan et al.

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(2020) investigated monthly water levels and other meteorological variables that effect the water level of Lake Mogan and Lake Eymir. These studies show the wide spread use of nonparametric trend tests, particularly the MK test, together with the ITA method to explore trend tendencies of different hydrologic variables.

Among these trend tests, the ITA method proposed by Şen (2012) allows the use of categorical data such as low, medium and high, in trend analysis. Furthermore, visual inspection of general and categorical trend of time series becomes possible with this method. Because of the wide applicability of the method, it has been applied in many regions, including Turkey, and for different variables such as temperature, wave height, stream flow, rainfall, or standardized precipitation index (Yilmaz 2019; Malik et al. 2019; Gedefaw et al. 2018; Caloiero 2018; Dabanlı et al. 2016; Güçlü 2018; Ay and Kisi 2015; Haktanir and Cıtakoglu 2014).

Changes in rainfall patterns have been the subject of interest in many studies. In particular, extreme rainfall data are used in many applications such as infrastructure design, agricultural production, and insurance. It has been reported that an increase in the temperature of the atmosphere will increase the water holding capacity of air, which would trigger the possibility of more intense rainfall (Zhang et al. 2017; Trenberth 2011). Therefore, it is crucial to define and investigate the extreme rainfall (in this study annual maximum rainfall of various storm durations) behavior and changes over time.

In this study, statistical analyses of the 5, 10, 15, 30 min and 1, 3, 6, 24 h annual maximum rainfall data of 13 cities in Central Anatolia, Turkey, were conducted using the following tools: the MK trend test to evaluate the annual maximum trend characteristics of the rainfall time series, the ITA method to detect categorial (trends in low, medium or high data values in the time series) trends, and ITA indicator to digitize the ITA results. The 5, 10, 15, 30 min and 1, 3, 6, 24 h annual maximum rainfall series at 13 central stations in Central Anatolia, Turkey, were used. According to Mall et al. (2006), a basin located in a comparatively drier region will likely be more sensitive to climatic changes and Palmer et al. (2008) have reported that almost all populated basins will face water stress. Central Anatolia is one of the main ecological regions in Turkey. Bozoglu et al. (2019) reported that Central Anatolia will be one of the parts of Turkey that will be the most effected from temperature increase and proposed the need for regional plans for effected stakeholders. Dudu and Çakmak (2018) also proposed that the Western and Central regions of Turkey are sensitive to extreme events in terms of economic impact (such as household income) owing to an increase in agricultural prices and a decline in crop yields. Dellal et al. 2011 projected a decrease in crop yield between 7.3% and 12.5% in Central Anatolia under climate change conditions. For this reason, Central Anatolia,

which is one of the regions in Turkey that is the most sensitive to the impact of climate change and which has already faced some of these impacts, was chosen for the analyses.

Study area and data

Central Anatolia is one of the seven geographical regions in Turkey and is located in the center of the country (Fig. 1). The area of Central Anatolia covers approximately 20% of the area of Turkey.

In Central Anatolia, most parts of the region are classified as semi-dry and semi-dry less humid. The difference between day and night temperatures is high in the region. The Taurus Mountains lay in the south and the North Anatolian Mountains in the north. The elevation of the region increases toward the east and the average altitude of the region is over 1000 m. The mild weather cannot exceed the surrounding mountains so continentality effects are dominant in the region. The spring and the winter are the rainiest seasons and the rain type is convectional and frontal.

The annual maximum rainfall series at thirteen weather stations were obtained from the Turkish State Meteorological Service. The 13 stations from which the data used in this study were obtained are listed in Table 1.

Methodology

The MK trend test was applied for various durations of rainfall time series recorded at different locations in Central Anatolia. A trend analysis was performed by applying the MK test. The results of the MK test were compared with those obtained through the ITA approach and ITA indicator.

The statistical analyses of the annual maximum rainfall data was conducted using the following tools:

- MK trend test to evaluate the annual maximum trend characteristics of the rainfall time series.
- ITA method to determine categorial trends details about the trends.
- ITA Indicator to digitize the ITA results.

Synthesis of methods was used to evaluate the rainfall time series' trend and described in the following sections.

Mann–Kendall test

Trend tests are generally classified into two categories; these are parametric and nonparametric tests. According to Yilmaz and Perera (2014), nonparametric trend tests are more appropriate for hydro-meteorological time series data as statistical tools to detect trends.

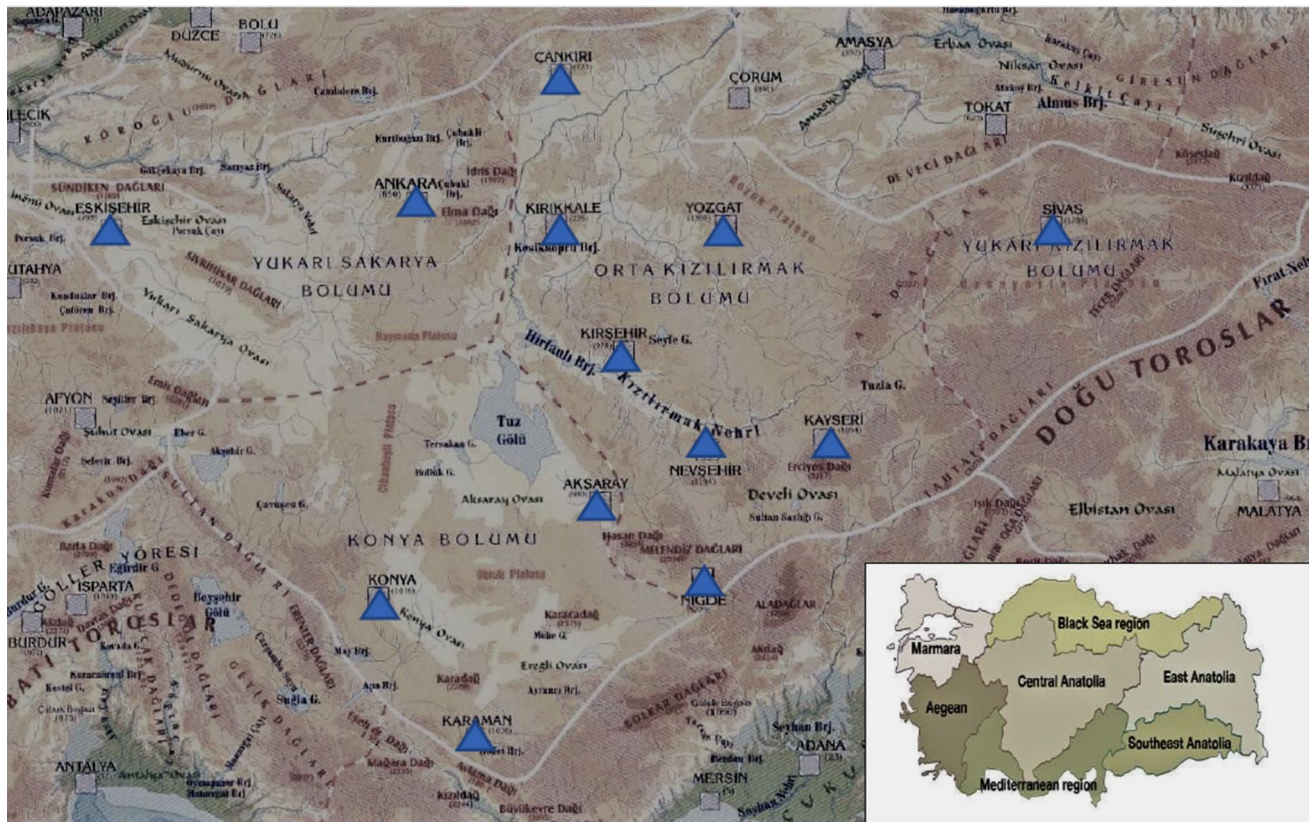


Fig. 1 Map of the selected stations in the study area (Bacanli et al. 2011)

Table 1 Selected 13 weather stations in Central Anatolia

Station	Lon	Lat	Elevation (m)	Data range
Aksaray	33.99	38.36	965	1966–2015
Ankara	32.86	39.97	891	1950–2015
Cankiri	33.61	40.6	751	1960–2015
Eskisehir	30.55	39.76	801	1957–2012
Karaman	33.22	37.19	1025	1966–2015
Kayseri	35.5	38.68	1,093	1956–2015
Kirikkale	33.51	39.84	751	1968–2015
Kirsehir	34.15	39.16	1007	1942–2015
Konya	32.55	37.96	1031	1950–2015
Nevsehir	34.7	38.6	1260	1966–2015
Nigde	34.67	37.95	1211	1960–2015
Sivas	37	39.74	1285	1958–2015
Yozgat	34.8	39.82	1298	1960–2015

The MK trend test is one of the nonparametric tests for trend detection and was used to detect the trends of time series in this study. The MK test is a rank-based test that has a widespread application for hydrometeorological time series data to detect trends (Yilmaz and Perera 2014; Cheng and AghaKouchak 2014; Onyutha et. al. 2015).

The MK test (Mann 1945; Kendall 1975; Gilbert 1987) is used to statistically assess the existence of a monotonic upward or downward trend of the interested variable over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) over time, but the trend may or may not be linear.

The main equations of the MK test are given below (Mann 1945; Kendall 1975; Longobardi and Villani 2010; Ahmad et al. 2015; Chen et al. 2016):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i) \tag{3.1}$$

in which S is the MK test statistic.

$$\text{sgn}(x_j - x_i) = \begin{cases} +1 & \left\{ \begin{array}{l} (x_j - x_i) > 0 \\ (x_j - x_i) = 0 \end{array} \right. \\ 0 & \\ -1 & \left\{ \begin{array}{l} (x_j - x_i) < 0 \end{array} \right. \end{cases} \tag{3.2}$$

$$\text{VAR}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5)}{18} \tag{3.3}$$

$$\begin{aligned}
 z &= \frac{S - 1}{\sqrt{\text{VAR}(S)}}, & \text{if } S > 0 \\
 z &= 0, & \text{if } S = 0 \\
 z &= \frac{S + 1}{\sqrt{\text{VAR}(S)}}, & \text{if } S < 0
 \end{aligned}
 \tag{3.4}$$

The hypothesis, H_0 , that there is no trend is rejected when the absolute value of Z is greater than the critical value Z_{α} , at a chosen level of significance α and the alternative hypothesis, H_1 , is accepted.

Although the MK test is free of normally distributed data assumption, it assumes the data independency. Moreover, if serial dependence exist, the probability of rejecting the null hypothesis (no trend) increases (Serinaldi and Kilsby 2015; Caloiero et al. 2019). Therefore, it is vital to check autocorrelation of data before using them in a MK test for detection of trends. R package trend (Pohlert 2020) was used for the MK test analyses.

ITA method

In this study, a 1:1 straight-line method (Şen 2012), which has been regarded as the best technical note in The Journal of Hydrologic Engineering, American Society of Civil Engineers in 2014, was used for trend detection. For this method, the time series are divided into two halves, sorted in ascending order. The first half of the series is the previous half and placed on the horizontal (X) axis. The second half of the time series is the latter half and is placed on the vertical (Y) axis. The existence of a trend is visually determined by the position of scattered points relative to a 1:1 line (Şen 2012; Haktanir and Citakoglu 2014; Güçlü et al. 2018; Ali et al. 2019; Alifujiang et al. 2020). The scattered points are also categorized according their position on the axis such as low, medium, and high values. For this categorization, the axis was divided in to 3 equal parts and points were designated according to the part they resided in. In this study, the low, medium, and high values of all the stations were also

evaluated separately by the ITA method. ITA analyses conducted by modifying the innovtrend function of R package trendchange (Patakamuri 2019).

ITA indicator

The mean value difference between X_i and X_j (X_i = data series in the first half series, X_j = data series in the second half series) could give the magnitude of trend of a given data series. To make the trend indicator of the ITA and MK test results of a similar scale, the trend indicator (ϕ) was multiplied by 10. The trend indicator is given as Eq. (3.5)

$$\Phi = \frac{1}{n} \sum_{i=1}^n \frac{10(X_i - X_j)}{\mu}
 \tag{3.5}$$

in which ϕ = trend indicator, n = number of observations in the series, X_i = data series in the first half series, X_j = data series in the second half series and μ = mean of data series in the first half series.

A positive ϕ value indicates an upward trend and a negative ϕ value indicates a downward trend. On the other hand, when the scatter points accumulate and get closer to the 1:1 line, it is accepted that the trend is insignificant. (Gedefaw et al. 2018; Dorjsuren et al. 2018).

Results and discussion

The MK test was applied to 5, 10, 15, 30 min and 1, 3, 6, 24 h annual maximum data for each of the 13 weather stations in Central Anatolia. The minimum data range was 49 years and the maximum data range was 74 years for the trend analyses period (as shown in Table 1 for each station) which is a satisfactory period for climate studies and long-term analysis. The results obtained through the MK test are shown in Table 2. The presence of a statistically significant trends was determined based on a comparison of the MK

Table 2 The results of the monotonic Mann–Kendall trend test for 5, 10, 15, 30 min and 1, 3, 6, 24 h annual maximum rainfall series Z values

	Aksaray Z	Ankara Z	Cankiri Z	Eskisehir Z	Karaman Z	Kayseri Z	Kirikkale Z	Kirsehir Z	Konya Z	Nevsehir Z	Nigde Z	Sivas Z	Yozgat Z
5 M	0.21	−3.07	−1.67	−1.78	−0.67	1.72	−0.74	0.78	−1.00	−1.27	1.12	0.21	0.69
10 M	1.18	−2.20	−1.17	−1.70	0.08	1.71	−0.41	0.86	−0.40	−0.30	1.77	0.11	0.28
15 M	1.17	−1.69	−0.28	−1.65	0.64	1.39	0.11	1.64	−0.06	−	2.50	0.08	0.49
30 M	1.42	−1.75	0.86	−1.06	1.18	1.83	0.36	2.65	0.43	0.59	3.37	0.50	1.60
1 H	1.53	−2.23	1.04	−0.47	1.23	1.56	−0.02	3.04	0.91	1.35	3.60	0.05	1.92
3 H	2.08	−0.66	1.40	−0.79	0.54	1.64	0.20	3.01	1.07	0.57	3.19	−1.09	2.09
6 H	1.15	−0.31	1.89	−0.59	0.50	1.35	−0.32	3.35	1.34	0.23	2.66	−0.38	1.89
24 H	0.41	−0.88	1.29	0.39	−0.77	1.46	−0.55	2.93	2.70	0.58	1.71	0.36	1.59

test statistics with the critical values at 0.1, 0.05, 0.01 significance levels.

Based on the MK test statistics, significant decreasing and increasing trend results were detected. A significant decreasing trends in the annual maximum rainfall at Ankara and Eskişehir Stations were observed, whereas increasing trends were observed at Kırşehir, Niğde and Yozgat Stations. Aksaray, Çankırı, Karaman, Kirikkale, Konya, Nevşehir and Sivas stations rainfall series show no significant trend except positive trends for 3 h rainfall for Aksaray, 5 min and 6 h rainfall for Çankırı and 24 h rainfall for Konya. In general, significant negative trends were identified for sub-hourly rainfall series, whereas significant positive trends were detected for hourly rainfall series considering all stations.

No significant trends were observed at seven of the thirteen stations at 0.05 significance level and four of thirteen stations at significance level 0.1 according to the MK test. The graphical illustration of sub-hourly and hourly data trends at 13 stations is shown in Figs. 2, 3, respectively. The 5 min data series had a significant trend with a Z value of -3.07 at 0.01 significance level, whereas the 10 min and 1 h series showed a trend at 0.05 significance level, and the 15 min and 30 min rainfall data showed a decreasing trend at the 0.1 significance level. On the other hand, a decreasing trend was significant at the 0.1 level for sub-hourly Eskişehir rainfall data. In contrast, an increasing trend was detected for Kırşehir at a significance level of 0.01 except for the 15 min data series. The maximum rainfall at Niğde station also showed a strong trend with

a significance level 0.01. As Kırşehir and Niğde stations, Yozgat station also showed an increasing trend, which was significant for hourly annual maximum rainfall. Additionally, the data from Aksaray, Ankara, Kırşehir, Niğde and Yozgat stations indicated a unidirectional trend whether significant or not and although they were not significant even at a significance level of 0.1, increasing trends were observed at Aksaray, Çankırı, Karaman stations for particular rainfall durations such as 30 min or 1 h. Sub-hourly rainfall series showed both increasing and decreasing trends, whereas the hourly rainfall series were dominated by mostly an increasing trend compared with the sub-hourly rainfall series, as shown in Figs. 2, 3.

For every selected station of Central Anatolia, significant and insignificant rainfall trends were detected by the MK trend test. Then, the ITA method was performed to determine the behavior of the rainfall timeseries, to check the MK Test results and to examine the rainfall time series' trend for low, medium, high values, and overall trend [Fig. 4 (upper panel 5, 10, 15, 30 min and lower panel 1, 3, 6, 24 h)].

Kırşehir station showed a clear increasing trend for 30 min, 1, 3, 6, 24 h rainfall series but when the ITA graph for Kırşehir showed that this behavior was mainly dominated by the low and medium data values of the annual maximum series. The 15 min data show a significant upward trend according to the MK test results but no trend tendency based on accumulation at the 1:1 line according to the ITA results. However, the negative trend behavior was detected for the highest values of all the rainfall durations at Kırşehir station.

Fig. 2 MK test Z-value for sub-hourly storm durations

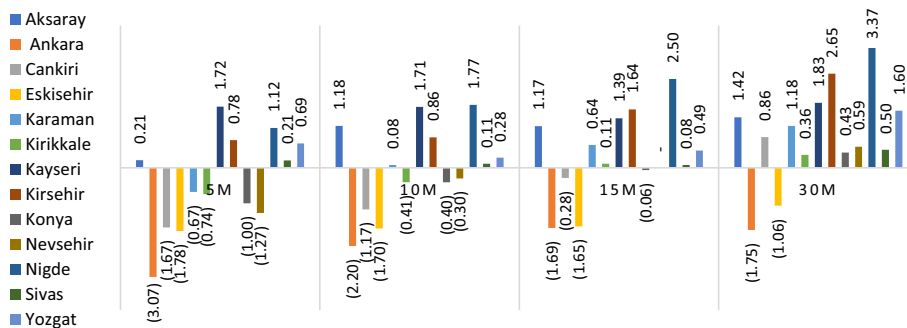
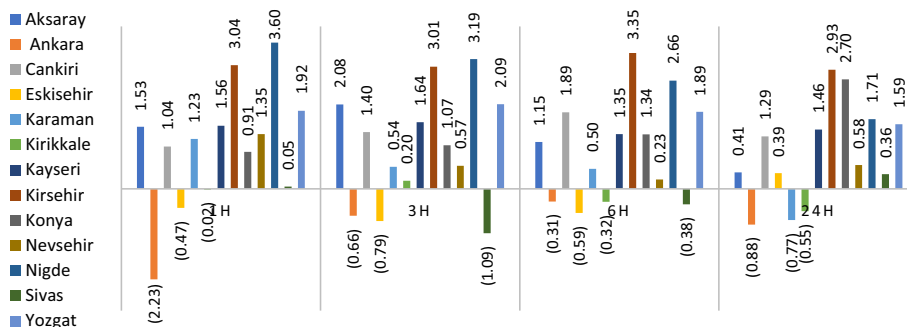


Fig. 3 MK test Z-value for hourly storm durations



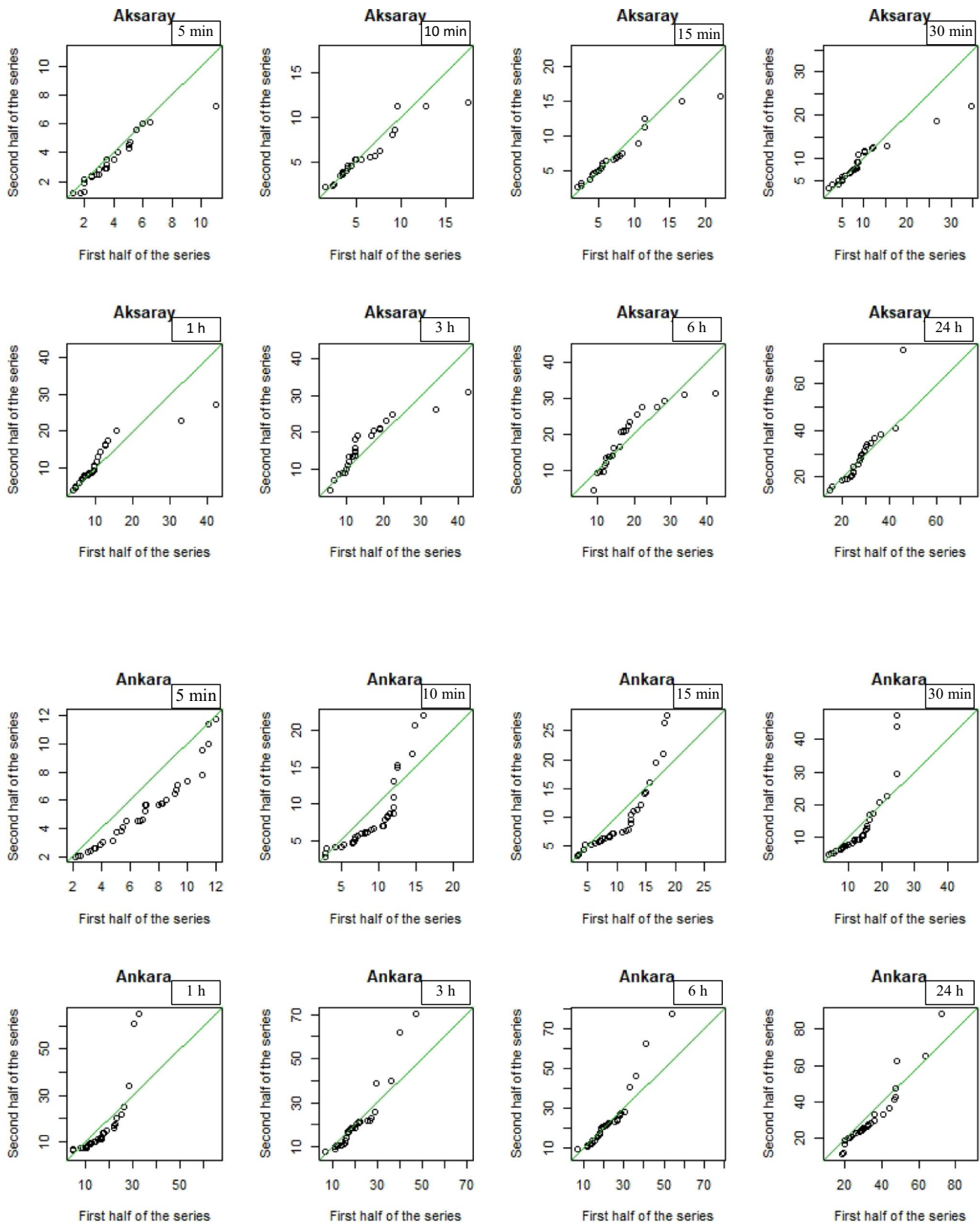


Fig. 4 The results of the ITA method for annual maximum rainfall series at 13 selected stations (upper panel 5, 10, 15, 30 min and lower panel 1, 3, 6, 24 h) series x-Axis: First half of the series (in mm) and y-axis: Second half of the series (in mm)

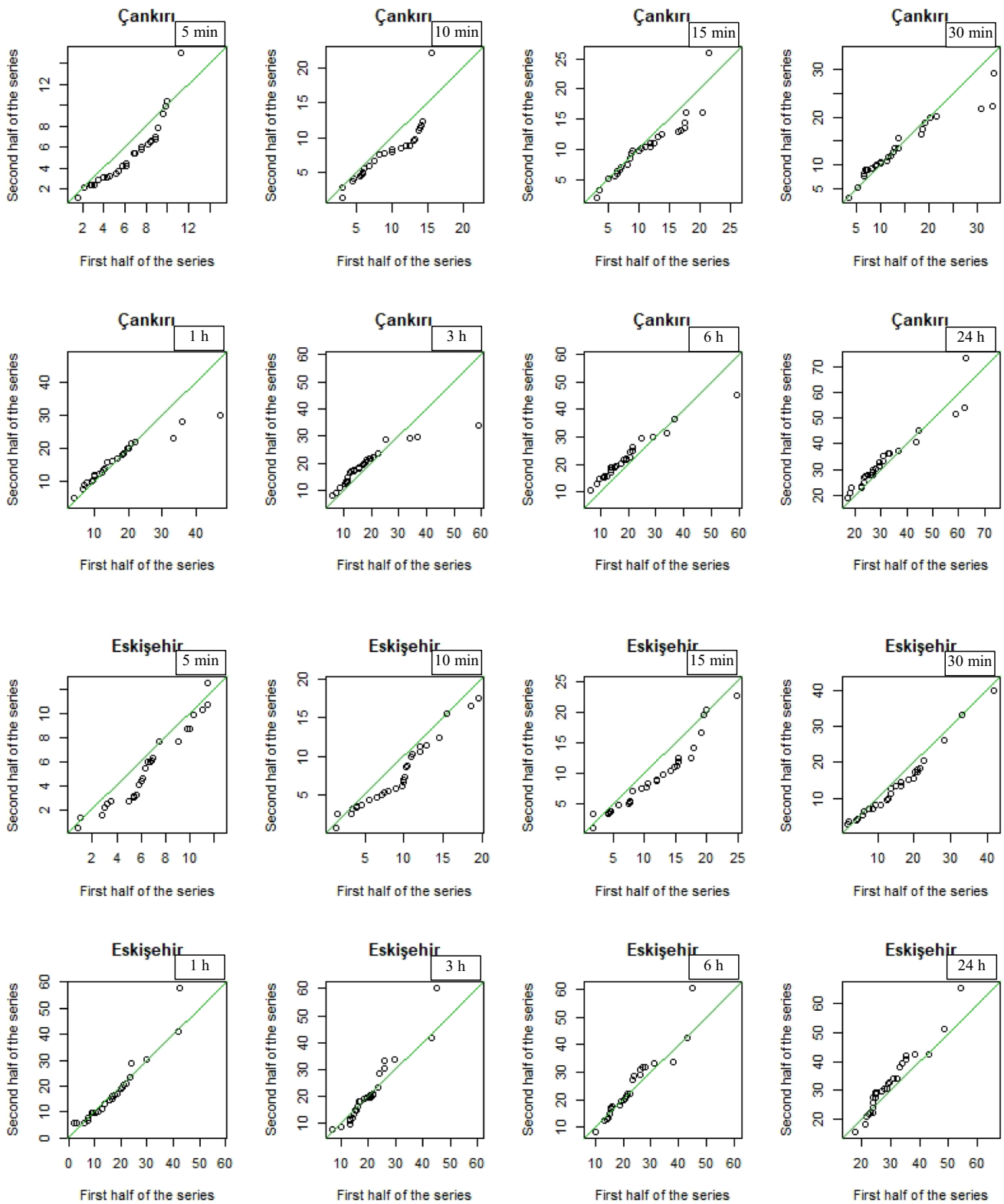


Fig. 4 (continued)

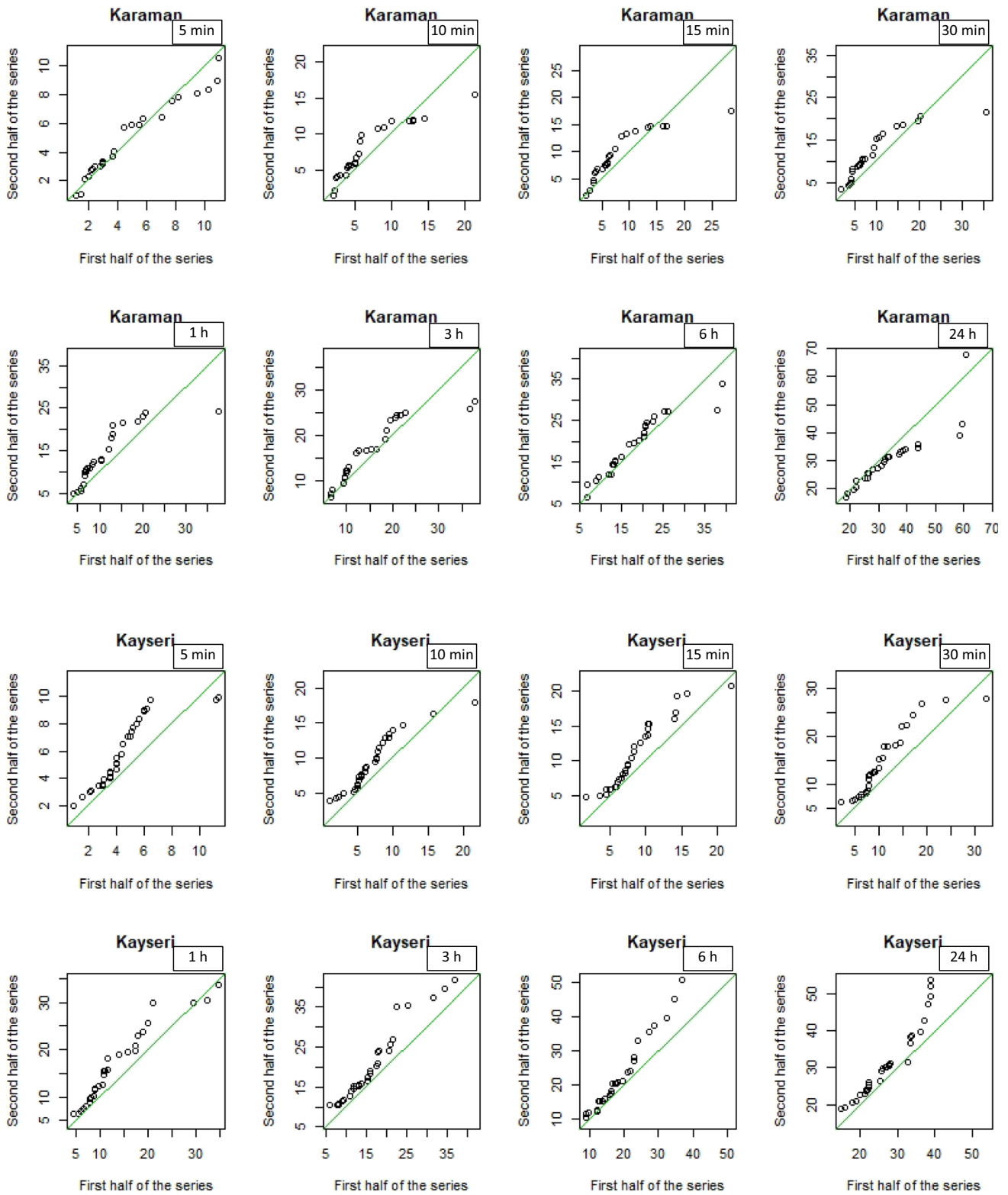


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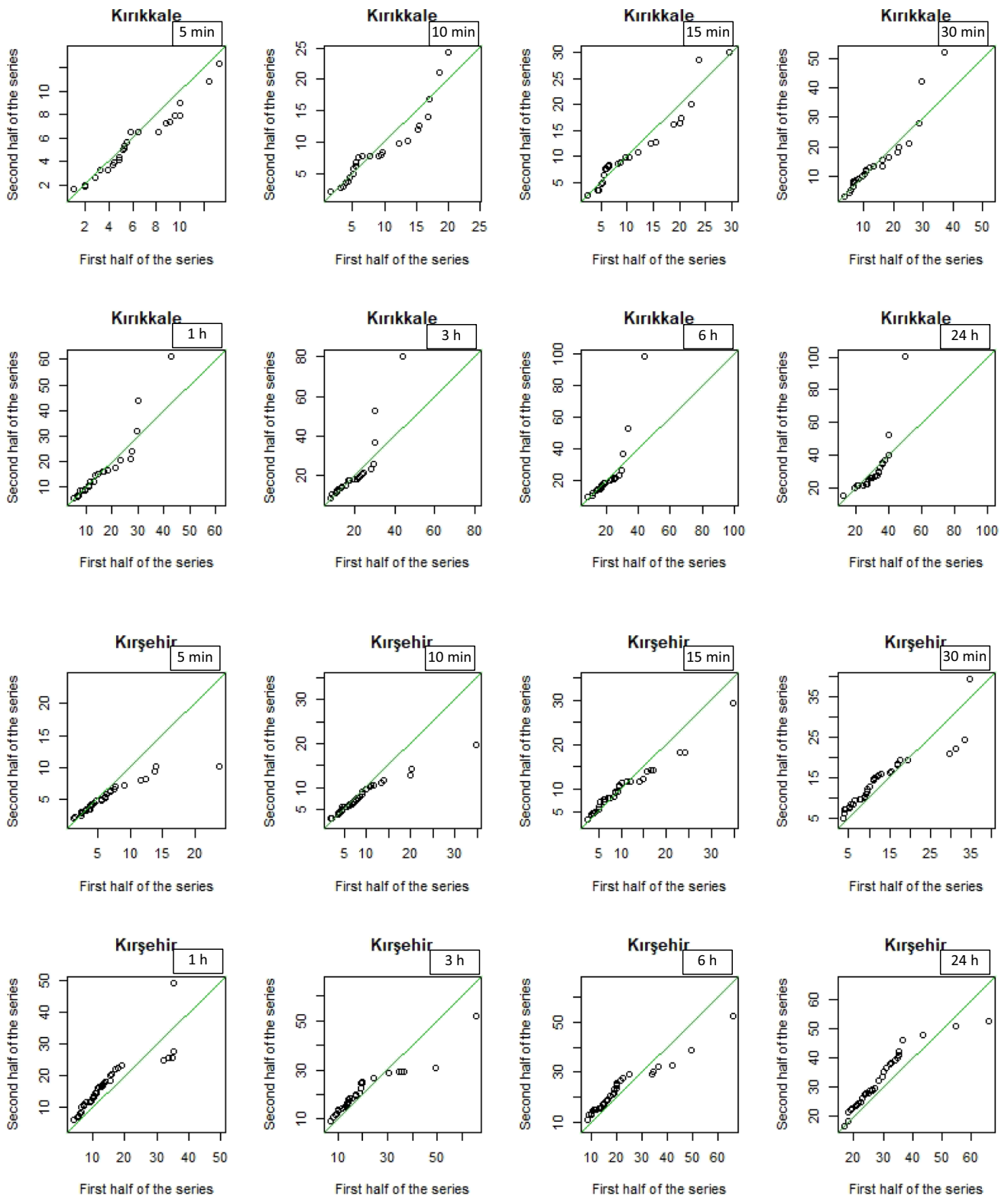


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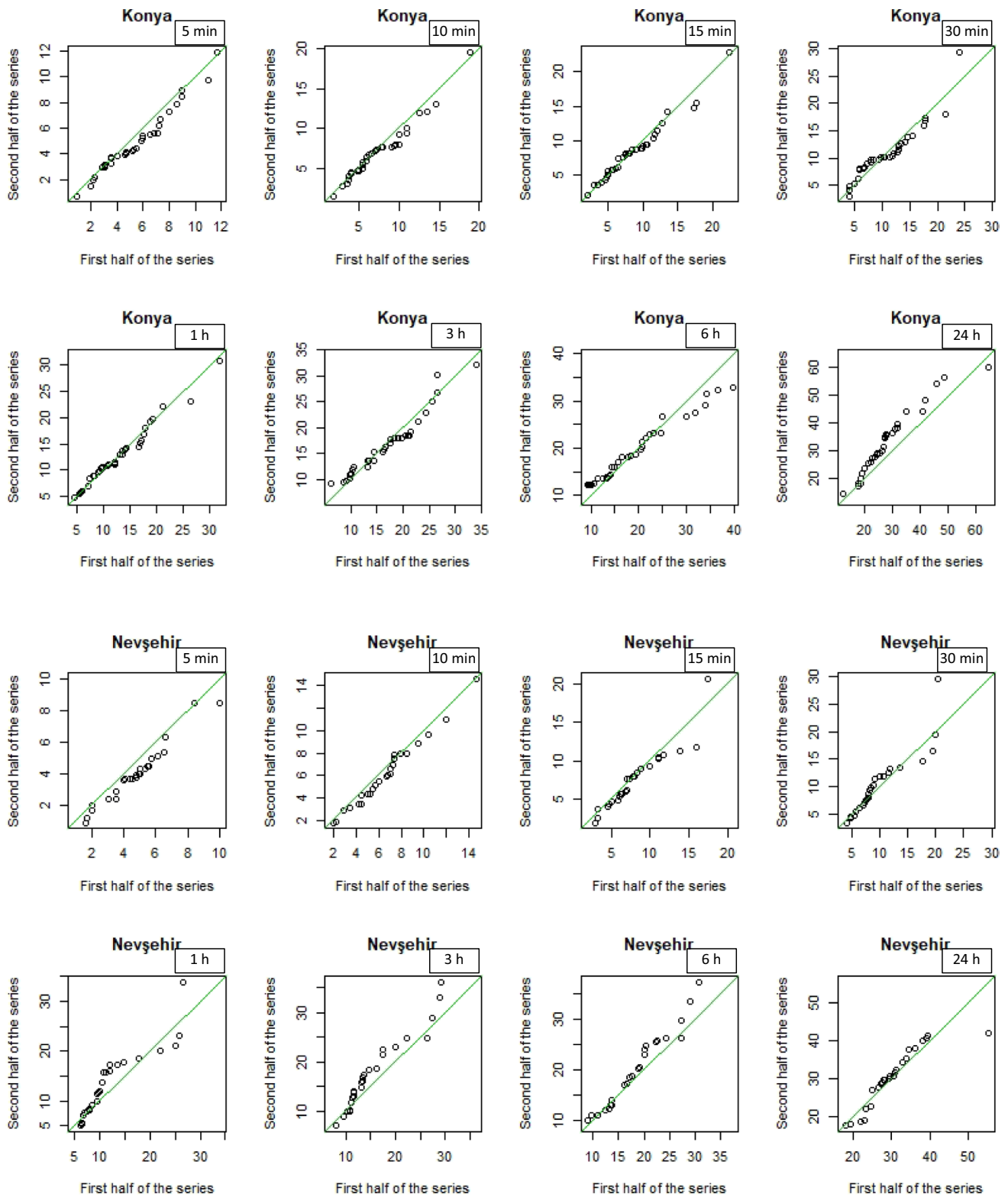


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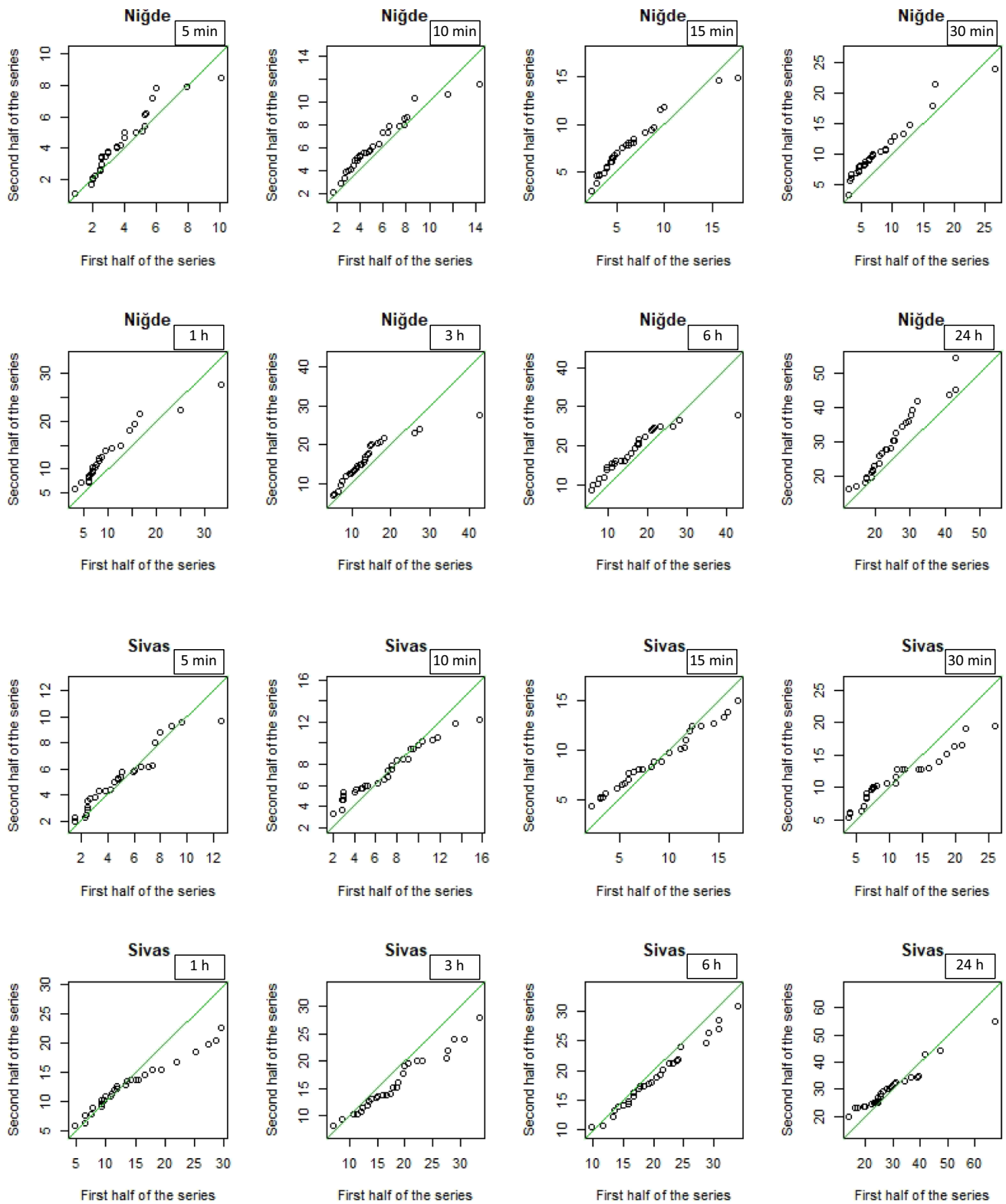


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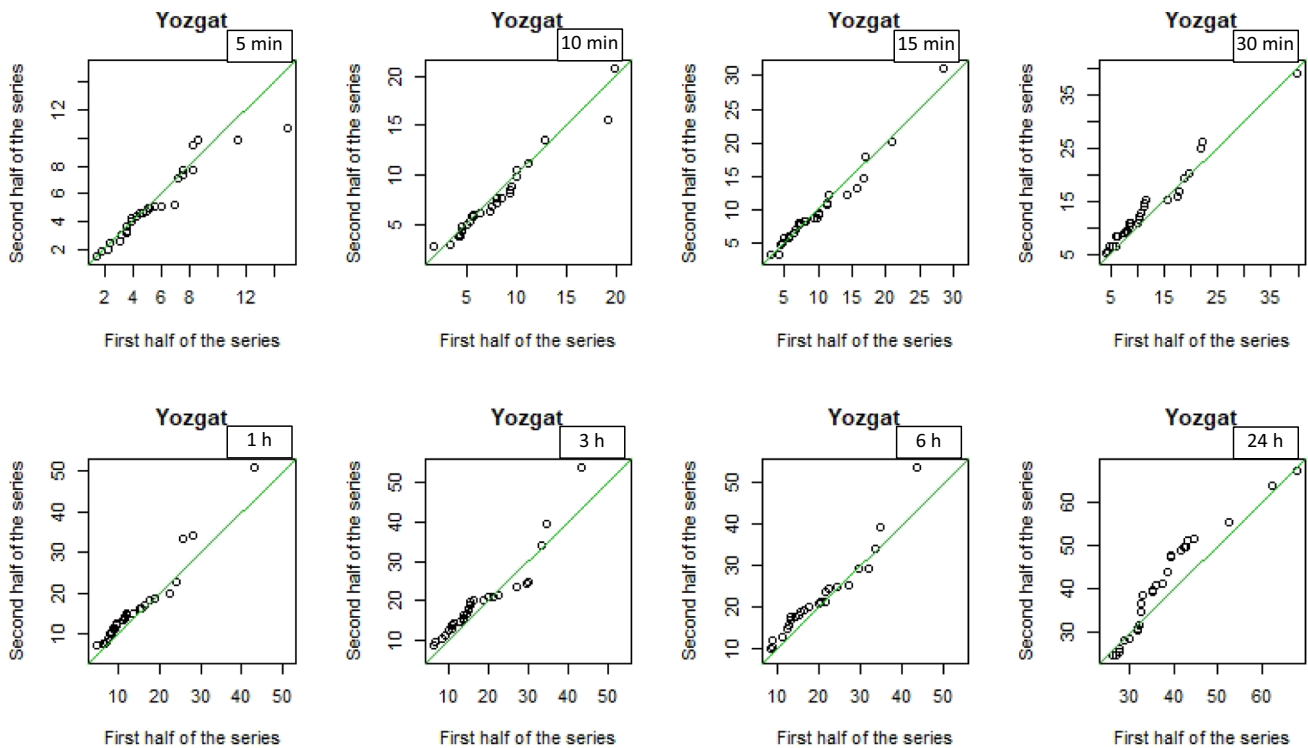


Fig. 4 (continued)

Contrasting tendencies were also observed for Ankara station. The 5 min rainfall data exhibited a clear downward trend, whereas the remaining rainfall time series had different trend characteristics for their corresponding low, medium, and high data values. The MK Test results for Ankara revealed a downward trend for all rainfall durations, which was significant for the 5, 10, 15, 30 min and 1 h series. The ITA results displayed a clear downward trend for low and medium values of rainfall data, which were significant according to the MK test but the trend tendency substantially changed when the high values of data were considered. Even medium data values of 10–15 min rainfall data showed an upward trend. Nevertheless, the data points mostly fell below the 1:1 line, implying an overall upward trend.

Considering Eskişehir station, the sub-hourly rainfall data points fell below the 1:1 line, whereas the hourly data points fell around the 1:1 line. On the other hand, The 24 h rainfall data showed a generally steady increase and fell above the 1:1 line. Moreover, the 3–6 h rainfall data also showed an upward trend for the medium values of rainfall data and no trend was observed for the rainfall values that were smaller than the medium values.

The results of applying the ITA method for Niğde station can be seen in Fig. 4, in which most of the rainfall data points were located in the upward trend area. This clearly confirmed the presence of a positive trend, however graphical illustration showed that the highest values were positioned

at the downward trend side of the 1:1 line except the 24 h rainfall data. Yozgat station, one of the stations that showed a significant trend for hourly rainfall series according to the MK test, showed evident result of an upward trend for hourly rainfall series together with the 30 min series by the ITA methods. However, the medium data values of these time series were located slightly below the 1:1 line. Moreover, the insignificant upward trend of the sub-hourly data series revealed by the MK test results cannot be validated using the ITA method at Yozgat station from a visual inspection.

Hourly rainfall data fell above the 1:1 line, which indicated an upward trend at Aksaray station. Low values were approximately on the 1:1 line, whereas medium values were positioned slightly above the 1:1 line. Conversely, the data from the high values were clearly in the downward trend area at Aksaray station. Çankırı station rainfall ITA analyses revealed both an upward and downward trend. The 5, 10, 15 min data of the low and medium values fell below the 1:1 line, except the highest data values. For the 30 min and 1 h rainfall data, almost all the points were near the 1:1 line, which indicated no trend. Although vaguely, the upward trend was also detected in the 3, 6, 24 h rainfall data, whereas high values of these series showed a downward tendency at Çankırı station. At Karaman station, both the upward and downward trend were detected from the results obtained by the ITA method. The 5 min and 24 h rainfall series showed a downward trend, whereas the subsets (low,

medium or high values of data) of the series behaved differently. The Kayseri station rainfall series showed a consistently upward trend. All low, medium, and high rainfall data values were positioned above the 1:1 line with a few exception points for the high values. Low level values were closer to the 1:1 line, whereas the medium and high values showed a strong upward trend and were located farther from the 1:1 line compared with the low values at Kayseri station. Considering the 10, 15, 30 min and 1 h rainfall series, a substantial upward movement of the medium values was clearly evident. For the high values, the pattern changed and most of them fell below the 1:1 line but the number of data points was not as much as the medium or low values. Trend results obtained for Kırıkkale station indicated no trend for all the low level and most of the medium values, which were generally positioned around the 1:1 line. However, all the high data values of the rainfall series except the 5 min data set clearly showed an upward trend, whereas only the 5, 10, 15 min medium rainfall values fell below the 1:1 line.

At Konya station, the ITA results showed no trend in general but the 5 min and 24 h rainfall series displayed slightly different behavior than the others. The 5 min rainfall data points fell below the 1:1 line, whereas the 24 h rainfall series points stayed above the line. The remaining rainfall data series were positioned along the 1:1 line with minor drifts from the 1:1 line and a general interpretation of the trend was not possible. However, the presence of a trend could be evaluated in terms of low, medium, and high rainfall series at Konya station. The ITA method results for the data from Nevşehir station showed a downward trend for 5, 10, 15 min and an upward trend of the medium values for 30 min and 1, 3, 6, 24 h rainfall series. Low level data points were generally positioned on the 1:1 line or slightly below the line. High level values exhibited similar trend tendencies with their corresponding medium level data points for 5, 10 min and 1, 3, 6 h rainfall series. However, these high category values were represented by a small number of points. The Sivas station rainfall series showed different trend patterns. Almost all the rainfall series high values deviated from the 1:1 line. Only the 3 h and 6 h time series showed a downward trend and the rest of the rainfall series had a tendency of an upward trend. However, the upward trend of rainfall series was not demonstrated for all the data points. For example, the medium values of the 10 min rainfall series were on the 1:1 line, which indicated no trend. Furthermore, the higher values of the 15 and 30 min rainfall series fell below the 1:1 line, whereas the rest of the data points were above that line, and it was not easy to find any evidence of a trend for such a series. A summary and comparison of the MK test and the ITA method results of the 104 time series is shown in Table 3.

As shown in Table 3, the high, medium, and low values of all the stations were individually analyzed by the ITA

method. As shown in table, significant trend results were mostly consistent with the general ITA results, but 6 of the 30 significant MK trends were visually estimated not to have a trend with the ITA method (Tables 3, 4). Sub-hourly estimates were more consistent in terms of significant trends. On the other hand, when these significant trends were evaluated in terms of low, medium, and high data values of the rainfall series, especially high values of data show different trend tendencies compared with the general trend tendency of the whole series. When the high data values that exhibited different trend tendencies were examined, as most of the other high values, these values were not as many as the low or medium values. Although no trend was detected with the MK test, the visual inspection of the ITA results indicated an increasing or a decreasing trend for the 25 rainfall series.

Furthermore, to validate the ITA results, an indicator (ϕ) was used to detect whether the ITA trends were statistically significant (Table 4). A positive value of ϕ indicates an upward trend and a negative value of ϕ indicates a downward trend. The trend analysis of all the stations examined by the MK test, ITA calculated indicator, ITA visual inspection methods and results are presented in Table 4. 29 of 30 significant MK test results were consistent with the ITA indicator results whereas 24 of 30 results of the visually inspected ITA results were consistent with the MK results. The inconsistent value was for the 15 min annual maximum rainfall data at Kırşehir station, which had a negative ITA indicator and showed no trend when it was visually inspected. Visually inspected ITA results and indicator-based ITA results did not always follow the same tendency. For instance, no trend tendency was evaluated by visual inspection according to the position and accumulation of the data points, whereas the ITA indicator calculations returned values that indicated a decreasing or an increasing trend.

Discussion and conclusions

The MK trend test (Mann 1945; Kendall 1975; Gilbert 1987) and the ITA method (Şen 2012) were applied to annual maximum rainfall series and the results were compared for 13 stations in Central Anatolia, Turkey. To digitize the ITA results, an indicator was calculated and used for the comparative analyses. The MK trend test has been used in many studies and is among the most widely used non-parametric trend tests (Yilmaz and Perera 2014; Cheng and AghaKouchak 2014; Onyutha et al. 2015; Yucel et al. 2015), whereas the Şen method is also used to detect the trend with a different aspect, in particular low, medium, and high values of time series (Caloiero et al. 2019; Caloiero 2020; Alifujiang et al. 2020; Haktanir and Citakoglu 2014.; Güçlü et al. 2018). The MK and ITA results have also been compared and have been found to provide consistent results in terms of

Table 3 Comparison of the Mann–Kendall (MK) trend test and the ITA method (Low (L_{ITA}), Medium (M_{ITA}), High (H_{ITA})) for the 5, 10,15, 30 min and 1, 3,6, 24 h annual maximum rainfall series

	5 min				10 min				15 min				30 min			
	MK	L_{ITA}	M_{ITA}	H_{ITA}	MK	L_{ITA}	M_{ITA}	H_{ITA}	MK	L_{ITA}	M_{ITA}	H_{ITA}	MK	L_{ITA}	M_{ITA}	H_{ITA}
<i>(a)</i>																
Aksaray	+	–	–	–	+	x	–	–	+	x	x	–	+	x	+	–
Ankara	–*	–	–	–	–*	–	–	+	–*	x	–	+	–*	x	–	+
Cankiri	–*	–	–	x	–	–	–	x	–	x	–	–	+	+	X	–
Eskisehir	–*	–	–	–	–*	–	–	–	–*	–	–	–	–	x	–	x
Karaman	–	+	+	–	+	+	+	–	+	+	+	–	+	+	+	–
Kayseri	+*	+	+	–	+*	+	+	–	+	+	+	–	+*	+	+	–
Kirikkale	–	x	–	–	–	x	–	+	+	x	–	x	+	x	–	+
Kirsehir	+	x	–	–	+	x	x	–	+*	+	x	–	+*	+	+	–
Konya	–	x	–	–	–	x	–	–	–	x	–	–	+	x	–	x
Nevsehir	–	–	–	–	–	–	–	–	–	–	x	x	+	x	+	x
Nigde	+	+	+	–	+*	+	+	–	+*	+	+	–	+*	+	+	x
Sivas	+	+	x	x	+	+	x	–	+	+	–	–	+	+	x	–
Yozgat	+	x	x	–	+	x	–	x	+	x	–	x	+	+	x	x
	1 h				3 h				6 h				24 h			
	MK	L_{ITA}	M_{ITA}	H_{ITA}	MK	L_{ITA}	M_{ITA}	H_{ITA}	MK	L_{ITA}	M_{ITA}	H_{ITA}	MK	L_{ITA}	M_{ITA}	H_{ITA}
<i>(b)</i>																
Aksaray	+	0	+	–	+*	0	+	–	+	0	+	–	+	–	+	+
Ankara	–*	–	–	+	–*	0	0	+	–	0	0	+	–	–	–	+
Cankiri	+	+	0	–	+	+	+	–	+*	+	+	–	+	+	+	0
Eskisehir	–	0	0	0	–	0	0	+	–	0	+	0	+	–	+	+
Karaman	+	+	+	–	+	+	+	–	+	+	+	–	–	0	–	–
Kayseri	+	+	+	–	+*	+	+	+	+	+	+	+	+	+	+	+
Kirikkale	–	0	–	+	+	0	–	+	–	0	–	+	–	+	–	+
Kirsehir	+*	+	+	–	+*	+	+	–	+*	+	+	–	+*	+	+	–
Konya	+	0	0	–	+	+	–	0	+	+	0	–	+*	+	+	+
Nevsehir	+	0	+	0	+	0	+	+	+	0	+	+	+	–	+	–
Nigde	+*	+	+	–	+*	+	+	–	+*	+	+	–	+*	+	+	+
Sivas	+	0	–	–	–	–	–	–	–	–	–	–	+	+	+	–
Yozgat	+*	+	0	+	+*	+	+	0	+*	+	+	0	+*	–	+	+

a)*denotes significant trend (0.01, 0.05,0.1) “+” denotes upward trend, “–”denotes downward trend, “0” denotes no trend

(b)*denotes significant trend (0.01–0.05–0.1) “+” denotes upward trend, “–”denotes downward trend, “0” denotes no trend

trend. Dabanlı et al. (2016) used the MK and ITA methods to investigate relative humidity, temperature, precipitation, and runoff data for the Ergene basin. Kişi and Demir (2016) analyzed annual total precipitation by using the MK and ITA methods at Sinop, Samsun, Ordu, Corum, Amasya, and Tokat and found that MK and ITA revealed the same results for peak and low values of annual total precipitation. Kişi et al. (2018) investigated the trend tendencies of streamflow at 9 stations by using the MK, Sen’s method and Şen’s innovative trend methods and showed the advantage of ITA over the Şen method and MK test in terms of applicability with the serially correlated, non-normally distributed time series

and time series with short record length. Ay et al. (2018) examined the monthly streamflow data at 2 stations in the Euphrates-Tigris Basin and indicated the advantage of visual evaluation of data.

In a recent study, Abbasnia and Toros (2020) examined extreme temperature and precipitation indices. Their results showed a decrease in heavy, very heavy, and extremely heavy rainfalls at stations located in inland Central Anatolia. However significant increasing trends were also detected for annual maximum time series at Kayseri, Kırşehir, Niğde and Yozgat stations in this study. Altın et al. (2012) presented evident results that showed decreasing trends in rainfall

Table 4 Comparison of the Mann–Kendall (MK) trend test, the ITA Indicator (ϕ) and visually inspected ITA (V_{isual}) results for 5, 10, 15, 30 min and 1, 3, 6, 24 h annual maximum rainfall series

	5 min			10 min			15 min			30 min		
	MK	ϕ	V_{isual}	MK	ϕ	V_{isual}	MK	ϕ	V_{isual}	MK	ϕ	V_{isual}
Aksaray	0.21	-1.05	-	1.18	-0.46	0	1.17	-0.28	0	1.42	-0.22	0
Ankara	-3.07	-2.27	-	-2.20	-0.97	-	-1.69	-0.69	-	-1.75	-0.15	-
Cankiri	-1.67	-1.27	-	-1.17	-1.15	-	-0.28	-0.57	0	0.86	-0.07	0
Eskisehir	-1.78	-1.61	-	-1.70	-1.66	-	-1.65	-1.76	-	-1.06	-1.16	-
Karaman	-0.67	-0.55	0	0.08	0.74	+	0.64	1.38	+	1.18	2.41	+
Kayseri	1.72	3.48	+	1.71	3.26	+	1.39	3.02	+	1.83	3.55	+
Kirikkale	-0.74	-0.97	-	-0.41	-0.18	0	0.11	0.17	0	0.36	1.09	0
Kirsehir	0.78	-1.60	0	0.86	-1.15	0	1.64	-0.22	0	2.65	1.17	+
Konya	-1.00	-0.96	-	-0.40	-0.56	0	-0.06	-0.24	0	0.43	0.01	0
Nevsehir	-1.27	-2.20	-	-0.30	-1.74	-	-	-1.85	-	0.59	-1.00	0
Nigde	1.12	1.24	0	1.77	1.39	+	2.50	2.12	+	3.37	2.92	+
Sivas	0.21	0.40	+	0.11	0.41	+	0.08	0.33	0	0.50	0.04	0
Yozgat	0.69	-0.49	0	0.28	-0.37	0	0.49	-0.06	0	1.60	1.08	0
	1 h			3 h			6 h			24 h		
	MK	ϕ	V_{isual}	MK	ϕ	V_{isual}	MK	ϕ	V_{isual}	MK	ϕ	V_{isual}
Aksaray	1.53	0.80	0	2.08	1.15	0	1.15	0.83	0	0.41	0.95	0
Ankara	-2.23	-0.37	-	-0.66	0.18	0	-0.31	0.53	0	-0.88	-0.86	-
Cankiri	1.04	0.17	0	1.40	0.56	+	1.89	1.23	+	1.29	0.39	+
Eskisehir	-0.47	0.22	0	-0.79	0.34	0	-0.59	0.50	0	0.39	0.80	+
Karaman	1.23	2.35	+	0.54	0.85	+	0.50	0.60	+	-0.77	-0.42	-
Kayseri	1.56	2.50	+	1.64	2.46	+	1.35	2.07	+	1.46	1.37	+
Kirikkale	-0.02	1.01	0	0.20	1.45	0	-0.32	1.16	0	-0.55	0.31	0
Kirsehir	3.04	1.92	+	3.01	0.62	+	3.35	0.78	+	2.93	1.11	+
Konya	0.91	-0.08	0	1.07	-0.09	0	1.34	-0.05	0	2.70	1.61	+
Nevsehir	1.35	-0.36	0	0.57	0.07	0	0.23	0.02	0	0.58	-0.41	0
Nigde	3.60	2.49	+	3.19	1.49	+	2.66	1.46	+	1.71	0.89	+
Sivas	0.05	-0.90	0	-1.09	-1.26	-	-0.38	-0.70	-	0.36	0.32	+
Yozgat	1.92	1.56	0	2.09	1.03	0	1.89	1.01	0	1.59	0.77	0

“+” denotes upward trend, “-“ denotes downward trend, “o” denotes no trend

intensity at stations in the south and east of Central Anatolia. In this study, significant decreasing trends were also detected for stations such as Ankara and Eskişehir, whereas for other stations, significant increasing trends existed. Çiçek and Duman (2015) found that in the semi-arid regions of Turkey, namely Central and Southeastern Anatolia, annual precipitation tends to decrease. On the other hand, this study showed increasing significant trends for annual maximum time series, which means intensification of extreme rainfall over these regions. One reason for this can be that the decrease in the wet days was higher than the annual precipitation that leads to an intensification. Haktanır and Çıtakoğlu (2014) indicated that 90% of the annual maximum time series in Turkey are trend free after detailed analyses of standard-duration annual maximum rainfalls series from 5 min to 24 h duration recorded in Turkey. However, results of this study

indicated that one third of the rainfall series exhibited significant trends. Güçlü et al. (2020) applied a method called innovative triangular trend analysis and reported a generally monotonically negative trend in Ankara, which was also consistent with the results of this study. One reason why the results of this study were different to those in other studies may be the temporal scale (in this study from 5 min to 24 h annual maximum) of the data and the length of the data (up to 2015). This also implies the need to periodically update the analyses with current data and use detailed data if possible to study rare events. Furthermore it is important to state that data ranges vary with stations and trend detection test results can be affected by the length of sample.

According to the MK test results in this study, there was no significant upward or downward monotonic trend at Karaman, Kirikkale, Nevşehir and Sivas stations, whereas the

rest of the stations showed significant upward or downward monotonic trends. A positive trend was detected in Niğde, Yozgat and Kırşehir for the hourly series, whereas no significant results were obtained in Sivas, Nevşehir, Kırıkkale, Eskişehir and Karaman for the sub-hourly data. Considering the sub-hourly data, Aksaray, Çankırı, Karaman, Kırıkkale, Konya, Nevşehir, Sivas and Yozgat showed no significant trends. However, Ankara, Eskişehir, Kayseri, Kırşehir and Niğde exhibited a significant trend for the sub-hourly rainfall series. Ankara and Eskişehir showed a significant downward trend, whereas Kayseri, Kırşehir and Niğde revealed an upward monotonic trend. These results partially confirmed the results obtained in the previous studies mentioned above; however, there are not many studies that have investigated the annual maximum rainfall trends in Central Anatolia to make concrete comparisons.

Serinaldi et al. (2020) performed a neutral validation study and claim that sample size, distribution shape and serial correlation affect the ITA methodology as like other parametric technique derived for trend analysis. The MK is based on the assumption that the time series do not have serial correlation so all 104 time series were checked for autocorrelation. Also, Alashan (2020) used the modified MK method supported with ITA instead of Şen Slope Estimate and indicated that a smaller (bigger) trend value in a negatively (positively) skewed series were obtained by the ITA method according to the Şen Slope Estimate in series with a significant correlation coefficient. Therefore, the statistical properties of the time series and MK results were also considered for the potential relationship with the ITA results. The ITA indicator and MK results are found responsive to kurtosis and skewness value together in general on the other hand, the MK results were not as sensitive as the ITA indicator for these changes. For example, the Z values of the 15 and 30 min data series were -1.69 and -1.75 , whereas the ITA indicators were -0.69 and -0.15 , respectively, with kurtosis values of 1.15 and 5.89 and skewness values of 1.12 and 2.14, respectively, at Ankara station; the 10 min and 1 h data approximately have the same MK test results. A similar behavior was observed for the Kırşehir station 1 and 3 h rainfall series and Kayseri station 3 h rainfall series, Niğde station 3 h rainfall series. However, the 1 and 3 h rainfall series with a significant trend did not comply with these findings at Yozgat station. In addition, it was observed that small skewness and kurtosis values assured more consistent MK test and ITA indicator relationship. The statistical properties of all 104 time series can be found in online Appendix 1.

In this study, almost all the higher values had a smaller number of points, which means that the data had a heavy tail. Moreover, the criteria of how the low, medium, and peak values of the ITA method are determined effects the trend interpretation. For example, if the series is divided according to the value range (e.g., maximum rainfall height

is 60 mm then the categories are 0–20, 20–40, 40–60 mm), then a higher portion includes few data points, even only one point in some cases such as the Ankara 24 h series, Yozgat 30 min series, and Aksaray 5 min rainfall series. When the low, medium, and high cluster is taken according to number of points ($n/3$ low, $n/3$ medium and $n/3$ number of high values), or quantiles (up to 50% quantile is low, 50–75% is medium and over 75% is high) then different trend tendencies will probably occur.

Significant increasing trends show that extreme rainfall will likely be intensified at these stations. Therefore, considering these results would be beneficial to obtain resilient long-term investment such as urban infrastructure and reducing the risk to human life in populated areas. Furthermore, an increasing extreme rainfall trend and magnitude must be evaluated together with land use/cover change to assess the potential flood risk. Moreover, the potential variations of these changes within the year, for instance shifting of extremes from one month to another, would affect crop production and growing season. Moreover, reasons behind the significant decreases are also important, for example, the region would be getting drier with increasing dry periods.

Exploring extreme rainfall characteristics and their long-term behavior is particularly important since this information is incorporated into many sectors. Urban infrastructures such as rainwater networks are designed based on extreme rainfall, agricultural insurance rates are determined and change based on the occurrence of extreme events. The ability to secure human welfare, sustain agricultural productivity and plan with resilience are all possible with the presence of sufficient and correct data. There is no doubt about the power of using visual inspection and categorical data in trend analysis. In some cases, an overall trend is not easy to detect with the ITA method and it is vital to use a combination of trend detection methods to obtain more valid conclusions. However, if a more precise evaluation is required, ITA allows the data categories to be examined individually.

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Compliance with ethical standards

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