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RESEARCH

Analyzing the trend and change point in various meteorological variables in Bursa with various statistical and graphical methods

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Abstract

Determining the trend in meteorological variables is vital in water resources planning, energy production, and the design of water structures. This study analyzed trends and years of change in seasonal and annual average, maximum, minimum temperature, maximum precipitation, average relative humidity, average wind speed, and sunshine duration values in Bursa. Innovative-Şen trend analysis was used to determine the trends, and the sequential Mann–Kendall method, standard normal homogeneity test, and Pettitt test were used to determine the year of change. In addition, meteorological variables were divided into three ranges as low, medium, and high, and the trends in these ranges were analyzed graphically with the ITA approach. The ITA tests showed statistically significant increases in average, minimum, and maximum temperatures and average wind speed in seasonal and annual periods. On the other hand, statistically significant decreasing trends were observed in the mean relative humidity and sum sunshine duration values in seasonal and annual periods. In addition, significant decreasing trends were observed in the 95% confidence interval in the summer and annual periods in the maximum precipitation values. According to the sequential Mann–Kendall method, there were changes in temperature values in 1995 and 2015, wind speed values in 1946, relative humidity values in 1975 and 1977, and sunshine duration values around 1996. This study's outputs significantly contribute to planners and decision-makers in terms of managing water resources, drought, and flood risk, developing adaptation strategies against climate change and agricultural irrigation and crop production.

1 Introduction

Climate change causes significant changes in meteorological and hydrological variables such as precipitation, temperature, evaporation, humidity, and runoff (Mohan et al. 2018; Xu et al. 2017). Revealing the magnitude of the change in these variables and the breaking time plays a vital role in water resources management, flood and drought management, agricultural irrigation, development of climate change adaptation strategies, forest fires, the spread of infectious diseases, and the economic development of the country (Wang et al. 2017, 2020). Long-term trends in meteorological variables are critical to revealing the effects of a region on its environment. Mann–Kendall (MK), innovative trend analysis (ITA), and ITA slope are of great interest in revealing the trend in meteorological and climatological variables (Kendall 1955; Mann 1945; Şen 2012, 2014). The MK test is one of the most used methods for trend detection. However, this method does not have data length, normality, and serial independence assumptions. In recent years, the ITA method is widely used to reveal the classes of the trend (Alashan 2018).

Şen (2012) suggested the ITA method, which has no restrictive assumptions and visually examines the trend status in various regions of the dataset. Various researchers have applied the ITA method to determine trends in variables such as evaporation (Ahmed and Ogedengbe 2021; Kisi 2015; Yong et al. 2022), precipitation (Caloiero 2020; Wang et al. 2020; Yürekli 2015), wind speed (Ceyhunlu et al. 2021), groundwater (Minea et al. 2020), temperature (Alashan 2018; Çiçek and Duman 2015), and streamflow (Ashraf et al. 2021; Gumus et al. 2022). In addition, many studies reveal the trend change year in various meteorological and hydrological time series. Sequential Mann–Kendall method is the sequential MK test statistic proposed by Sneyers (1990). This test has been used to predict various meteorological variables such as precipitation (Bisai 2019; Hussain et al.; Rahman et al. 2017; Salehi et al. 2020; Soltani et al. 2013; Tabari et al. 2015), temperature (Chatterjee et al.

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2013; Hekmatzadeh et al. 2020; Mie Sein et al. 2021; Zarenistanak et al. 2014), runoff (Yang and Tian 2009), mean water vapor pressure (Tonkaz et al. 2007), droughts (Chong et al. 2022; Modarres et al. 2016; Nasri and Modarres 2009; Zhao et al. 2019), flood events (Modarres et al. 2016), relative humidity (Liu et al. 2020; Zerouali et al. 2020), reference evapotranspiration (Rahman et al. 2019), water vapor (Jindal et al. 2020), and water level (Lei et al. 2020). In addition, a detailed literature review used to reveal change points and trends in meteorological and climatological data is presented in Table 1.

Trend analysis of meteorological time series is vital in terms of future drought, improvement of flood forecasts, effective use and management of water resources, effective use of energy resources, development of climate change adaptation and adaptation strategies, and economic development of the region (Şen 2018). Therefore, the trend in the main components of the hydrological cycle is analyzed in this study. The main purpose of this study is to reveal the trends and change years in the low, medium, and high values of meteorological variables such as seasonal and annual temperature, maximum precipitation, relative humidity, wind speed, and sunshine duration. In addition, the applicability of an ITA method to observe meteorological trends and the comparison of ITA and sequential Mann–Kendall method results are aimed.

2 Material and methods

2.1 Study area and data

Bursa, with a surface area of 10.819 km^2, is Turkey's 4th largest city. Bursa has a transitional climate between the Mediterranean climate and the Black Sea climate. The highest temperatures in Bursa are observed in July and the lowest in February. The annual precipitation average at the station is 707.5 mm (Bacanlı and Kargı 2019). This study used seasonal and annual precipitation, temperature, wind speed, relative humidity, and sunshine duration data covering 1934–2019 in Bursa meteorology observation station. The location map of the study area is presented on the digital elevation model of Turkey (Fig. 1).

In Table 2, the average, maximum, minimum, and standard deviation values of the data at the meteorology station 17,116 in annual and seasonal periods are shown.

2.2 Innovative-Şen trend analysis (ITA)

The ITA method, first suggested by Şen (2012), determines trends in hydro-meteorological variables. It can reveal monotonic and non-monotonic trends in different subgroups in the time series (Pour et al. 2020). In the application of the ITA method, the data of the original series are divided into 2 sub-series consisting of an equal number of observations, and the series are arranged in ascending order. The ITA graph is drawn by matching the data for the first half and the second half. The collection of data on the 1:1 (45°) line indicates the presence of a trend. If the scattering of data points is within the triangle area at the top (bottom) of the 45° line (1:1), it indicates an increasing (decreasing) trend in Fig. 2 (Şen 2012, 2014).

Şen (2017) expressed the trend slope (s) with Eq. 1 at 5% and 10% significance levels of the ITA method to explain the structure of the trend in the time series in more detail.

$$s = \frac{2(\overline{y_2} - \overline{y_1})}{n} \quad (1)$$

where y_1 and y_2 represent the arithmetic means of the first and second half of the dependent variable and n represents the total number of data. Positive (negative) slope values represent increasing (decreasing) trends (Alashan 2020; Cui et al. 2017; Kambezidis 2018). In addition, the trend's confidence limit (CL) is given as follows.

$$CL_{(1-\alpha)} = 0 \pm S_{ITA}\sigma_s \quad (2)$$

where α shows the significance level and σ_s indicates the standard deviation of the slope:

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{1 - \rho\overline{y_1 y_2}} \quad (3)$$

If the s values exceed the confidence limits, there is a statistically significant trend in the time series (Şen 2017).

2.3 Sequential Mann–Kendall test

Sneyers (1990) analyzed the variation of the sequential values of $u(t)$ and $u'(t)$ from the stepwise analysis of the MK test to reveal the variation of the trend over time. This test shows the trend change point rather than determining the trend. Many researchers have used this test to reveal the point of change in hydroclimatic variables (Sayemuzzaman and Jha 2014; Jones et al. 2015; Sharma et al. 2016; Alhathloul et al. 2021). This method consists of two series, a progressive $u(t)$ and a backward $u'(t)$. These curves intersect, and their separation beyond a certain threshold value (95% confidence interval: 1.96) indicates a statistically significant trend. The intersection point of the curves indicates the approximate year the trend started (Mosmann et al. 2004). Here, $u(t)$ is a standardized variable with a mean of zero and a unit standard deviation. The test statistics for each x_i element are found as follows by calculating the number of n_i elements before it, x_j $(i > j)$, thus rank(x_i) > rank(x_j).

Table 1 Literature research on trend and change points in meteorological variables

Authors	Method	Purpose and data	Result	Period and location
Zarenistanak et al. (2014)	Pettitt's test (PT), sequential MK	Trend analysis and change point detection precipitation, mean, maximum and minimum temperature	The annual and seasonal precipitation series generally showed insignificant trends. Positive significant change points in temperature data generally began in the 1990s	1950–2007, Southwest Iran
Kundu et al. (2015)	MK, Sen's slope	Trend analysis Temperature, precipitation, wind speed, relative humidity, solar radiation	An increasing trend in rainfall, solar radiation and minimum temperature values and a decreased trend in maximum temperature, wind speed and relative humidity values were observed	1979–2010, Western Rajasthan, India
Palaniswami and Muthiah (2018)	MK, Sen's slope	Change point detection and trend analysis Rainfall and temperature	An increasing trend in monthly, seasonal, and annual maximum, minimum, and average temperatures and precipitation has been determined. The maximum temperature and minimum temperature change points are 1985 and 2001 and 1987 and 2013, respectively	Northern Tamil Nadu
García-Marín et al. (2020)	SNHT and Buishand test, PT, sequential MK, Mann–Whitney U, and cumulative sum	Breakpoints Annual, rainfall	The breaking point could not be determined in four of the stations used To facilitate the work of practitioners and engineers, homogeneity tests and multifractal algorithms should be combined	The 1950s2017, –Central Italy
Tomozeiu et al. (2000)	Empirical Orthogonal Function, PT, and MK	Shift points and trends The summer precipitation	All stations showed an increasing trend, usually around 1962. The change in summer precipitation was largely due to the change in August	1922–1995, Emilia-Romagna, Italy
Suhaila and Yusop (2018)	PT, sequential MK	Change point Annual and seasonal temperature	Most of the change points in the temperature series occurred in 1996, 1997, and 1998. Breakpoints are related to El Nino and La Nina. In addition, significant increasing trends in annual and seasonal average, maximum, and minimum temperatures were determined	Peninsular Malaysia

Table 1 (continued)

Authors	Method	Purpose and data	Result	Period and location
Sharma and Saha (2017)	MK, modified MK, Theil-Sen's slope	Change point Rainfall	Except for the southeastern part of the basin, it was observed that the precipitation trend decreased in the annual and monsoon seasons. The highest decrease occurred in the northwestern part during annual and monsoon seasons, and the lowest in the northeastern part	Damodar River basin, India
Ahmed and Ogedengbe (2021)	ITA, MK	Trend Evaporation and solar radiation	Monthly evaporation data usually has decreasing trends. Solar radiation decreased significantly by 5% in January, July and October. It was found that the ITA method showed more reliable results than the MK	1973–2018, Nigeria
Serencam (2019)	MK, ITA	Trend Total annual rainfall and temperature	Precipitation records showed significant downward trends in low, medium and high levels, on average − 3.4%, − 3.8%, and − 2.4%, respectively In the temperature series, it was found to be + 4.6%, + 4.8% and + 7.2% at low, medium, and high levels, respectively	Yesilirmak region, Turkey
Lei et al. (2020)	Sequential MK, PT, MK, Spearman's rho	Trend test, abrupt change Water level	No significant abrupt change in the trend in mean water levels was detected	1956–2012, Poyang Lake, China
Singh et al. (2021)	ITA, MK, modified MK (mMK), linear regression	Spatio-temporal trends Rainfall	In monsoons and annual precipitation, generally increasing trends of the peninsula and northwestern India have occurred. However, decreasing trends were found in the central, northeastern parts of the country. Therefore, it has been determined that ITA is more advantageous than MK in terms of giving more detailed results	1901–2019, India
Salehi et al. (2020)	Pettitt-Whitney-Mann, the SNHT, Buishand's, the Von Neumann tests, MK, sequential MK	Change point Seasonal and annual precipitation	In most stations, upward and downward trends in annual and seasonal precipitation occurred after 1960 and 1990, respectively	1957–2016, Iran

Table 1 (continued)

Authors	Method	Purpose and data	Result	Period and location
Gumus et al. (2022)	MK, ITA	Trend Streamflow	According to the MK and ITA, the trend directions were found to be generally similar. However, according to the ITA method, most annual flows have a low trend. In addition, decreasing trends are usually dominant in the basin's middle region	Tigris river basin, Turkey
Yürekli (2015)	MK and Theil–Sen slope estimator, sequential MK	Direction, the magnitude of trend Precipitation	The change years in Kilis, Şırnak, Ağrı, Elazığ, Bitlis, and Siirt stations generally occurred around 1980, 1979, 1987, 1986, 1984, and 1965	Euphrates–Tigris basin, Turkey
Şişman (2021)	MK, ITA	Trends Sea surface temperature	According to ITA, more trend increase was seen at Giresun, Ayvalık, and Mersin stations. In addition, increasing trends were seen in Turkey's sea surface temperature data at the stations of the Mediterranean coastal region	Turkey
Katipoğlu and Acar (2022)	MK, mMK	Trend Hydrological drought	Significant decreasing trends in the summer generally dominate the standardized runoff index (SRI) values. It has also been determined that the basin is at considerable risk from hydrological drought	Euphrates basin, Turkey
Katipoğlu (2022a)	ITA, MK Spearman's rho	Trend Monthly, seasonal, and annual mean temperatures	As a result, increasing temperature trends occurred, usually at the 1% significance level, according to the ITA method. According to MK and SR, there are statistically significant increases in February, March, April, July, August, Spring, Summer, and Annual periods	1967–2017, Euphrates basin, Turkey
Katipoğlu (2022b)	ITA, sequential MK	Trend, change point Potential evapotranspiration	According to ITA, significant increasing trends have been detected in PET values. According to sequential MK, PET trends are generally up, except for the winter season. In addition, ITA and sequential MK tests showed remarkable similarities	1964–2017, Tigris basin, Turkey

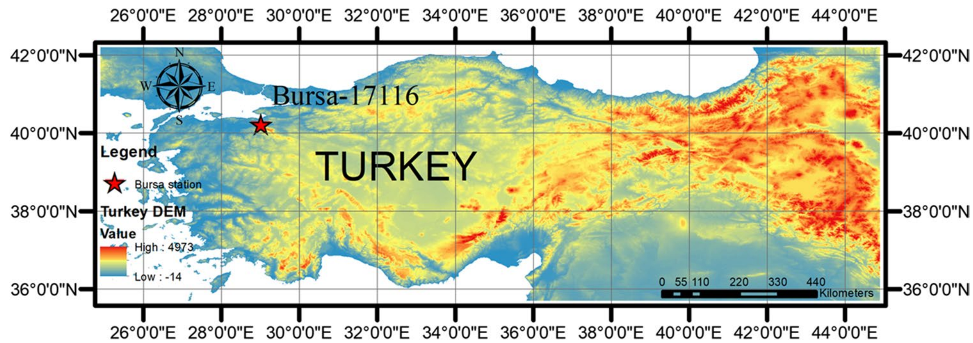


Fig. 1 Location map of Bursa meteorology station

Table 2 Summary statistics of various climatic parameters of Bursa meteorological observation station

Data	Statistic/Time period	Spring	Summer	Autumn	Winter	Annual
Mean temp. (°C)	Mean	12.99	23.59	15.61	6.31	14.63
	Max	16.30	25.67	17.83	9.83	16.81
	Min	10.80	21.50	13.17	2.27	12.98
	Std	1.21	0.94	1.04	1.53	0.75
Max. temp. (°C)	Mean	32.21	37.92	34.30	21.90	37.96
	Max	37.00	43.80	40.30	27.30	43.80
	Min	25.70	33.60	28.10	16.40	33.60
	Std	2.35	1.93	2.36	2.32	1.93
Min. temp. (°C)	Mean	– 3.22	9.81	-0.70	-8.63	-8.51
	Max	0.30	14.80	4.60	-2.50	-2.40
	Min	– 10.50	4.00	-8.40	-19.20	-19.20
	Std	2.02	1.98	2.49	4.34	4.31
Mean WS (m/s)	Mean	1.73	2.04	1.67	2.37	2.01
	Max	3.10	3.27	3.60	4.07	3.03
	Min	0.10	0.33	0.37	0.60	0.42
	Std	0.58	0.65	0.57	0.74	0.58
Mean RH (%)	Mean	69.88	60.61	71.50	73.90	68.97
	Max	78.73	69.63	81.40	81.40	75.39
	Min	60.13	49.63	63.10	64.50	62.15
	Std	4.22	4.16	3.50	3.50	2.76
Max Prec. (mm)	Mean	27.48	26.48	38.80	37.06	50.89
	Max	55.00	200.90	114.40	89.20	200.90
	Min	10.00	3.90	8.80	15.40	22.10
	Std	9.58	23.16	19.51	13.58	23.21
Sum SD (hour)	Mean	543.39	938.83	528.34	268.41	2278.97
	Max	714.40	1095.80	706.20	403.10	2678.30
	Min	32.00	369.90	182.00	20.50	1197.10
	Std	101.34	123.07	93.49	65.03	289.31

$$t = \sum_{i=1}^{n} n_i \tag{4}$$

Mean *E(t)* and variance *Var(t)* values of test statistics

$$E(t) = \frac{n(n-1)}{4} \tag{5}$$

$$Var(t) = \frac{n(n-1)(2n+5)}{72} \tag{6}$$

The forward-sequential values of *u(t)* statistic are calculated as follows (Sneyers 1990).

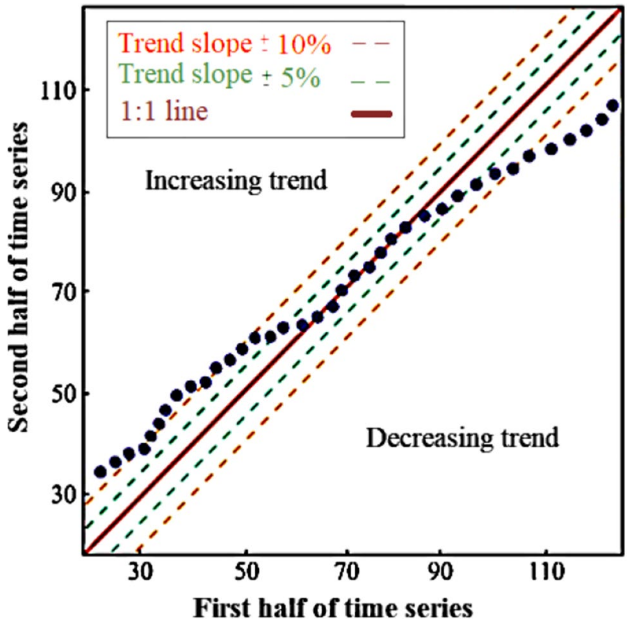


Fig. 2 Interpretation of the ITA method (Şişman and Kizilöz 2021)

$$u(t) = \frac{[t - E(t)]}{\sqrt{Var(t)}} \tag{7}$$

Similarly, $u'(t)$ values are calculated backward, starting from the end of the series.

2.4 Standard normal homogeneity test (SNHT)

This method proposed by Alexandersson is used to reveal the homogeneity and change point in many climatic and meteorological variables (Alexandersson 1986). This method is preferred because it is simple to implement. The $T(c)$ statistic is used to compare the average of the first "c" year of recording with that of the last "$n-c$" year. The $T(c)$ statistic is calculated by Eq. 8.

$$T(c) = c \cdot \overline{z_1} + (n - c) \cdot c \cdot \overline{z}_2^2 \tag{8}$$

$$\overline{z}_1 = \sum_{i=1}^{c} (y_i - \overline{y})\sigma / c \tag{9}$$

$$\overline{z}_2^2 = \sum\nolimits_{i=1+c}^{c} ((y_i - \overline{y})\sigma / (n - c) \tag{10}$$

where $\overline{y}is$ mean and σ is the standard deviation of the annual series (y_i). The year c is the change point if the value of T_0 is maximum. The T_0 test statistic is as in Eq. 11.

$$T_0 = \max_{1 \le c \le n} T(c) \tag{11}$$

If the T_0 test statistic exceeds the critical values in Table 3, the null hypothesis is rejected, and it is decided that the data is not homogeneous. The critical values indicate the data length (N) value in the analyzed hydro-meteorological time series at the 5% confidence interval in Table 3.

When interpolated in Table 3 for 86 years of observation, the critical value is found as 8.99. This value is greater than the test statistic, indicating a break.

2.5 Pettitt test (PT)

PT is a non-parametric statistical test proposed by Pettitt (1979) to determine the change point in a time series. The test statistic is related to the Mann–Whitney statistic, and its value can be calculated with Eqs. 12 and 13 (Wijngaard et al. 2003).

$$X_k = 2\sum_{i=1}^{k} r_i - k(n+1) \tag{12}$$

where r_i is the rank of the ith observation when the values x_1, x_2,..., x_n in the series are arranged in ascending order. When there is a break in year K, the statistic is maximum or minimum in year $k = K$. The statistical change point is calculated by Eq. 13 (Zarenistanak et al. 2014).

$$X_K = \max_{1 \le k \le n} |X_K| \tag{13}$$

Table 4 shows the test statistics for the 95% confidence interval. If the result of the homogeneity test is less than the critical value, that dataset is called homogeneous. The

Table 3 T_0 test values for 95% confidence interval

N	20	30	40	50	70	100
5%	6.95	7.65	8.10	8.45	8.80	9.15

Table 4 X_K test values at 95% confidence interval

N	20	30	40	50	70	100
5%	57	107	167	235	393	677

critical values depend on the time series's data length (N) at the 5% confidence interval in Table 4.

When interpolated in Table 4 for 86 years of observation, the critical value is found as 544. This value is greater than the test statistic, indicating a break.

3 Results and discussion

This study examines the trends of various meteorological data recorded at the Bursa meteorological observation station and determines their years of shift. For this purpose, the trends in seasonal and annual temperature, maximum precipitation, relative humidity, wind speed, and sunshine duration time series were analyzed using ITA and sequential Mann–Kendall methods. Meteorological data trends were evaluated by taking 5% interval line as a reference in the graphical ITA method and with 90% and 95% confidence intervals in the ITA slope method. In addition, statistically significant trends and years of trend shifts were evaluated with the sequential Mann–Kendall method test. When the ITA trend graphs of seasonal and annual average temperature values recorded in the Bursa meteorological observation station were examined, the most important trend was observed during the winter. Analyses showed that the lowest values increase by 5% in the winter season, while the highest values tend to decrease by 5%. There was no significant trend observed in median values. In the spring, temperature values between 12 and 13 °C had a monotonic upward trend line in the range of 5%. There was no significant trend for other periods. In addition, a monotonic upward trend below the 5% interval line was observed in the summer and annual periods. In autumn, no significant trend was observed. When the non-monotonic trends of annual and seasonal average temperatures are evaluated, increasing trends are dominant in spring, autumn, and annual periods, while a decreasing trend is observed in winter (Fig. 3).

ITA trend graphs of seasonal and annual maximum temperature values recorded in the Bursa meteorological observation station showed that while there was no significant

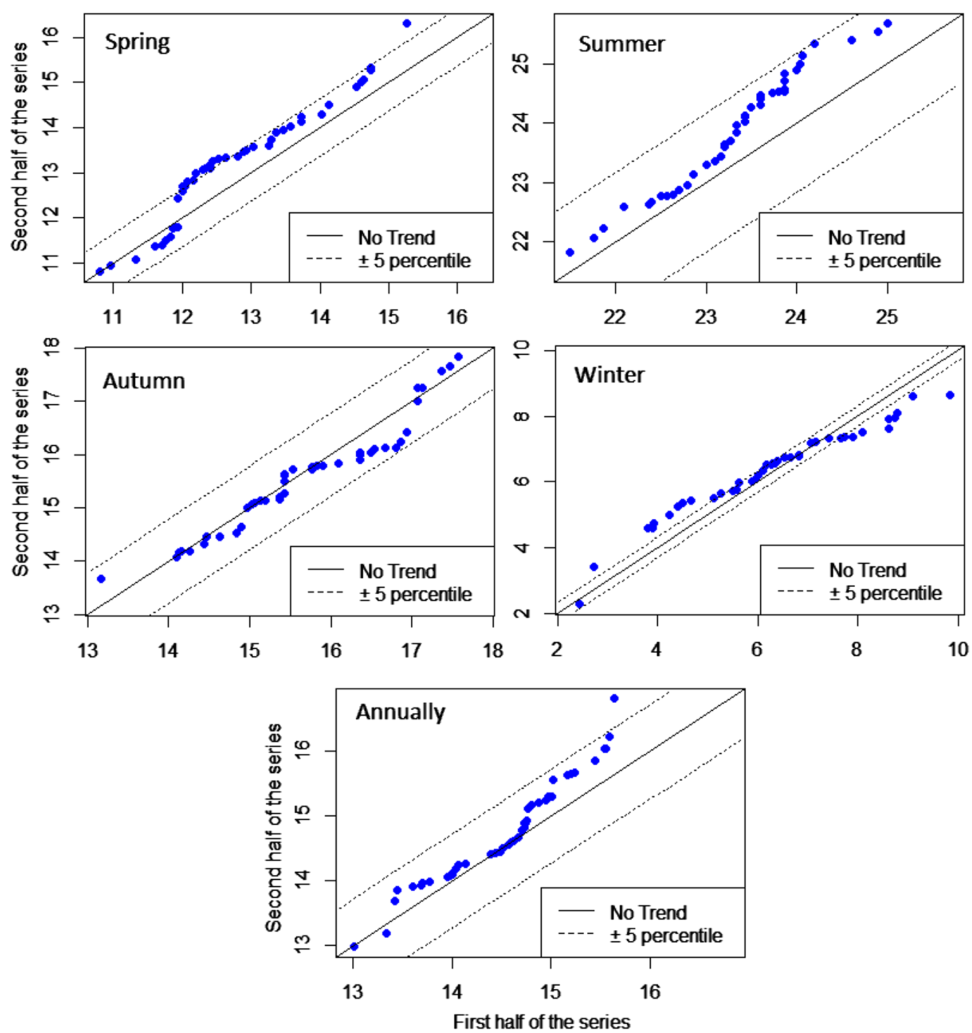


Fig. 3 ITA results of annual and seasonal average temperatures (°C)

trend for the spring, summer, and yearly periods, monotonic upward trends prevailed in the autumn and winter seasons. While a monotonic upward trend line in the range of 5% in the lowest and highest values stayed in the autumn period, a trend line does not exist for average values since these were scattered around the 1:1 line. When the non-monotonic trends of annual and seasonal maximum temperatures are evaluated, it is seen that decreasing trends are dominant in spring, summer and annual periods (Fig. 4).

According to ITA trend graphs of seasonal and annual minimum temperature values recorded in the Bursa meteorological observation station, while spring, summer, winter, and annual periods had monotonic upward trend lines in the range of 5%, the results for the autumn period were unstable. In the autumn period, while an upward trend line in the range of 5% was observed for values under − 3 °C, a decreasing trend line in the range of 5% was observed for values over − 3 °C. When the non-monotonic trends of annual and seasonal minimum temperatures are evaluated, it is seen that decreasing trends are dominant in autumn, winter, and annual periods (Fig. 5).

ITA trend analysis of seasonal and annual average wind speed values in Bursa showed a monotonic upward trend in the range of 5% usually prevails in the spring. In summer, winter, and annual periods, there was a monotonic downward trend in the range of 5% for values below 2 °C and an upward trend in the range of 5% for values over 2 °C. In autumn, there was a downward trend in the range of 5% for values below 1.5 °C and an upward trend in the range of 5% for values over 1.5 °C. When the non-monotonic trends of annual and seasonal average wind speed values are evaluated, it is seen that decreasing trends prevail in all seasons and in the annual period (Fig. 6).

According to the ITA trend analysis of seasonal and annual average humidity values in Bursa, monotonic downward trends in the range of 5% were prevalent for these values in the spring and summer seasons. In winter, significant monotonic downward trends in the range of 5% prevailed for values below 75% average humidity, and there were no trends for values over 75% average humidity. While significant downward trends prevail for values below 72% in the annual period, there are no trends

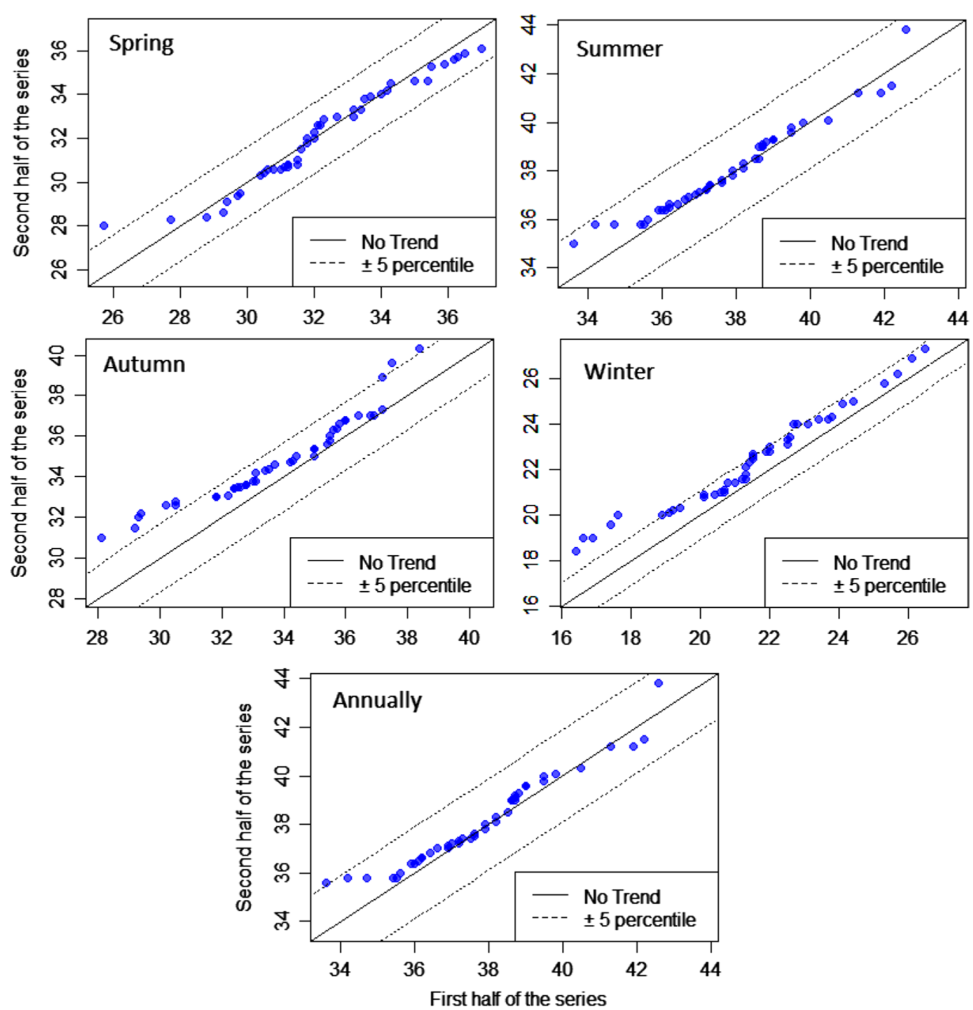


Fig. 4 ITA results of annual and seasonal maximum temperatures (°C)

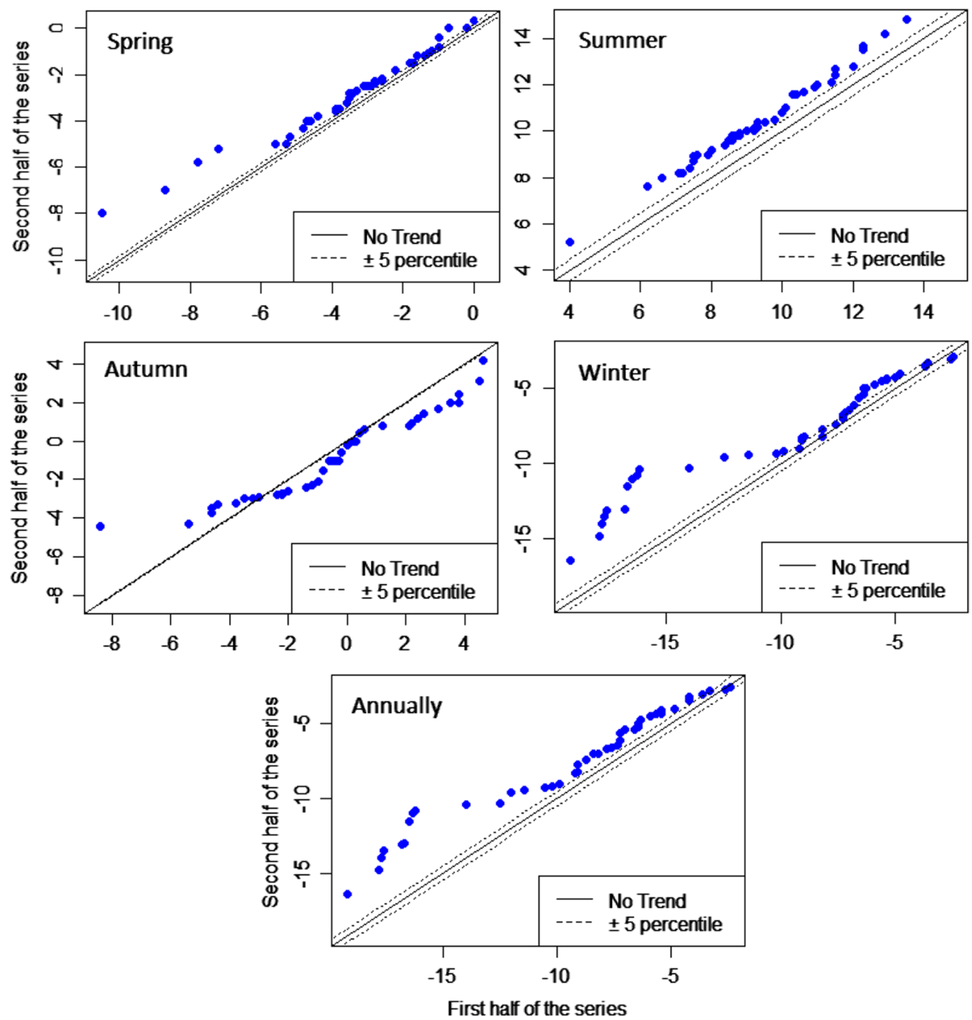


Fig. 5 ITA results of annual and seasonal minimum temperatures (°C)

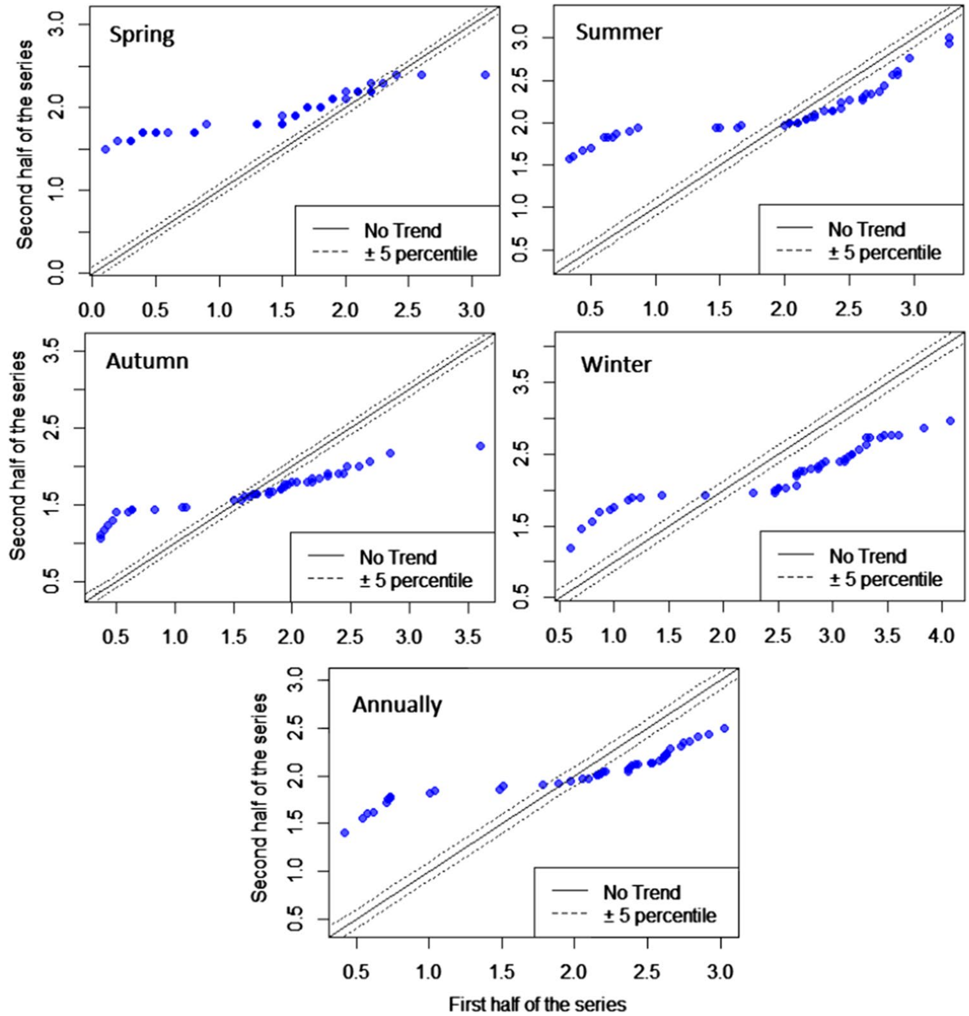
for values above 72%. There was no significant trend in autumn. When the non-monotonic trends of annual and seasonal average relative humidity values are evaluated, it has been determined that increasing trends are dominant in all periods except for the spring season (Fig. 7).

According to the ITA trend analysis of seasonal and annual average maximum rainfall values in Bursa, while there was an unstable result in spring and autumn, a monotonic upward trend generally prevailed. In the summer and annual periods, downward trends in the range of 5% prevailed. In the winter, downward trends in the range of 5% prevailed for value above 40. When the non-monotonic trends of annual and seasonal maximum precipitation values are analyzed, while increasing trends are dominant in autumn, there are decreasing trends in other time periods (Fig. 8).

According to the ITA trend analysis of seasonal and annual sunshine duration values in Bursa, monotonic downward trends in the range of 5% prevailed in all time periods (Fig. 9).

ITA slope results of various meteorological variables in Bursa province were shown in Table 5. When the results were evaluated, it was seen that significant upward trends in the 95% confidence interval in all seasons and annual periods for average temperatures prevailed. For maximum temperature values, downward trends in the 95% confidence interval were present for the spring period. There were no significant upward trends for other time periods. While downward trends for minimum temperatures were observed in the autumn season, statistically significant upward trends prevailed in other time periods. For average wind speeds, significant upward trends prevailed in the 95% confidence interval in spring and summer and in the 90% confidence interval in the annual time period. A significant downward trend in the 95% confidence interval was present in the winter season. In autumn, there was no statistically significant trend. It has been found that statistically significant downward trends for average relative humidity values prevailed. Significant downward trends for average relative humidity values in seasonal and annual periods prevailed. While

Fig. 6 ITA results of annual and seasonal average wind speed (m/s)



maximum precipitation values had downward trends in the summer and annual periods, upward trends prevailed in the autumn season. It was noted that statistically significant downward trends for sunshine duration prevailed in all time periods.

Sequential Mann–Kendall method test result graphs of the seasonal and annual average temperature values recorded in the Bursa station were shown in Fig. 10. When the graphs were examined, it was observed that the u(t) curve intersected the u'(t) curve in 2015 in the spring period and ended without reaching the 95% confidence interval (± 1.96). Thus, even though there were upward trends for temperature in spring, these trends have no statistical significance. In the summer season, the u(t) curve intersected the u'(t) curve in 2015 and crossed the 95% confidence interval. Therefore, there is a statistically significant upward trend in average temperatures in the summer season. Since the curves do not intersect each other in the autumn, no meaningful trend was observed. In the winter season, a downward trend that has been ongoing since 1962 was observed. In the annual period, there was an upward trend that began in 2015, although this trend was statistically insignificant.

Sequential Mann–Kendall method result graphs of the seasonal and annual maximum temperature values recorded in the Bursa station were shown in Fig. 11. When the graphs are examined, it was observed that the u(t) curve does not intersect the u'(t) curve in the spring; thus, no significant trend was present. In the summer and annual periods, the u(t) curve and the u'(t) curve moved parallel to each other until they intersected in 1995. This indicates that there was a trend, although statistically significant, in summer maximum temperatures in 1995. However, the curves moving parallel to each other again since 2010 indicate that this trend ended. The u(t) curve intersects the u'(t) curve in autumn 2005 and moves upwards. However, since the curves do not exceed the 95% limit, it cannot be said that a statistically significant trend has started. In the winter season, the u(t) curve intersects the u'(t) curve in 2002 and reaches the 95% confidence interval. Therefore, a statistically significant upward trend began in 2002 in the winter season.

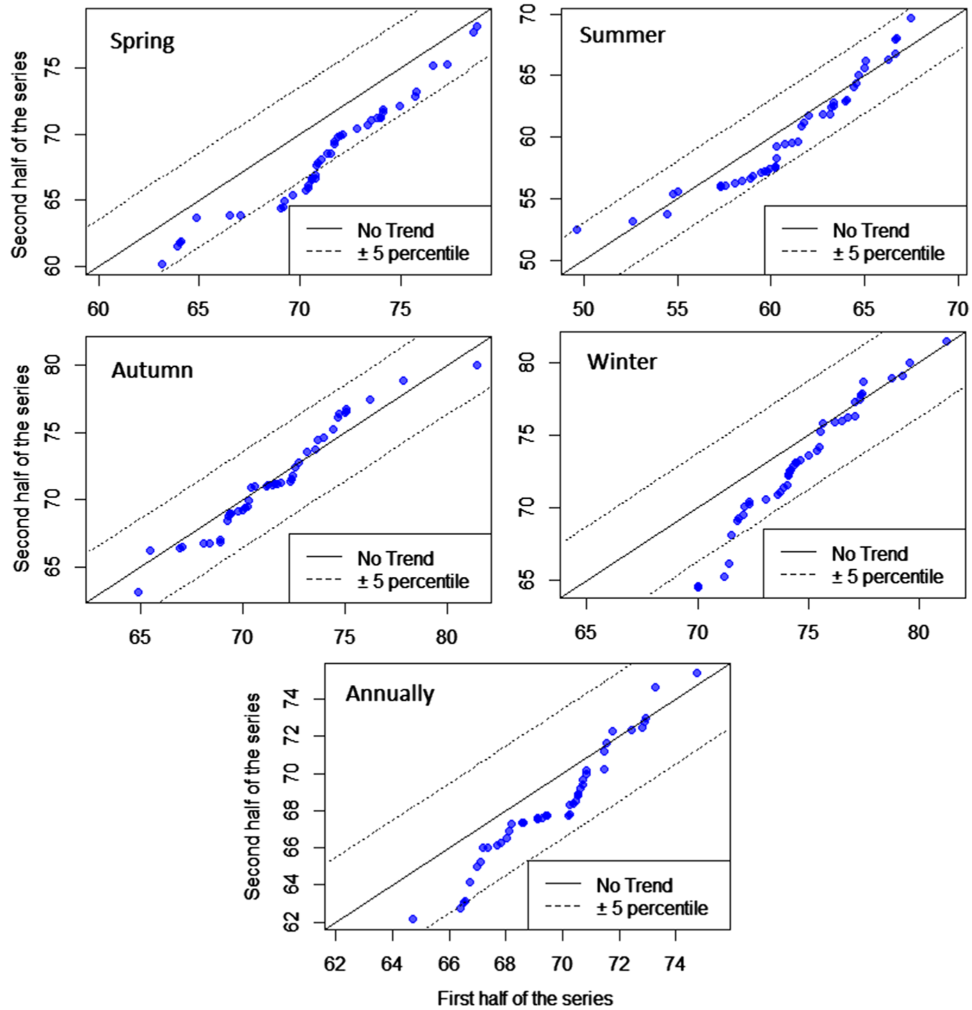


Fig. 7 ITA results of annual and seasonal average relative humidity (%)

Sequential Mann–Kendall method result graphs of the seasonal and annual minimum temperature values recorded in the Bursa station were shown in Fig. 12. When the graphs are examined, it is seen that in spring period, the u(t) curve intersects the u'(t) curve in 2013. In summer, the u(t) curve intersected the u'(t) curve in 2006 and crossed the 95% confidence interval. This indicates that an upward trend in maximum temperatures in the summer season began in 2006. In autumn period, the u(t) curve intersects the u'(t) curve in 1947 and falls below the 95% confidence interval. Therefore, it can be said that statistically significant downward trends were prevailing in the autumn period. It is seen that the statistically insignificant downward trend in the minimum temperature in the winter season started in 1950. The graph showed that while downward trends in minimum temperatures during the annual time period began in 1947, an upward trend began in 2015.

Sequential Mann–Kendall method result graphs of the seasonal and annual average wind speed values recorded in the Bursa station were shown in Fig. 13. When the graphs were analyzed, it was seen that the u(t) curve intersected the u'(t) curve in the spring of 1955 and crosses the 95% confidence interval. Thus, it was seen that statistically significant upward trends are present in the spring period. In the summer, autumn, winter and annual periods, the u(t) curve intersected the u'(t) curve in 1946 and crossed the 95% confidence interval. Therefore, a significant upward trend in average wind speeds has begun for these time periods. However, since the u(t) curve ends below the 95% confidence interval, no significant trend was present.

Sequential Mann–Kendall method test result graphs of the seasonal and annual average relative humidity values recorded in the Bursa station were shown in Fig. 14. When the graphs were examined, a significant downward trend in the 95% confidence interval that began in the spring of 1977 was observed. A upward trend started in 1950 in the summer season. In 1962, an upward trend started in the autumn season. During the winter period, significant downward trends which began in 1934 and were in the 95% confidence interval have started. In addition, upward trends in the annual time period that started in 1950 were observed; these ended in 1980.

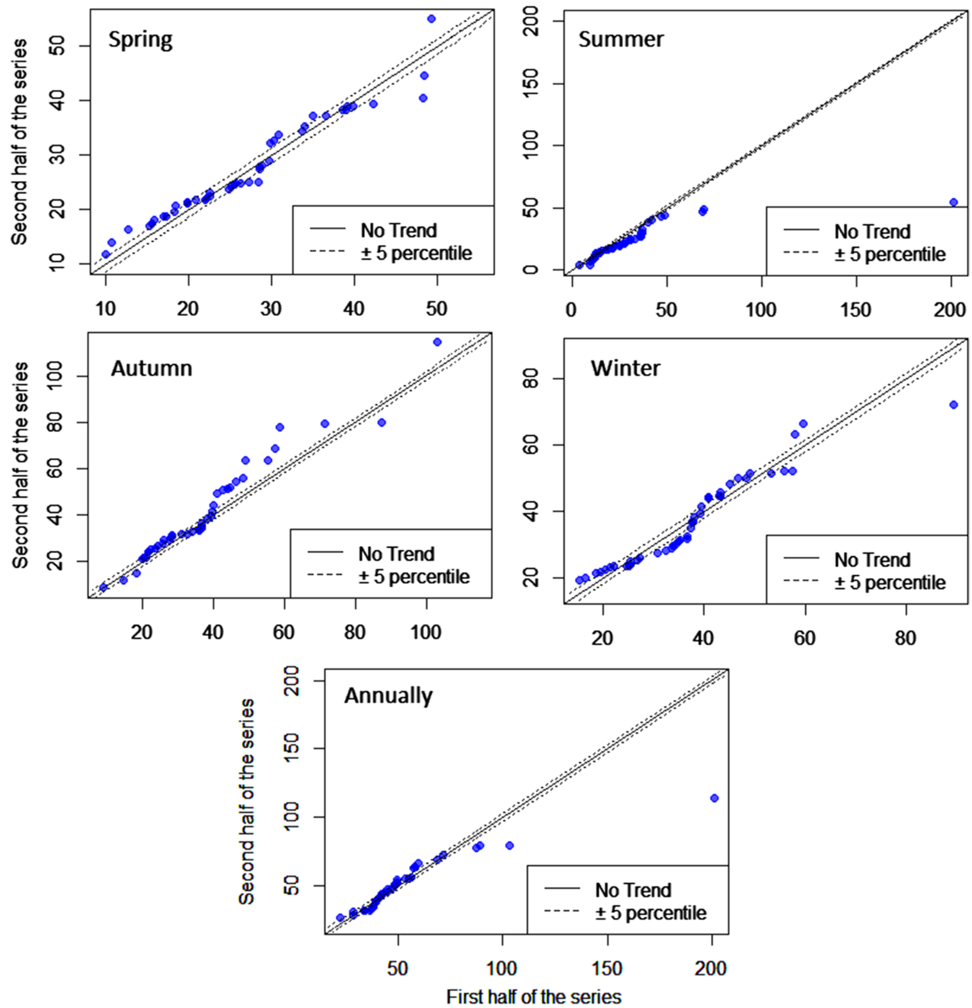


Fig. 8 ITA results of annual and seasonal maximum precipitation (mm)

Sequential Mann–Kendall method test result graphs of the seasonal and annual average maximum precipitation values recorded in the Bursa station were shown in Fig. 15. According to the graphs, no significant trends for all periods can be mentioned since the curves move parallel.

Sequential Mann–Kendall method test result graphs of the seasonal and annual average sunshine duration values recorded in the Bursa station were shown in Fig. 16. According to the graphs, there were significant downward trends in the 95% confidence interval for spring starting in 1995, for summer starting in 1985, for autumn beginning in 1996, for winter starting in 2003, and for the annual time period beginning in 1997.

Table 6 shows the years of change in meteorological parameters analyzed with the sequential Mann–Kendall method. According to the analysis, the increase in average temperature values in 2015 in summer, increase in maximum temperatures in 2002 in winter, increase in minimum temperatures in 2006 in summer, and increasing trends in mean wind speed and mean relative humidity in the 1950s draw attention. In addition, it is seen that the decreasing trends started in the sunshine duration values in the 1990s.

Table 7 shows the change points of meteorological variables in Bursa station were determined according to SNHT and Pettitt tests. Values above the critical T_0 value = 8.99 X_E test values = 544 show significant changes in the 95% confidence interval. Accordingly, it is noteworthy that there were significant changes in average temperature data around 2009 and 1997, mean wind speed values around 1948, mean relative humidity around 1975, maximum precipitation data around 1942, and sunshine duration data around 2004. In addition, when the analysis results are compared with the sequential Mann–Kendall test, the change points are similar in seasonal and annual at wind speed and in the winter period at sunshine duration data. However, there are quite a lot of inconsistencies in the test results. It is thought that the main factors in the emergence of this situation are that the sequential Mann–Kendall method determines the year of change graphically, while the SNHT and Pettitt tests determine the changes statistically. In addition, the SNHT

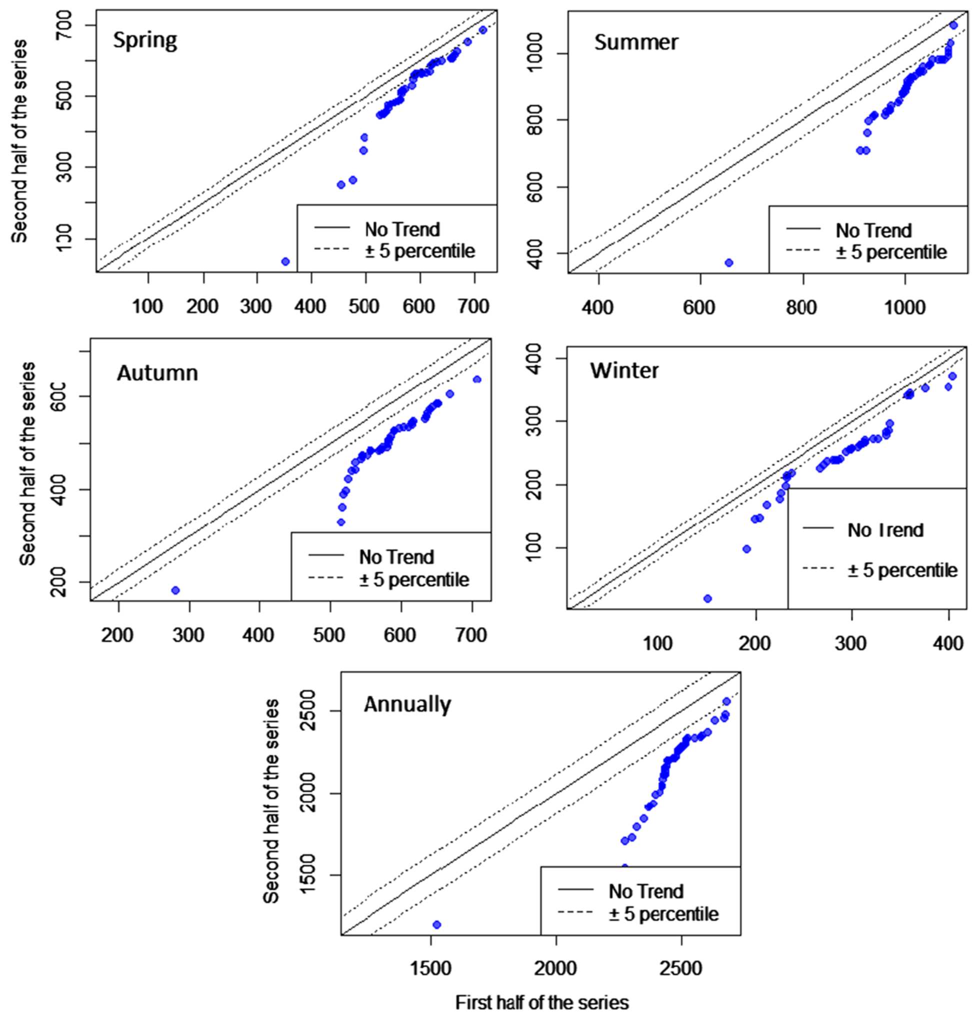


Fig. 9 ITA results of annual and seasonal average sunshine duration (hour)

and Pettitt tests generally showed near-change year results (Tables 6 and 7).

This study aims to analyze the trends and change years in various meteorological variables under the effects of climate change. According to the analysis results, a significant decrease trend was observed in precipitation in summer and annual periods. The study of Partal and Kahya (2006) aligns with these results. Partal and Kahya (2006) used MK and Sen's estimator of slope methods to analyze the trend of annual average precipitation values in Turkey. As a result, it has been revealed that significant downtrends dominate. It is thought that the decrease in precipitation in summer and annual periods may have negative consequences on greenhouse activities and agricultural production in the region. Hakan et al. (2010) examined the trend in annual average precipitation, temperature, and potential evapotranspiration data in Turkey with the MK test. While no significant trend was observed in precipitation, significant increase trends occurred in temperatures. Ceribasi and Aytulun (2018) applied Spearman's rho, MK tests to examine the trend in annual total rainfall and the annual average temperature in Bursa. According to the analysis, while no trends were found in the precipitation data taken from the Bursa station, increasing trends occurred in the temperature data. The outputs of the available literature largely agree with the results of the study. Moreover, Acar (2005) examined the trend in daily averages, maximum-minimum temperatures and precipitation data between 1931 and 2002 in Bursa and determined that the increasing trend was dominant. The study of Acar (2005) contradicts the study. It is thought that the use of the daily period and the data period used on this situation are effective. It is believed that the decrease in precipitation and the increasing trends in temperatures may cause the surface and groundwater levels to decrease in the region and therefore decrease in agricultural production, increase in groundwater pumping costs, and increase the severity of drought in the region, causing the spread of various diseases and forest fires to become important. In addition, decreasing precipitation and increasing temperatures may cause an increase in evapotranspiration, especially in the dry summer season, which may lead to a significant decrease in crop yields in the region. Moreover, since the lack of precipitation

Table 5 ITA slope results

		Spring	Summer	Autmn	Winter	Annual
Mean temp	Slope	0.0095	0.0131	−0.0023	0.0016	0.0055
	CL 5%	0.0015	0.0009	0.0013	0.0015	0.0009
	CL 1%	0.0013	0.0007	0.0010	0.0013	0.0007
	Trend	↑	↑	↑	↑	↑
Max. temp	Slope	−0.0025	0.0055	0.0246	0.0214	0.0073
	CL 5%	0.0024	0.0020	0.0033	0.0023	0.0022
	CL 1%	0.0020	0.0016	0.0028	0.0019	0.0018
	Trend	↓	↑	↑	↑	↑
Min temp	Slope	0.014	0.025	−0.008	0.039	0.042
	CL 5%	0.002	0.001	0.003	0.005	0.004
	CL 1%	0.001	0.001	0.003	0.004	0.003
	Trend	↑	↑	↓	↑	↑
Mean WS	Slope	0.0105	0.0039	−0.0003	−0.0066	0.00087
	CL 5%	0.0009	0.0016	0.0007	0.0012	0.00091
	CL 1%	0.0007	0.0013	0.0006	0.0010	0.00077
	Trend	↑	↑	↔	↓	↑*
Mean RH	Slope	−0.067	−0.018	−0.0035	−0.038	−0.031
	CL 5%	0.005	0.006	0.0038	0.003	0.003
	CL 1%	0.004	0.005	0.0032	0.003	0.002
	Trend	↓	↓	↓*	↓	↓
Max prec	Slope	0.008	−0.182	0.073	−0.010	−0.050
	CL 5%	0.010	0.075	0.022	0.019	0.047
	CL 1%	0.009	0.063	0.018	0.016	0.039
	Trend	↔	↓	↑	↔	↓
Sum SD	Slope	−1.63	−2.71	−2.07	−0.99	−7.41
	CL 5%	0.13	0.14	0.16	0.08	0.61
	CL 1%	0.11	0.12	0.14	0.07	0.51
	Trend	↓	↓	↓	↓	↓

↓ ↑ shows CL 5%, * shows CL 1%, ↔: no trend

will increase the need for irrigation water in the region, it may increase the water transfer of the water structures and cause an increase in water stress. In this case, the ecological systems in the area may be adversely affected.

Yagbasan et al. (2020) analyzed the trend in the values of average monthly temperature, precipitation, humidity, wind speed, sunshine duration, evaporation, and cloud cover, located in Ankara meteorological observation station in Turkey, with MK, Modified MK, ITA, linear trend (LT) tests. As a result, MK, modified MK, and LT test results are similar to each other, with an increasing trend in WS values and a statistically significant decreasing trend in RH values. According to the ITA test, increasing trends in temperature, precipitation, WS, and cloud cover values and statistically significant decreasing trends in SS, RH, and pan evaporation values are dominant. Yılmaz (2021) analyzed the trend in wind speed data in Turkey with the MK test. As a result of the study, it was concluded that decreasing trends are dominant in seasonal and annual wind speed data in the Bursa meteorology observation station. When the findings are compared with the Bursa station, which has a similar climate structure, it shows a great deal of similarity.

Zeleňáková et al. (2018) in sixteen climatic stations in Eastern Slovakia monthly, seasonal, and annual temperature and precipitation time series trends and change points were analyzed by MK and Sen slope methods. Trends in temperature showed an increasing trend in winter and spring. The majority of precipitations showed an increasing trend. An abrupt change in rainfall in 1985 (+) and temperatures in 1970 (+) attracted attention. In the Kale (2020) study, seasonal and annual mean temperature trends were analyzed with the sequential Mann–Kendall method in the Tapi basin. In the annual and winter mean temperature time series, significant uptrends that started in 1974 and 1972 were found. Mphale et al. (2018) applied sequential Mann–Kendall method to analyze the change in annual T_{min} and T_{max} time series in the Southern Africa Botswana station. As a result, the change of note was generally found in 1982/1983, and it showed that this change was related to the oscillation of El Niño. Although the result of the study largely overlaps

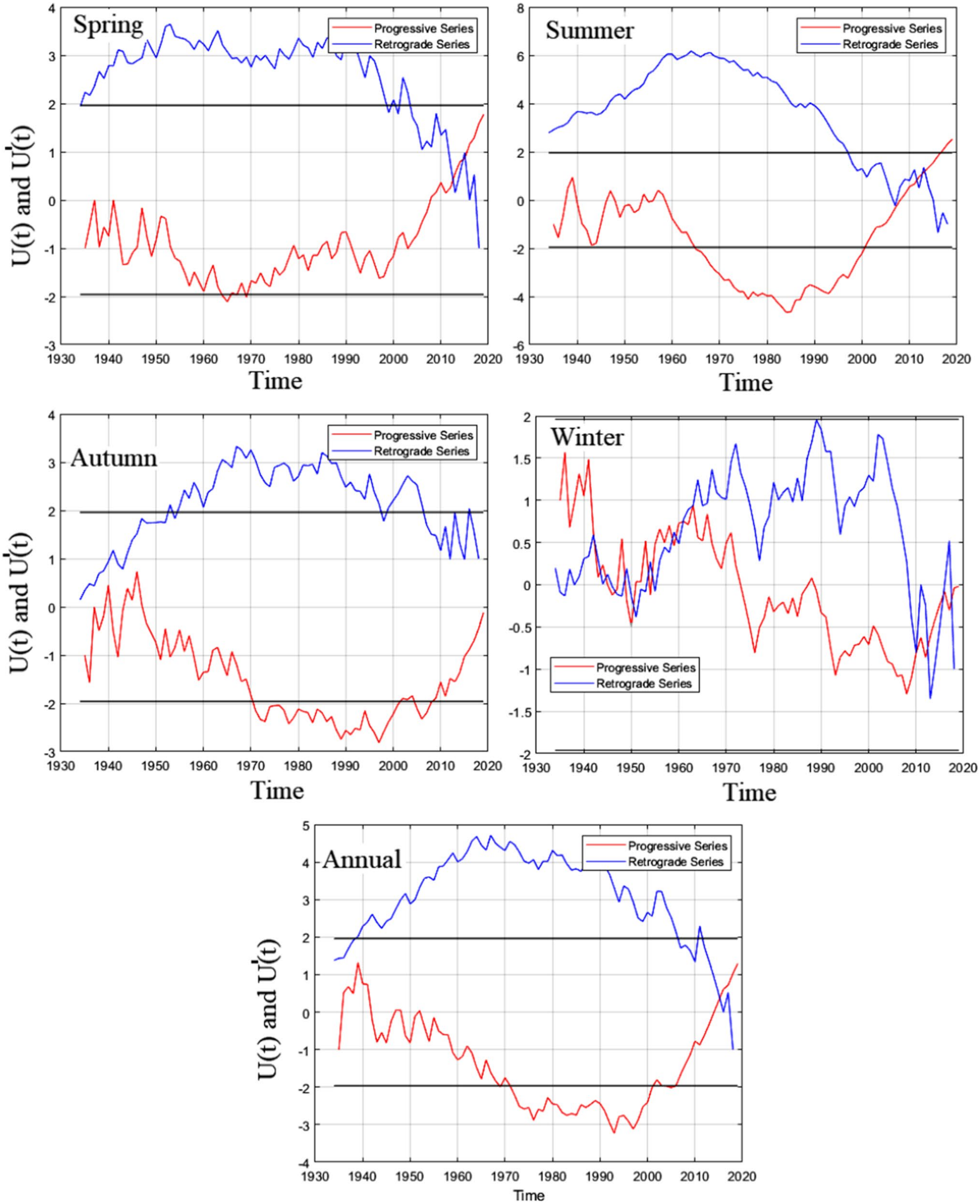


Fig. 10 Sequential Mann–Kendall method results of annual and seasonal average temperatures

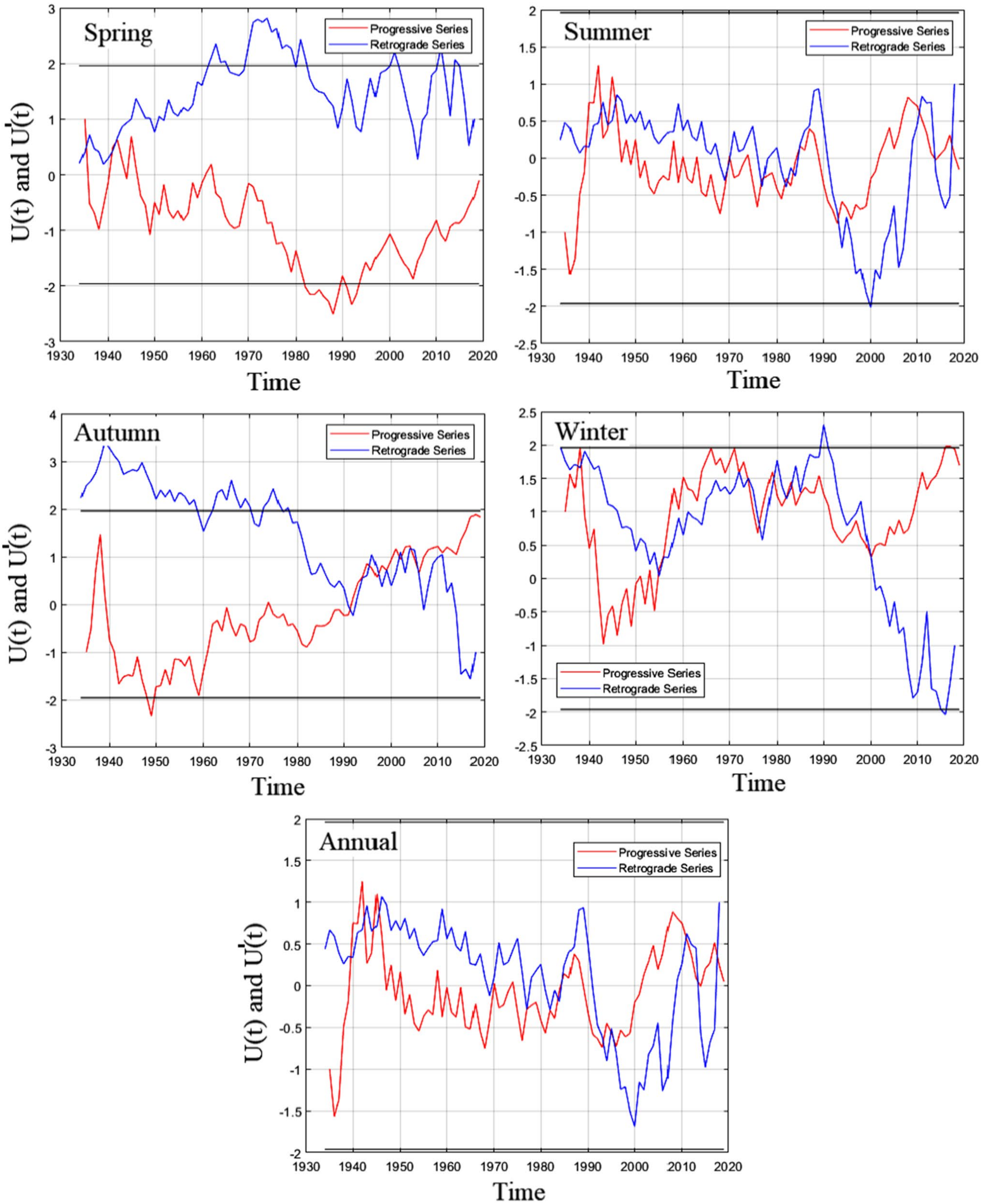


Fig. 11 Sequential Mann–Kendall method results of annual and seasonal maximum temperatures

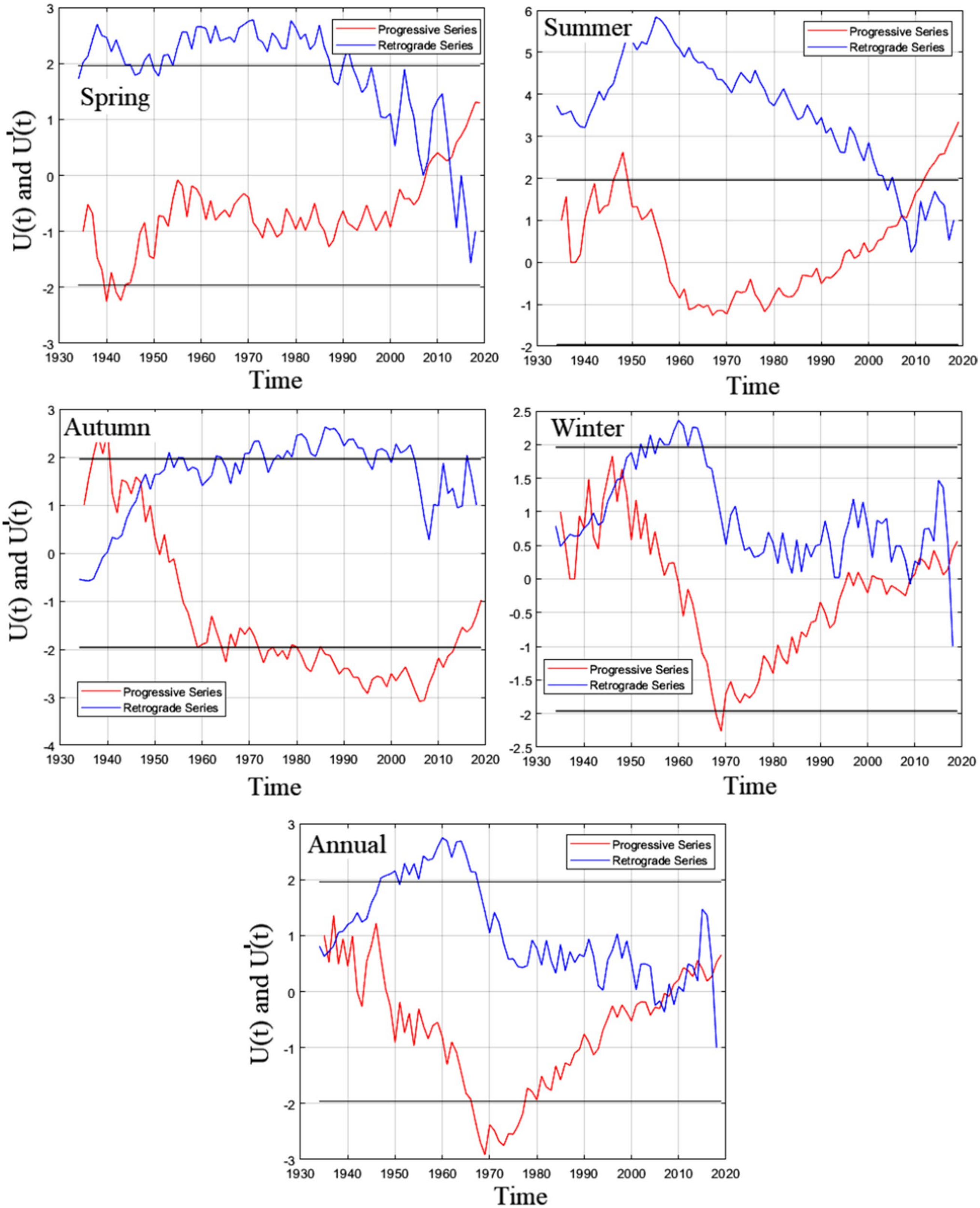


Fig. 12 Sequential Mann–Kendall method results of annual and seasonal minimum temperatures

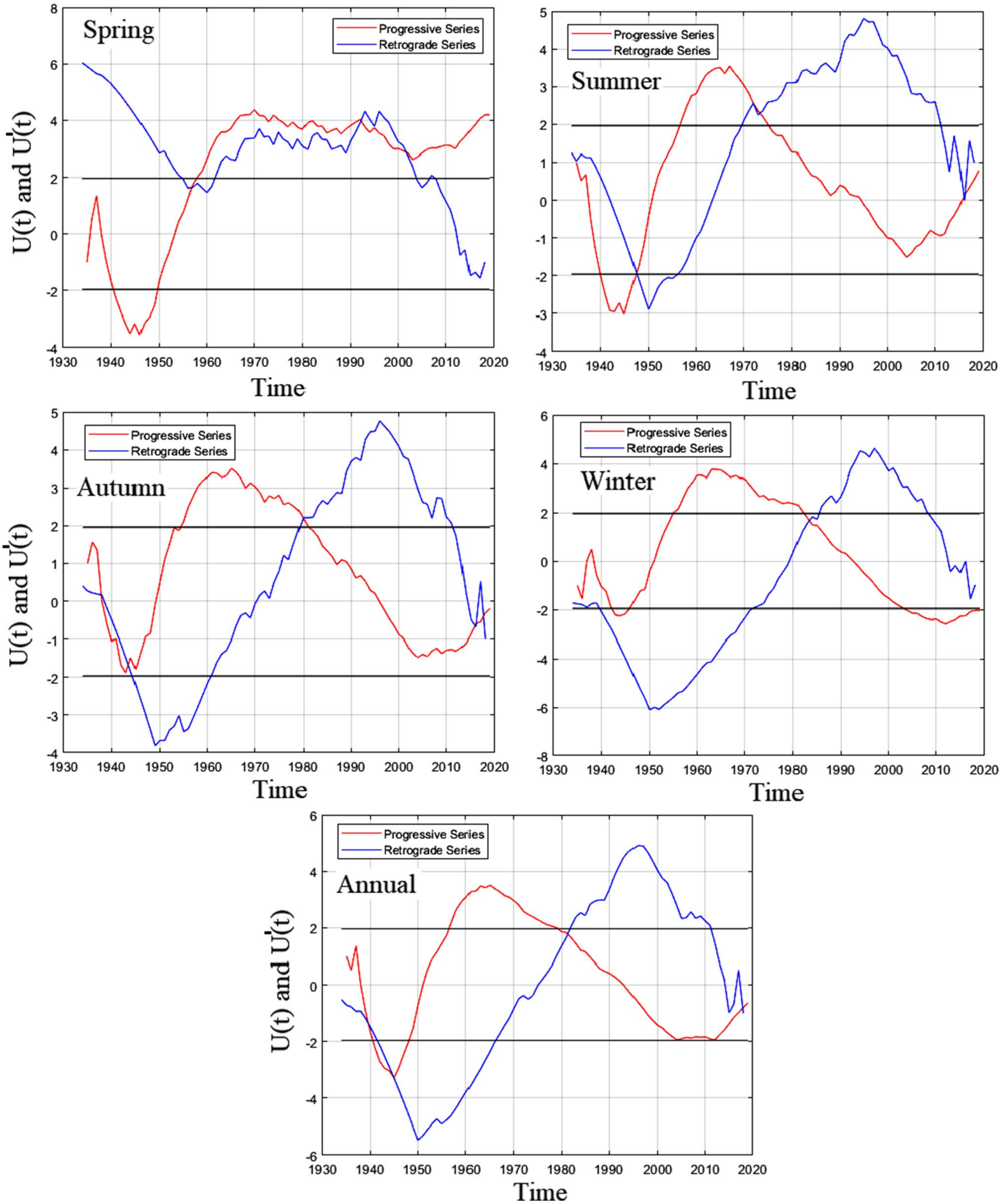


Fig. 13 Sequential Mann–Kendall method results of annual and seasonal average WS

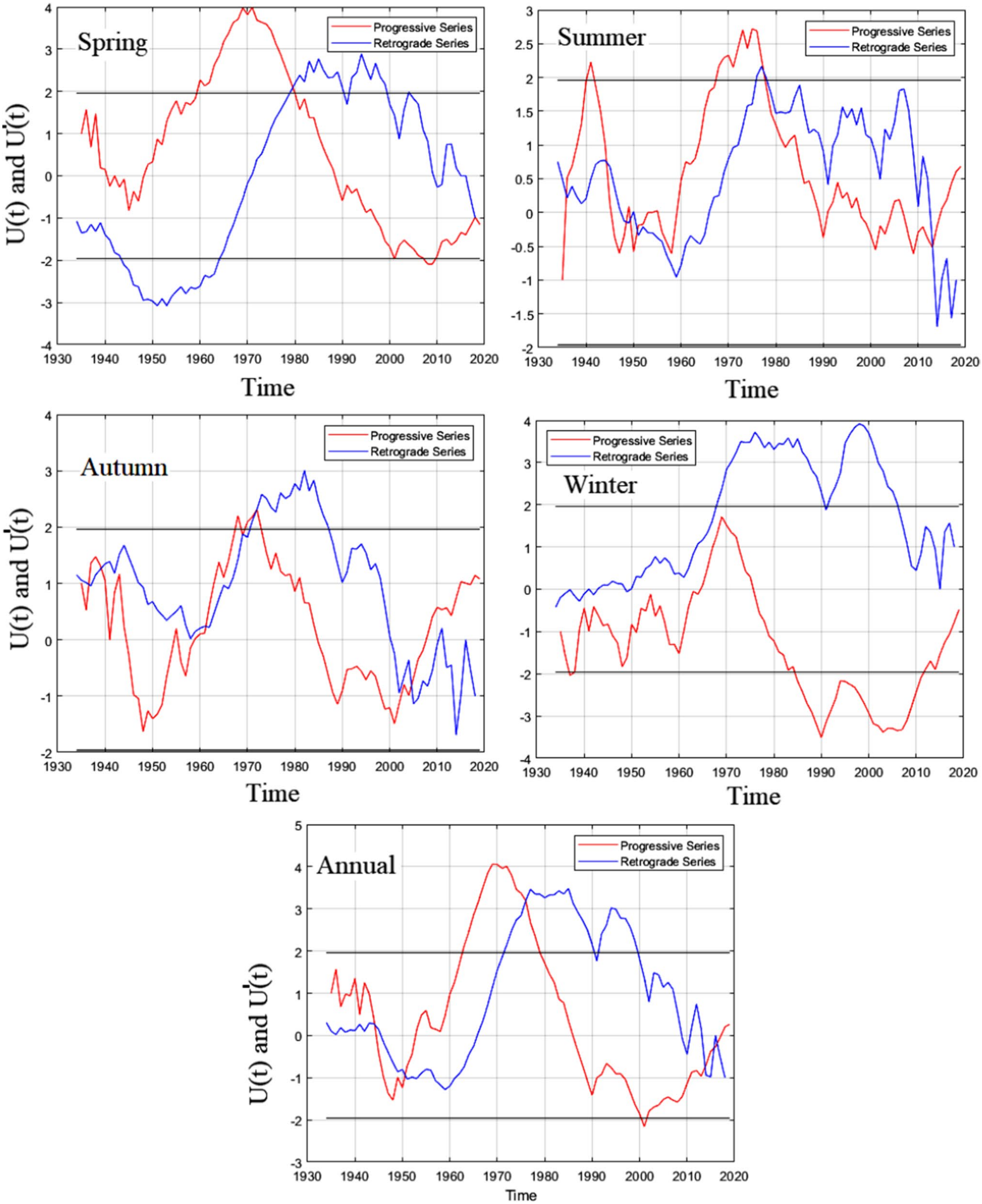


Fig. 14 Sequential Mann–Kendall method results of annual and seasonal average RH

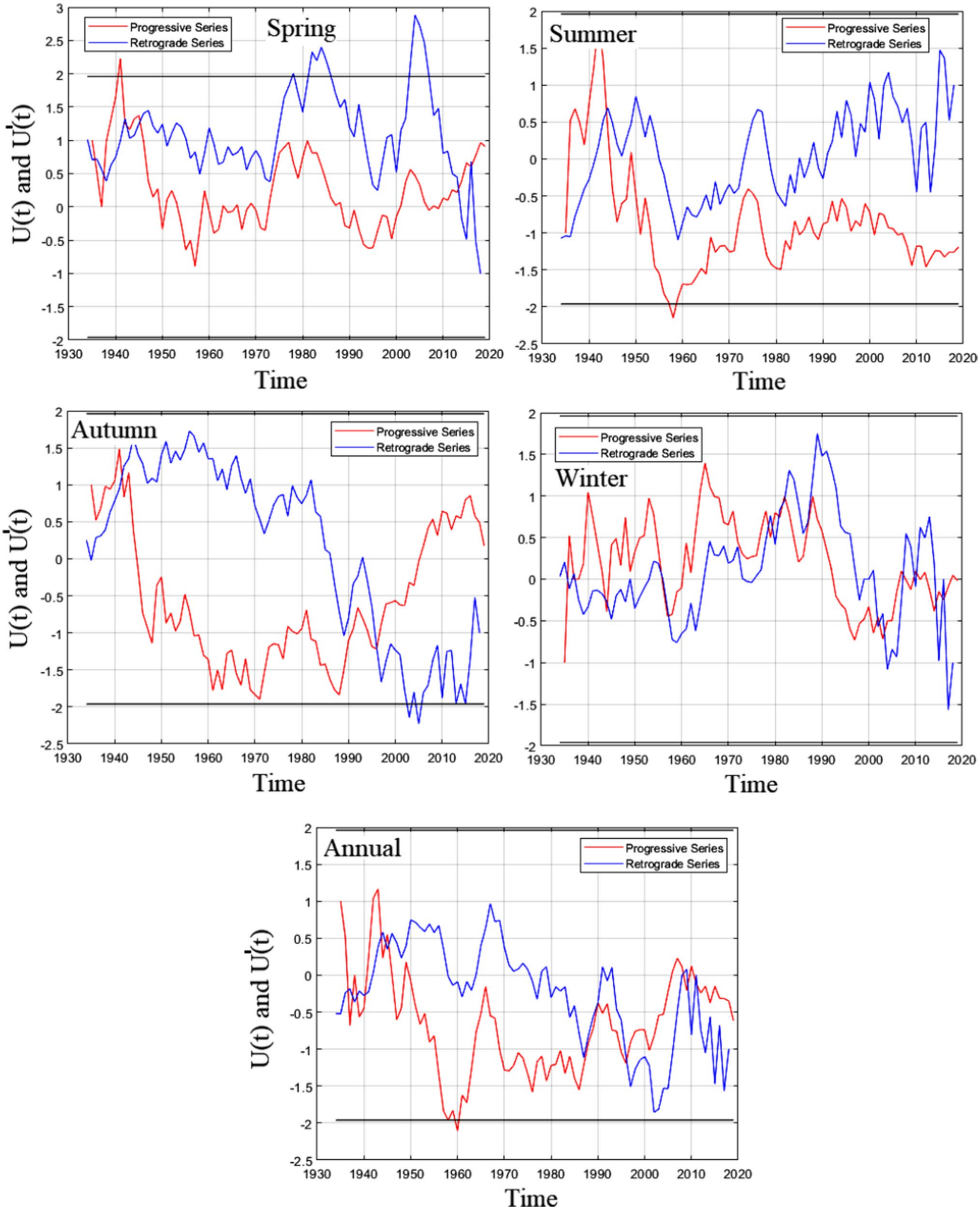


Fig. 15 Sequential Mann–Kendall method results of annual and seasonal maximum precipitation

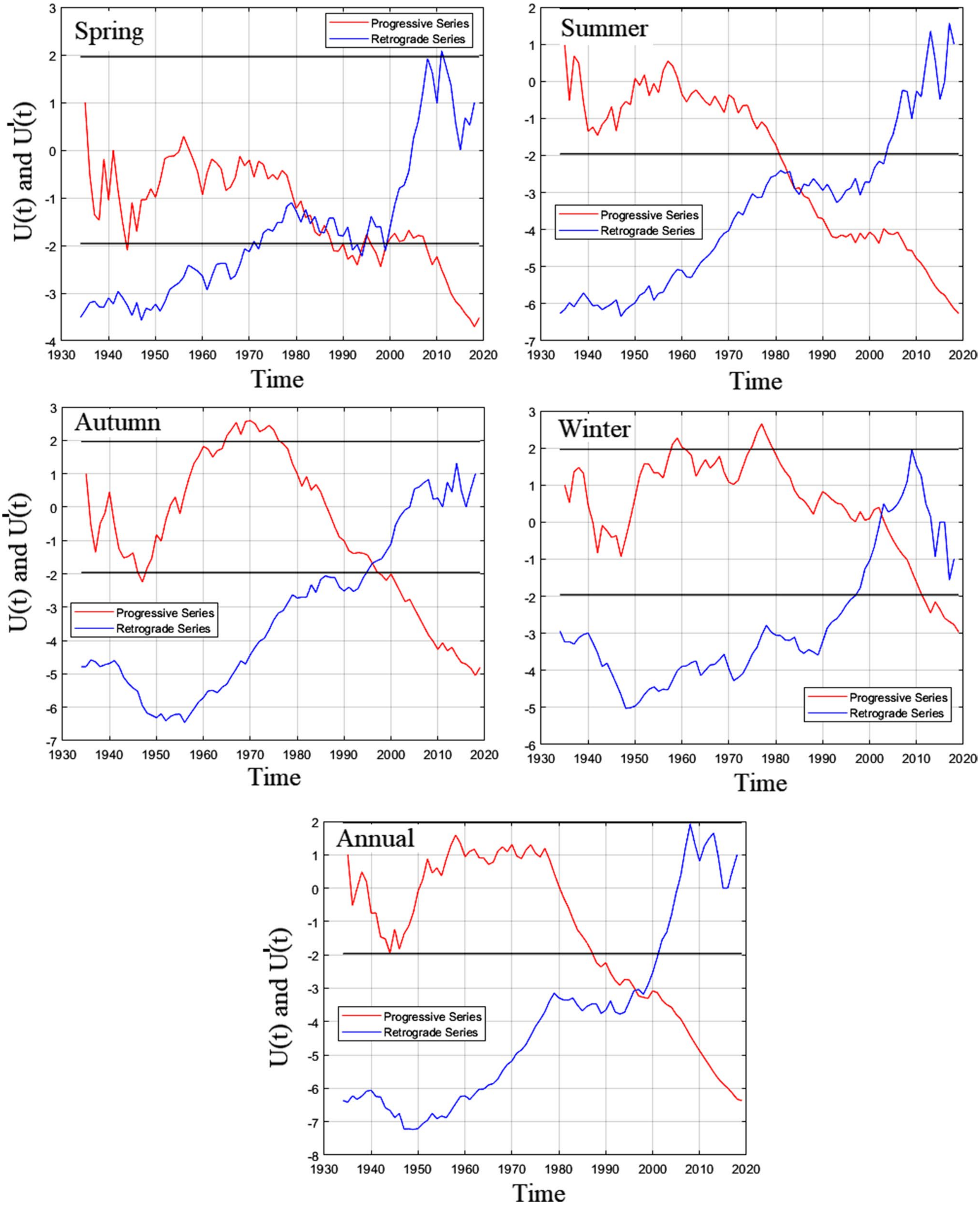


Fig. 16 Sequential Mann–Kendall method results of annual and seasonal sum SD

Table 6 Years of change in meteorological parameters according to the sequential Mann–Kendall method

	Spring	Summer	Autmn	Winter	Annual
Mean temperature		2015↑			
Max. temperature				2002↑	
Min. temperature		2006↑	1947↓		
Mean wind speed	1955↑	1946↑	1946↑	1946↑	1946↑
Mean relative humidity	1950↑	1950↑	1962↑	1934↓	1950↑
Max. precipitation					
Sunshine duration	1995 ↓	1985↓	1996↓	2003↓	1997↓

↓ ↑ shows CL 5%, * shows CL 1%

with the present study, there is a difference in the years of the trend change. This situation is thought to be caused by the effect of atmospheric oscillations occurring in different regions on precipitation and temperature variables. Although the results of the studies in the literature largely overlap with the analysis presented, there is a difference in the years of trend change. This situation is thought to be caused by the effect of atmospheric oscillations occurring in different regions on precipitation and temperature variables.

4 Conclusion

This study used ITA and sequential Mann–Kendall methods to examine the trend in various meteorological time series in Bursa. The trend of the variables in the low, medium, and high ranges according to the ITA method and the change years according to the sequential Mann–Kendall method were analyzed. The study outputs are valuable in evaluating extreme climate events, ensuring the sustainability of ecosystems, making a flood drought management plan, and taking precautions against climate change. The main results obtained in the study are listed as follows:

- A significant increasing trend was observed in the mean, minimum, and maximum temperatures in seasonal and annual periods, generally in the 95% confidence interval. The beginning years of significant trends appear in 1995 and 2015. On the other hand, significant increase trends are observed in the average wind speed values, except for the autumn and winter seasons. The beginning years of the trends draw attention as 1946/1955. Statistically significant decreasing trends were observed in average relative humidity values, with the start year of the trend being 1973/1977. Significant decreasing trends were observed at the 95% confidence interval in the summer and annual periods in maximum precipitation values. Significant decreasing trends occurred in the sum sunshine duration values in all time periods in the 95% confidence interval of the trend starting the year 1985/1995.
- Similar trends are generally observed when the sequential Mann–Kendall method and ITA graphs are analyzed.
- The ITA method can easily detect hidden sub-trends thanks to its ability to present important trends graphically. Thanks to this feature, it is more effective than the sequential Mann–Kendall method. However, the sequential Mann–Kendall method is more useful in showing the year of change in trend.
- SNHT and Pettitt tests showed very similar results in determining the year of change in meteorological variables.
- The SNHT and Pettitt statistical tests, which are used based on the homogeneity test, showed a slight similarity

Table 7 Years of change in meteorological parameters according to the SNHT and Pettitt

	Test	Spring	Summer	Autmn	Winter	Annual
Mean temperature	SNHT	2008/2.910	**2005/13.926**	**2009/35.302**	**2011/9.483**	**2006/21.512**
	Pettitt	2008/290	**1998/707**	**1997/1189**	2006/439	**1997/804**
Max. temperature	SNHT	**1954/9.107**	2005/4.0134	2017/1.795	1991/8.614	2017/1.890
	Pettitt	1954/521	2005/365	2008/204	**1982/596**	1996/215
Min. temperature	SNHT	1934/4.574	2000/7.202	2008/20.250	**1947/9.260**	1973/4.234
	Pettitt	1983/321	2000/532	**1993/856**	**1952/572**	1975/385
Mean wind speed	SNHT	**1949/25.44**	**1949/57.733**	**1948/43.997**	**1948/35.881**	**1949/45.478**
	Pettitt	**1981/867**	**1955/1250**	**1949/924**	**1948/878**	**1949/969**
Mean relative humidity	SNHT	**2007/11.18**	**1982/10.233**	2013/7.188	**2001/11.451**	2008/7.549
	Pettitt	**1972/610**	**1975/751**	1958/375	**2001/ 601**	**1976/558**
Max. precipitation	SNHT	1938/1.300	1934/3.329	**1942/12.608**	1943/2.980	1942/7.399
	Pettitt	1988/239	1995/345	1949/462	1988/ 367	1949/292
Sunshine duration	SNHT	**2002/25.255**	**2007/22.969**	**2006/33.252**	**2004/27.399**	**2006/44.599**
	Pettitt	**2002/883**	**1977/792**	1978/132	1978/123	1978/152

Note: Bold characters indicate change points at 5% significance level with the sequential Mann–Kendall test while determining the year of change.

- Significant progress will be achieved in revealing meteorological data trends in the region, managing water resources in the region, increasing agricultural productivity, and constructing of water structures.
- For future studies, it will be useful to compare the trends in meteorological variables with different trend methods and to correlate the changes in the trend with atmospheric oscillations. In addition, to better understand meteorological variables trends, it is possible to analyze the trend in more detail by separating it into components with signal decomposition processes such as wavelet transform and imperial mode decomposition.

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Author contribution O. M. Katipoğlu solely made the study.

Data availability Data will be made available upon reasonable request.

Declarations

Ethics approval The manuscript complies with all the ethical requirements, the paper was not published in any journal.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The author declares no competing interests.

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