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Evaluation of meteorological time series trends in Southeastern Anatolia, Turkey

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In this study, trend analyses of six climatic variables (mean, minimum, and maximum temperature, relative humidity, wind speed, and precipitation) for 1966–2020 are conducted for the Southeastern Anatolia Region, which is the main focus of the integrated development project in Turkey (Turkish acronym GAP). The trends for seasonal and annual periods are determined using the Mann-Kendall (MK) test, and Sen's slope method and regression analyses are used to find the trends' slopes. Moreover, Innovative Trend Analysis (ITA) is also used to find the time series changes for low, medium, and high values. As a result of the analyses, the mean, minimum, and maximum temperatures in the GAP region show increasing trends according to both methods. Significant trends are obtained at a limited number of stations for the precipitation, relative humidity, and wind speed with the MK test, while consistent decreasing trends are found at most stations with the ITA method.

Keywords: trend analysis, climatic variables, Mann-Kendall test, innovative trend analysis, Sen's slope

1. Introduction

Climate is defined as the average variation in meteorological variables such as temperature, humidity, precipitation, and pressure recorded in a region over many years (Anders et al., 2014). A region's geographical and topographical features play an essential role in its climate. The changes in these meteorological variables are usually caused by climate change (Özfidaner and Topaloğlu, 2020). Climate change is a complex phenomenon, as it does not only depend on weather conditions and climate variability. The adverse effects of climate change also affect agricultural activities and water resources; thus, the ecological balance might deteriorate (Arnell, 1998). As a result of the deterioration, significant changes occur in precipitation, run-off, evaporation, etc., which are the elements of the hydrological cycle. As a consequence of climate change, the number and severity of natural disasters, such as drought and flood, will increase in some areas of the world, and long-term and severe droughts may cause widespread aridity in some regions (Heltberg and Bonch-Osmolovskiy, 2011; Santos and Fragoso, 2013).

Minimizing the adverse effects of climate change is essential for managing agricultural activities and water resources planning. Meteorological data should be analyzed to determine the precautions and priorities to be taken for the continuation of these activities. For this purpose, determining climate data trends related to hydrological and climatological fields for researchers and planners is an exciting subject for researching climate change scenarios and developing climate impact research. Although different researchers have developed many methods to determine the trends in hydrological and meteorological data, Mann-Kendall (Mann, 1945, Kendall, 1948), Sen's slope (Sen, 1968), and Innovative Trend Analysis (Şen, 2012) methods are frequently preferred in different studies (Partal and Kahya, 2006; Hamed, 2008; Da Silva et al., 2015; Gümüş et al., 2021). The Mann-Kendall (MK) test is a nonparametric, distribution-free method and is generally preferred for determining monotonic trends in hydrological and meteorological time series. However, to apply the MK test, the serial correlation effect must be removed from the time series, and the time series should be long-term. Monotonic trend analysis methods only give results about whether there is a trend in the time series. Sen's slope method (Sen, 1968), which assumes that the trend of a time series is linear, is often used to detect trends since it is less sensitive to outliers in the time series compared to the ordinary linear regression method.

Innovative Trend Analysis (ITA), another trend-setting method suggested by Şen (2012), has been frequently used to determine the trend of hydrological and meteorological time series in recent years (Wu and Qian, 2017; Caloiero, 2018; Marinović et al., 2021; Pandey et al., 2021). Compared to monotonic trend analysis methods, this method allows the graphical evaluation of the trends for different ranges (*e.g.*, low, medium, and high) in the time series. Furthermore, unlike the MK test, the ITA does not have assumptions such as serial correlation or data length (Şen, 2012; Kişi, 2015). Numerous studies have been conducted to determine the trend of hydrological and meteorological time series with these trend analysis methods (separately or together) in different parts of the world. For example, the hydrological and meteorological time series trend in Iran (Tabari et al., 2011; Nikzad Tehrani et al., 2018; Asadi and Karami, 2022), in India (Gupta et al., 2021; Mandal et al., 2021), in China (Cui et al., 2017; Wang et al., 2020) and in Hungary and Northern Serbia (Gavrilov et al., 2020) were determined with these methods. Besides, investigating the historical trends of climate variables in different regions will help to understand the impact of climate change on these variables.

On the other hand, many trend analysis studies are carried out with the MK test and ITA for the whole of Turkey or its different regions using different climatic values, especially precipitation and temperature (Kadioğlu, 1997; Dogan et al., 2014; Ay, 2019; Ceribasi and Iyad Ceyhunlu, 2020; Citakoglu and Minarecioglu, 2021). However, a few studies focused on the Southeastern Anatolia Region; for example, Partal and Kahya (2006) carried out a trend analysis of monthly and annual precipitations in Turkey. The study results of the MK test showed a statistically significant decrease in precipitation in the southern region of Turkey. Yilmaz and Okkan (2018) determined the trend of annual precipitation data at nine stations in the Southeastern Anatolia Region of Turkey using ITA. In this study, a mixed sign of trends was found with a positive trend at three stations and a negative at two stations. Cicek and Duman (2015) studied the trends of seasonal and annual precipitation data in Turkey using the MK test. As a result of the study, a statistically insignificant decreasing trend was determined in the GAP region. In this region, it is necessary to pay attention to the sustainability of semi-arid climate characteristics and irrigation systems; decreasing precipitation may cause serious ecological problems. Hence, this study is carried out in the Southeastern Anatolia Region of Turkey, which is mostly arid and semi-arid (Türkeş, 1999) and known to be vulnerable to climate change, and covers the Southeastern Anatolia Project (Turkish acronym GAP) area.

The GAP is a multi-sectoral, integrated regional project for sustainable socio-economic development in the Southeastern Anatolia Region of Turkey. The construction of 22 dams, 19 hydropower plants with a total installed capacity of 7476 MW, the annual energy production of 27 billion kWh, and 1.8 million ha of land irrigation are envisaged in the GAP region (GAP, 2022). This project, which is expected to increase the development level of the region, is one of Turkey's most costly and comprehensive projects at the national level (Özis, 1983; Unver, 1997). In addition, it aims to create new employment opportunities that provide an economically viable income source by using the existing resources in the region.

Determining the changes occurring in the climatic variables in the GAP region contributes to the planning and management of the water resources in the region. In reviewing the studies on trend analysis of climatic variables by different researchers in Turkey, it has been found that these studies are mostly on a large scale and generally focus on the monotonic trends of annual mean temperatures and annual mean/total precipitation values. Here, the trends of annual and seasonal data for six climatic variables (mean, minimum, and maximum temperatures, humidity, wind speed, and precipitation) are analyzed for the period 1966–2020 at eight stations in the GAP region using the MK, ITA, and Sen's slope methods.

2. Materials and methods

2.1. Study area and data

The GAP area (Fig. 1) is an arid and semi-arid region located in the Southeastern Anatolia Region of Turkey. It covers the land borders extending from the south of the arc formed by the Southeastern Taurus Mountains in Turkey to the borderlines of Syria and Iraq, and it is located in the Southeastern Anatolia Region of the country. As seen in Fig. 1, the GAP region covers nine provinces (Siirt, Gaziantep, Kilis, Adiyaman, Sanliurfa, Mardin, Diyarbakir, Batman, and Sirnak) and generally shows continental climate characteristics. Summers in the region are quite long, hot, and dry, while winters are cold and rainy. Although the terrestrial climate prevails in the region, a transitional climate between continental and Mediterranean climates is seen in Adiyaman, Gaziantep, and

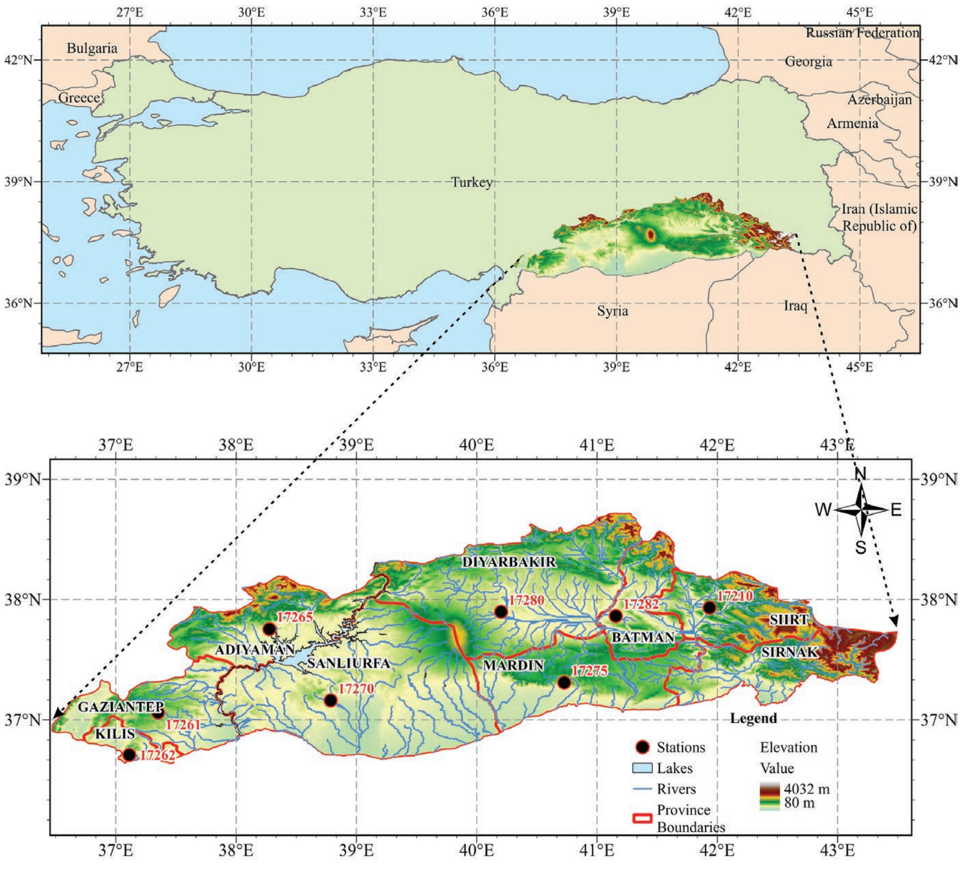

Figure 1. Study area.

Mardin provinces (Şimşek and Gülsoy, 2017). Approximately 10% of Turkey's population and land area and 20% of its irrigable lands are located in this GAP region (Demir, 2003). About half of the total land assets of the region are suitable for agricultural production. However, the low relative humidity in the region increases evaporation; hence, a severe summer drought negatively affects production in the region where summer precipitation is already low (Sensoy et al., 2008). Therefore, providing the required amount of water for agriculture is a vital issue for achieving the targets in the region.

Monthly mean temperature (T_{mean}), monthly mean minimum temperature (T_{min}), monthly mean maximum temperature (T_{max}), monthly mean relative humidity (RH), monthly mean wind speed (WS), and monthly total precipitation (P) parameters are measured between 1966 and 2020 at synoptic observation stations in eight city centres in the GAP region and used in trend analysis. However, as there had not been continuously measured climate data for Sirnak Province in the region, the station in this province could not be evaluated. The geographical information of stations and the corresponding mean annual values of six parameters are given in Tab. 1. In the last row of the table, there are long-term averages of the studied climatic variables in Turkey obtained from MGM (2020). The data used in this study are obtained from the Turkish State Meteorological Service. In this study, the outliers in the time series, which are values greater than 1.5 IQR (interquartile range), are determined. These outliers are deleted from the data set and accepted as missing values. The number of missing data (with deleted outliers) in the time series is at most 1.2%, and the missing data of the stations are completed with linear regression using nearby station data. The table shows that the temperatures (mean, minimum, and maximum) in the GAP region are approximately 3.5 °C higher than the long-term average values in Turkey. In contrast, the precipitation and humidity values in the region are 4 mm and 10% lower, respectively. Therefore, it can be said that the GAP region is more sensitive to drought.

Table 1. Information of stations and long-term averages of parameters.

Station No	Station name (Province)	Altitude (m)	Latitude (° N)	Longitude (° E)	Long-term annual averages (1966–2020)					
					T_{mean} (°C)	T_{min} (°C)	T_{max} (°C)	RH (%)	WS (m/s)	P (mm)
17210	Siirt	895	37.9319	41.9354	16.3	11.3	21.9	50	1.5	57
17261	Gaziantep	854	37.0595	37.3510	15.4	9.7	21.9	60	1.4	47
17262	Kilis	640	36.7085	37.1123	17.3	11.9	23.3	54	2.7	41
17265	Adiyaman	672	37.7553	38.2775	17.3	12.1	23.1	49	1.9	60
17270	Sanliurfa	550	37.1608	38.7863	18.6	13.1	24.5	51	1.7	38
17275	Mardin	1040	37.3103	40.7284	16.2	12.4	20.4	48	3.8	55
17280	Diyarbakir	674	37.8973	40.2027	15.8	9.0	22.7	55	2.5	42
17282	Batman	610	37.8636	41.1562	16.3	9.0	23.7	57	1.7	41
Long-term averages of Turkey (MGM, 2020)					13.2	7.8	19.1	64	2.0	52

2.2. Methodology

2.2.1. Mann-Kendall and Sen's slope methods for trend detection

The nonparametric Mann-Kendall (MK) test is one of the most commonly used tests to determine the monotonic trend of hydrological and meteorological data (Mann, 1945; Kendall, 1948). Unlike parametric trend tests, the MK test stands out because the data set does not have to comply with any distribution and is less affected by outliers or missing data (Hamed, 2008; Gavrilov et al., 2016). Therefore, this test can easily determine whether the trend in the time series is statistically significant. However, the most critical problem in nonparametric trend methods (such as the MK test) is the effect of serial correlation on the test results. For this reason, the serial correlation effect on the time series is checked with the method proposed by Salas (1980) and used in the literature (Mohsin and Gough, 2009; Suhaila and Yusop, 2017; Gümüş et al., 2021; Şimşek, 2021). In this method, the data set's Lag-1 correlation coefficient (r_1) is first checked for being in the range of Eq. (1).

$$\frac{-1-1.645\sqrt{n-2}}{n-1} < r_1 < \frac{-1+1.645\sqrt{n-2}}{n-1} \tag{1}$$

In Eq. (1), n represents the sample size of the time series. If the Lag-1 correlation coefficient is outside the range, there is a serial correlation effect on the time series. Finally, if the time series has a serial correlation effect, it is removed by applying the "pre-whitening" method suggested by von Storch (1995) in the time series where the serial correlation effect is detected. In this method, the "pre-whitened" time series is obtained by applying the process (x_2-r_1x_1, x_3–r_1x_2, …, x_n–r_1x_{n-1}, where x is data in the time series) to the time series with serial correlation, and trend analysis is performed by applying the MK test to these series (Mohsin and Gough, 2009).

In the MK test, the existence of the monotonic trend is checked with the H_0 and H_1 hypotheses. The null hypothesis, H_0, indicates that the data are ordered independently and randomly, while the alternative hypothesis, H_1, states a monotonic trend in the data. In this study, the presence of a statistically significant trend is checked at the 95% confidence level. Additionally, the magnitude of the trend that occurs in a time series is determined by the nonparametric method developed by Sen (1968) and known as Sen's slope estimator. The details of the methods can be found in Gümüş et al. (2022). In addition to the Mann-Kendall test and Sen's slope estimator methods, linear regression analysis can also be applied to detect and analyze the trend in a time series. The linear regression equation is $\alpha x+\beta$. Here β represents the intersection, and α is the slope and shows the mean temporal variation of the studied variable. Positive slope values indicate increasing trends, while negative values describe decreasing trends (Tabari et al., 2011; Gavrilov et al., 2016).

2.2.2. Innovative trend analysis (ITA)

The Innovative Trend Analysis (ITA), which investigates the existence of a trend by dividing the data set into two and ascending sorting in a Cartesian coordinate system, is proposed by Şen (2012). The ITA allows a clear definition and graphical display of the hydrological and meteorological time series trends of low, medium, and high values. Compared to other trend analysis methods, it does not require assumptions such as serial correlation effect, number of data, data distribution, etc. In this method, the first data set (y1) is sorted on the *X*-axis, and the second data set (y2) is ordered on the *Y*-axis. The trend is determined according to the scatter of the data above the 1:1 line (Fig. 2). If the data is accumulated around the 1:1 line, there is no trend. If it is above this line, there is an increasing trend, and if it is below this line, there is a decreasing trend. The distance of the data in the scatter plot from the line gives an idea of the trend's strength. The values close to the line mean that the trend has low strength, but if they are far from the line, a strong trend occurs. In recent studies, indicators have been added to graphs that specify confidence levels (Caloiero et al., 2018; Achite and Caloiero, 2021). This is meant to help the reader understand the distance between the non-trend line and the occurrence of a strong trend. For this purpose, two confidence limit lines (±5% and ±10%) have been added to the ITA graph in this study. It is assumed that there is "no trend" for values between 1:1 and ±5% lines, a "trend" for values between ±5% and ±10% lines, and a "strong trend" for values exceeding ±10% lines, as seen in Fig. 2.

In the case of a single monotonic trend in which all data increase or decrease, it is not necessary to evaluate the "low, medium, and high" ranges of values since

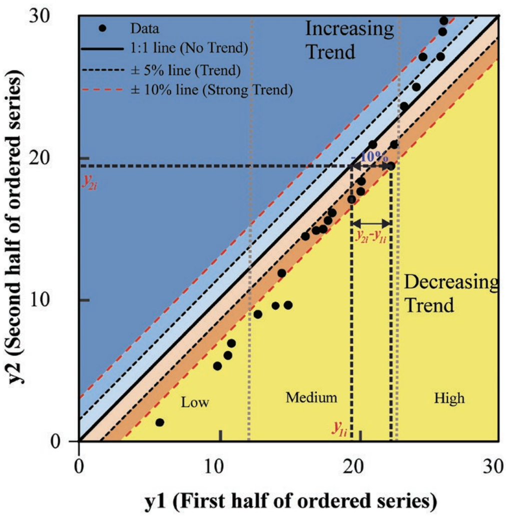

Figure 2. Illustration of the innovative trend analysis method (ITA).

there is only one trend slope. However, if there are data distributions with both increasing and decreasing trends, the data set can be divided into different groups to determine the trend of the data (Alashan, 2018; Caloiero et al., 2018). In this study, the data set is classified as low, medium, and high, and the low and high-value limits are calculated as $\bar{X} - S$ and $\bar{X} + S$, respectively, where $\bar{X}$ is the mean and S is the standard deviation of the first half of the time series (Alashan, 2018).

3. Result

3.1. Result of the MK and Sen's slope tests

The distribution of the calculated lag-1 correlation coefficients (seasonal and annual) of the meteorological parameters of eight stations located in the GAP region is given in Fig. 3. In the figure, the dashed lines represent the calculated ranges according to Eq. (1). If the calculated lag-1 correlation coefficient falls in the grey-filled part of the figure, there is no serial correlation effect in this value at the specified period, and the original data set is used in the MK test. For instance, the lag-1 correlation coefficient is in the calculated range in all periods (except for two stations in summer) for the P parameter. Also, almost all stations are in the calculated range in the winter, spring, and autumn periods for T_{mean} and T_{max} values. Figure 3 shows a serial correlation for WS in all periods, for T_{mean}, T_{min}, and T_{max} in annual and summer, and for RH in summer, autumn, and annual periods in almost all stations. In these periods, the "pre-whitening" procedure is performed before the MK test, and then the test is conducted on the "pre-whitened" series. The serial correlation effect of eight stations is removed, and the MK test is performed on the obtained time series.

For seasonal and annual periods, trend slopes (SS) calculated with Sen's slope method are given in Tab. 2 for each station. The distribution of the calcu-

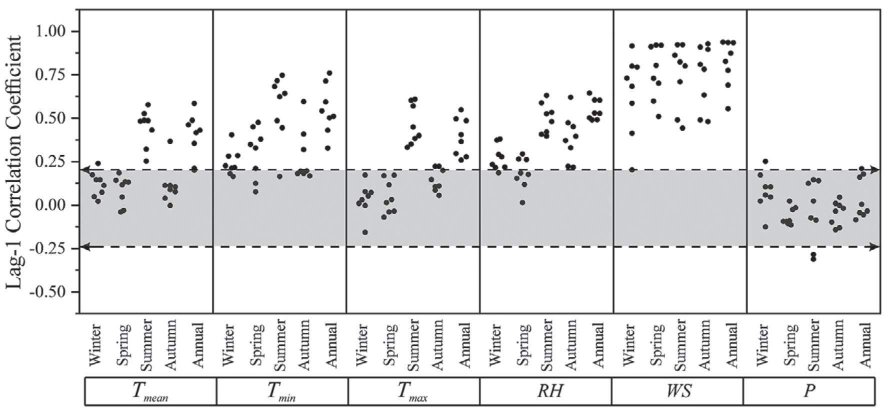

Figure 3. Distribution of Lag-1 correlation coefficient for T_{mean}, T_{min}, T_{max}, RH, WS, and P on seasonal and annual scales at eight stations.

Table 2. SS values of climatic variables for different periods (▲ and ▼ represent significant increasing and decreasing trends, respectively. The change is given per decade).

Station	Season	T_{mean} °C/decade	T_{min} °C/decade	T_{max} °C/decade	*RH* %/decade	*WS* m/s/decade	*P* mm/decade
17210 Siirt	Winter	0.4 (▲)	0.4 (▲)	0.3 (▲)	0.7	–0.2 (▼)	–1.5
	Spring	0.3 (▲)	0.4 (▲)	0.3 (▲)	–0.3	–0.3	–0.3
	Summer	0.4 (▲)	0.5 (▲)	0.3 (▲)	–0.2	–0.3	0.2
	Autumn	0.3 (▲)	0.4 (▲)	0.2 (▲)	0.2	–0.3	–1.3
	Annual	0.3 (▲)	0.5 (▲)	0.3 (▲)	0.1	–0.3	–0.6
17261 Gaziantep	Winter	0.4 (▲)	0.3 (▲)	0.4 (▲)	–1.1	–0.3	0.9
	Spring	0.4 (▲)	0.5 (▲)	0.4 (▲)	–1.9 (▼)	–0.3	–1.0
	Summer	0.5 (▲)	0.6 (▲)	0.4 (▲)	–1.6	–0.5	0.2
	Autumn	0.4 (▲)	0.7 (▲)	0.3 (▲)	–1.6	–0.3	0.7
	Annual	0.5 (▲)	0.6 (▲)	0.4 (▲)	–1.6	–0.4	–0.4
17262 Kilis	Winter	0.3 (▲)	0.4 (▲)	0.2	–1.5	–0.2 (▼)	–1.3
	Spring	0.3 (▲)	0.5 (▲)	0.2	–1.6 (▼)	–0.3	–1.4
	Summer	0.4 (▲)	0.6 (▲)	0.3 (▲)	–1.1	–0.5 (▼)	–0.0
	Autumn	0.3 (▲)	0.5 (▲)	0.1	–1.4	–0.2 (▼)	–0.1
	Annual	0.3 (▲)	0.5 (▲)	0.2 (▲)	–1.4 (▼)	–0.3 (▼)	–1.7
17265 Adiyaman	Winter	0.3 (▲)	0.2 (▲)	0.4 (▲)	–0.3	–0.3 (▼)	1.8
	Spring	0.3 (▲)	0.2 (▲)	0.5 (▲)	–0.4	–0.3 (▼)	–1.8
	Summer	0.4 (▲)	0.4 (▲)	0.6 (▲)	–0.1	–0.4	0.1
	Autumn	0.2 (▲)	0.2 (▲)	0.3 (▲)	–0.7	–0.3 (▼)	0.4
	Annual	0.3 (▲)	0.3 (▲)	0.5 (▲)	–0.5	–0.3	0.1
17270 Sanliurfa	Winter	0.3 (▲)	0.4 (▲)	0.4 (▲)	–0.7	–0.1	–1.8
	Spring	0.4 (▲)	0.4 (▲)	0.5 (▲)	–1.1 (▼)	–0.1	–2.1
	Summer	0.5 (▲)	0.6 (▲)	0.6 (▲)	0.8	–0.2	0.1
	Autumn	0.3 (▲)	0.4 (▲)	0.3 (▲)	0.3	–0.2	0.4
	Annual	0.4 (▲)	0.5 (▲)	0.5 (▲)	–0.1	–0.1	–1.2
17275 Mardin	Winter	0.4 (▲)	0.4 (▲)	0.5 (▲)	–2.1	–0.2 (▼)	–6.2
	Spring	0.4 (▲)	0.4 (▲)	0.5 (▲)	–1.9 (▼)	–0.2 (▼)	–4.6
	Summer	0.5 (▲)	0.5 (▲)	0.6 (▲)	–0.6	–0.2 (▼)	0.2 (▲)
	Autumn	0.3 (▲)	0.3 (▲)	0.4 (▲)	–1.3	–0.1 (▼)	–2.6
	Annual	0.4 (▲)	0.5 (▲)	0.5 (▲)	–1.5 (▼)	–0.2 (▼)	–4.1 (▼)
17280 Diyarbakir	Winter	0.2	0.0	0.3	–0.5	0.1	–0.9
	Spring	0.0	–0.2	0.2	–0.1	0.1	–0.5
	Summer	0.2 (▲)	0.0	0.4 (▲)	–1.7 (▼)	0.1	0.2
	Autumn	0.0	–0.1	0.1	–1.7 (▼)	0.1	1.2
	Annual	0.1 (▲)	–0.1	0.3 (▲)	–0.9	0.1	0.1
17282 Batman	Winter	0.2	0.1	0.2	–0.6	0.1	0.4
	Spring	0.1	0.0	0.2 (▲)	–0.4	0.0	–1.6
	Summer	0.2	0.2	0.3 (▲)	–0.6	0.0	0.1
	Autumn	0.2 (▲)	0.2	0.1	–1.2	0.0	–0.3
	Annual	0.2 (▲)	0.1	0.2 (▲)	–0.7	0.0	–0.3

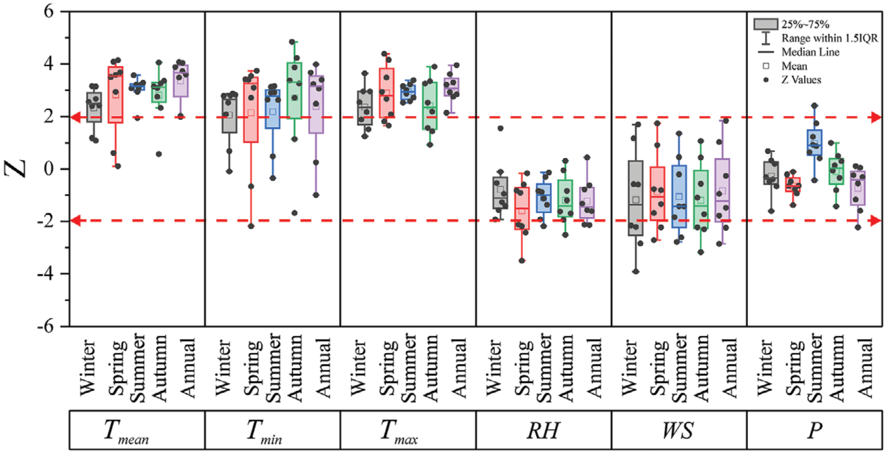

Figure 4. *Z* values obtained by MK test in climatic variables for different periods (The dashed lines represent the 95% confidence level, and the box represents 25% and 75% of *Z* values).

lated Z values of the stations according to the periods is given in Fig. 4. The dashed lines represent the 95% confidence level ($Z_{a/2} = \pm 1.96$). If Z values of the relevant parameter at the station exceed this line, the station has a statistically significant (increasing or decreasing) trend occurrence. According to Fig. 4 and Tab. 2, the annual T_{mean} shows a significant increasing trend at the 95% confidence level for all stations. For example, in all seasons for T_{mean}, the significant increasing trends are determined at all stations except Diyarbakir and Batman. Although the *Z* values calculated with the MK test are positive at the Diyarbakir and Batman stations, there is no significant trend for the Diyarbakir station for the winter, spring, and autumn, and for the Batman station for the winter, spring, and summer. The corresponding slope values for statistically significant trends vary between 0.1 °C/decade and 0.5 °C/decade. In the T_{min} values, there are significant increasing trends (at the 95% confidence level) for all periods and all stations except for two (Diyarbakir and Batman). While most temperature values have a significant increasing trend, a decreasing trend is observed in the T_{min} values at the Diyarbakir station. This decrease is determined as significant in the spring. At stations with a significant increasing trend, the *SS* values of T_{min} vary between 0.2 °C/decade and 0.7 °C/decade. The highest increase occurs at the Gaziantep station. The T_{max} value shows significant increasing trends at all stations, except the Kilis, Diyarbakir, and Batman stations. Significantly increasing trends are determined at all stations in the summer and annual periods. It is seen that the temperatures in the GAP region show significant increasing trends in the majority of the region when all three temperature parameters (T_{mean}, T_{min}, and T_{max}) are evaluated together.

As seen in Tab. 2, *RH* values have a significant trend at few stations in general, and the trends are in a decreasing direction in these stations. The significant trends are determined at the Gaziantep, Kilis, Sanliurfa, and Mardin stations (southeast and south parts of the study area) in the spring season, the Diyarbakir station only in the summer season, and the Kilis, Mardin and Diyarbakir stations in the annual period. The majority of the *Z* values of *RH* do not exceed the significant trend limits, but the negative *Z* and *SS* values indicate that the trend is in a decreasing direction (not significant). The decrease in slope values of stations with significant trends varies between 1.1%/decade and 1.9%/decade. The maximum decrease occurred at the Mardin station in the spring season.

According to the *Z* values of *WS*, significant decreasing trends are determined at different periods at a limited number of stations. Nonetheless, no significant trend in the increasing direction is found at any station. For instance, a significant decrease is observed at the Siirt station only in the winter, at the Kilis station in all periods except the spring, and at the Adiyaman station except in the summer and annual periods. In addition, significant decreasing trends are determined at the Mardin station in all periods. At stations with a significant

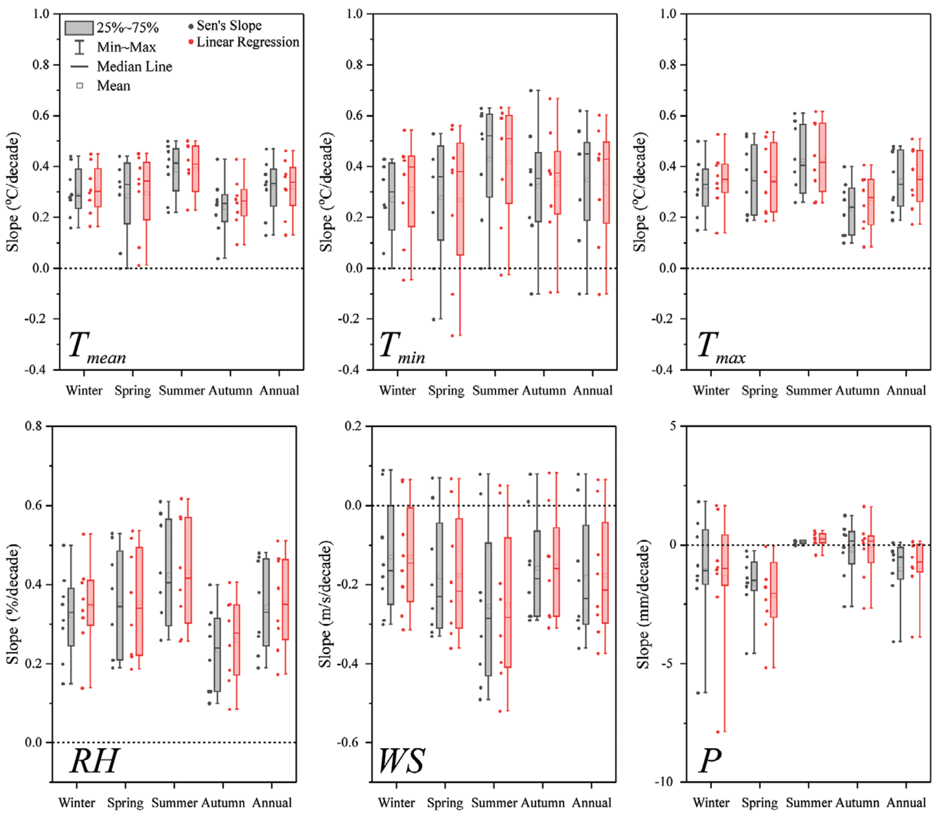

Figure 5. Distribution of trend slopes calculated by linear regression and Sen's slope methods of seasonal and annual time series.

trend, the maximum decreasing slope value is obtained as –0.21 m/s/decade in the winter season at the Siirt station, and the minimum decreasing slope value is determined as –0.14 m/s/decade in the autumn at the Mardin station.

According to the Z values for P in the GAP region, it is seen that the number of stations and periods with a significant trend in the region is quite limited. A significant increasing trend is determined only at the Mardin station in the summer, while a significant decreasing trend is also found in the annual period. The slope values of the station's annual mean values are 4 mm/decade.

Figure 5 depicts the distributions of a, calculated by linear regression analysis and SS values calculated by Sen's slope method for seasonal and annual time series. In all parameters, except for a few exceptions, the trend direction is determined the same by both methods. At the same time, the values are found to be very close to each other, especially for temperatures. In addition, the mean slope value is similar in both methods, and there are slight differences for winter for RH and spring, summer, and annual for P. In the distribution of values, the only variable that is incompatible is summer for P. It has been appraised that this situation is due to the low summer precipitation in the region. Here, it can be seen that Sen's slope is less sensitive to extremes.

3.2. Result of the ITA test

The ITA results of the annual mean values of the meteorological parameters evaluated in the GAP region are given in Figs. 6 to 11 for T_{mean}, T_{min}, T_{max},

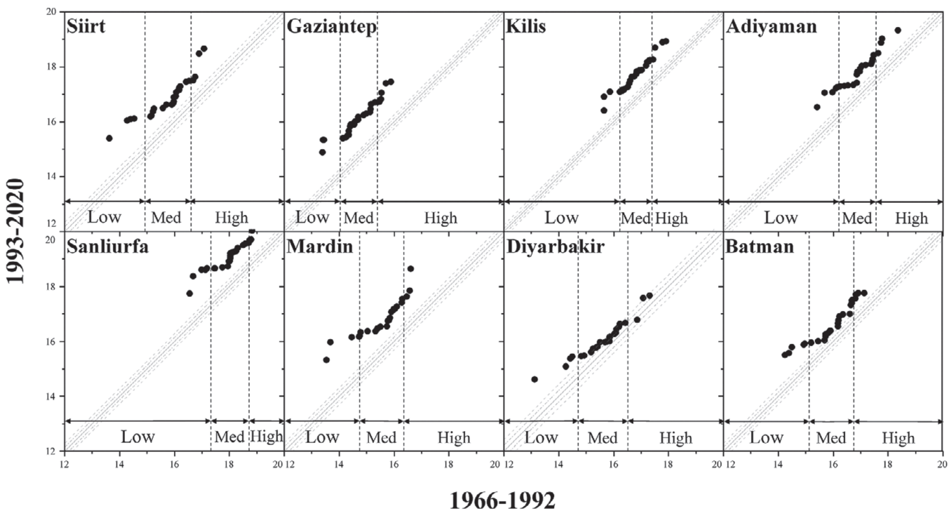

Figure 6. ITA results of T_{mean} for the annual period (Reference lines of 1:1, 5%, and 10% are shown as solid dashes with dot and dashed lines, respectively. Vertical lines represent the boundary of low, medium, and high values).

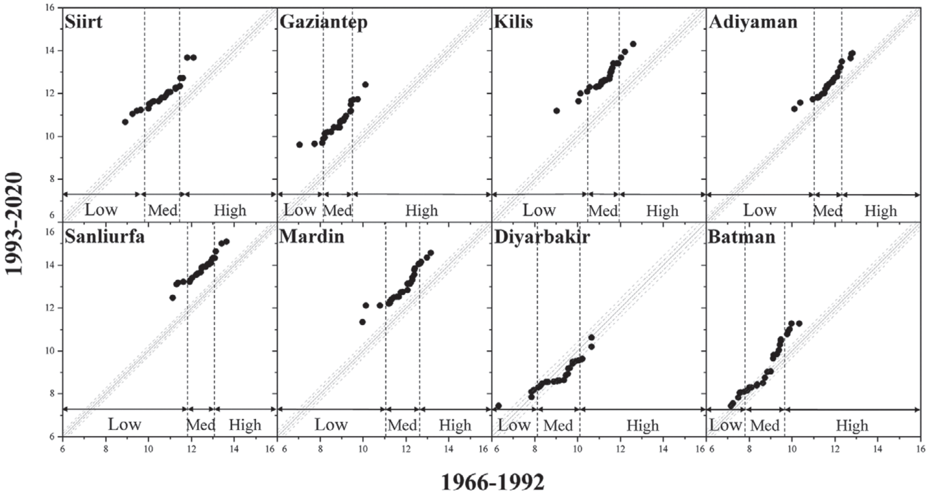

Figure 7. ITA results of T_{min} for the annual period.

RH, *W*, and *P*, respectively. The figure shows low and high values with vertical dashed lines, and reference lines of 1:1, 5%, and 10% are shown as solid dashes with dot and dashed lines, respectively. T_{mean} values in Fig. 6 vary between 13 °C and 19 °C. A considerable part of the data is included in the medium values calculated according to the relevant station, and the values in the low or high values are few. A "strong increasing" trend is observed at all stations in low values, while an "increasing" trend is observed only at the Diyarbakir station in medium and high values, and a "strong increasing" trend occurs at all other stations. In the T_{min} parameter (Fig. 7), the "strong increasing" trend is mostly in the low, medium, and high values at the Batman station and "strong decreasing" in the medium values at the Diyarbakir station. In the T_{max} parameter (Fig. 8), the "increasing" trend is determined by the low values at the Kilis station, while the "strong increasing" trends are determined at all other stations in all periods.

On the other hand, in the *RH* parameter (Fig. 9), the data are mostly on the 1:1 line or in the range of ±10%, and there is no "strong increasing" or "strong decreasing" trend occurrence at the Adiyaman station. The other stations mostly show a "decreasing" or "strong decreasing" trend, and the medium values of the Gaziantep and Sanliurfa stations (SW of the study area) have "increasing" trends. A clear "strong decreasing" trend is observed in the *WS* parameter (Fig. 10) except in the Diyarbakir and the Batman stations, and a limited number of "increasing" or "strong increasing" trend occurrences are observed at the medium values of the Diyarbakir and Batman stations. Finally, as the changes in *P* values are analyzed (Fig. 11), most of the data is seen above the 1:1 line or in the range of ±10%. However, the high values show a

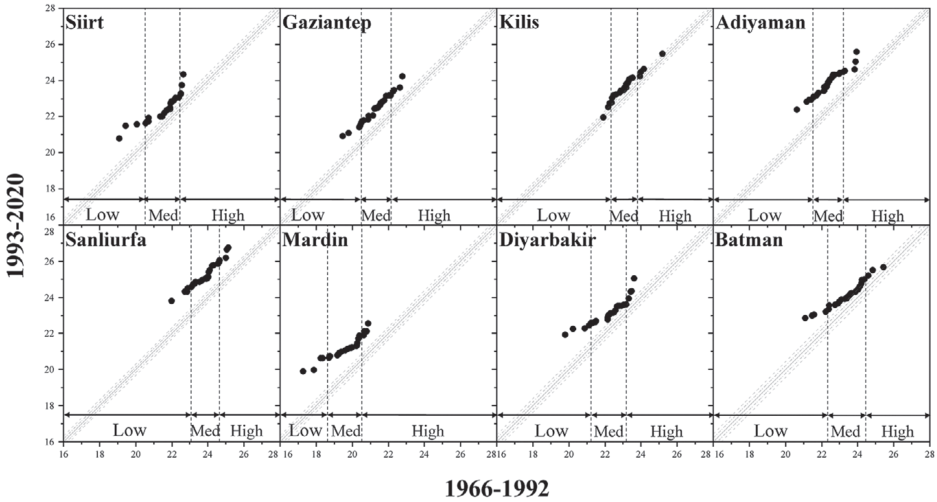

Figure 8. ITA results of T_{max} for the annual period.

"strong decreasing" trend, especially at the Siirt, Mardin, and Batman stations (east of the study area).

For all periods, the occurrence of trends at low, medium, and high values is calculated with the ITA for the meteorological parameters. The percentages of occurrence are given in Fig. 12. The low values of T_{mean} show a "decreasing" trend in only one station in the autumn, while a "strong increasing" or "increasing" trend is determined in most of the stations in the GAP region in all periods

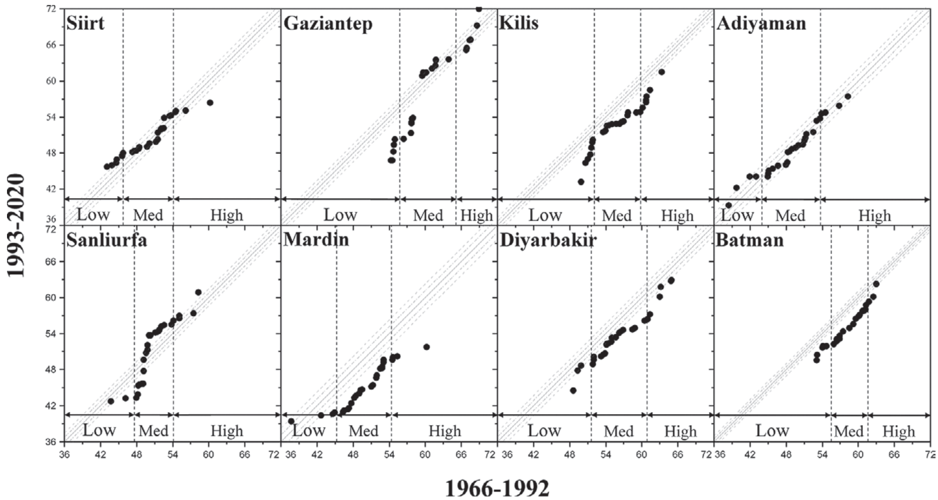

Figure 9. ITA results of *RH* for the annual period.

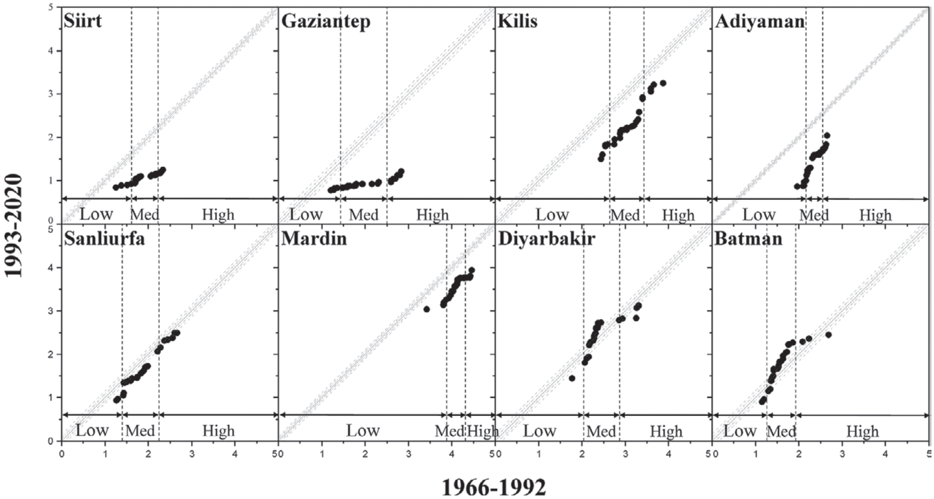

Figure 10. ITA results of *WS* for the annual period.

(including annual). The low values of T_{min} indicate a "strong decreasing" trend occurred at one station in the spring, "decreasing" trends occurred at two stations in the autumn, and a "strong increasing" trend is detected in other periods, similar to T_{mean}. The low values of T_{max} demonstrate a "strong increasing" trend occurring in all stations (all periods) except one station in the autumn. The trends of the medium values of the temperatures are mostly "strong increasing", similar to the low values. A "strong decreasing" trend occurred at only one station for

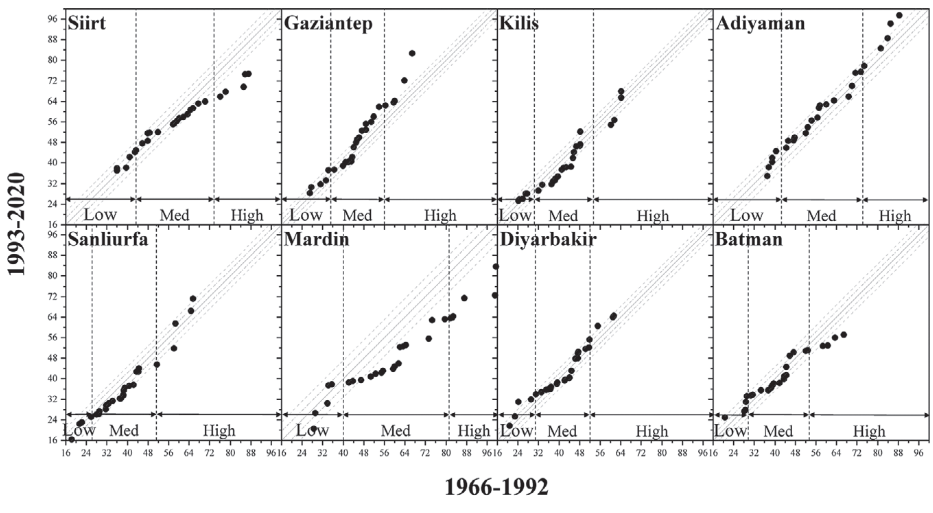

Figure 11. ITA results of *P* for the annual period.

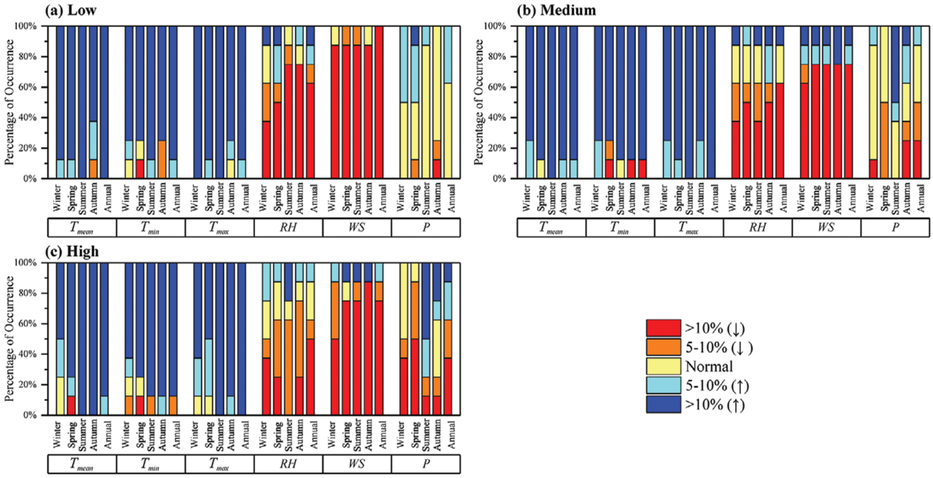

Figure 12. The percentage of occurrence according to ITA (*a* - Low, *b* - Medium, *c* - High).

the T_{min} value in the spring, autumn, and annual periods. At high values for T_{mean} and T_{min}, a "strong decreasing" trend is determined in only one station in the spring, while a "strong increasing" trend occurs at high, low, and medium values. However, no decreasing trend is found at any period and station for T_{max}, and the trend direction is observed as "increasing" or "strong increasing" at almost all stations. For the temperatures (T_{mean}, T_{min}, and T_{max}), the trend occurrences obtained by the MK test and the trend occurrences determined for three different value ranges of the ITA are similar. It has emerged that the GAP region temperatures have increased monotonic trends (according to the MK test) and in a specific range (low, medium, and high) for the ITA.

The *RH* values mostly showed a decreasing (significant or insignificant) trend. For example, most stations (six stations) have a decreasing trend in summer and autumn. Three stations show a "strong decreasing" trend in the winter. At low values of the *RH*, the number of "increasing" or "strong increasing" trend stations is quite limited. It has been observed that the medium values of *RH* exhibit a similar result in all periods. At high values of *RH*, the number of "strong decreasing" trends decreases noticeably compared to low and medium values, and the strongest decrease is found in the annual period. Although *RH* values in the MK test generally show a decreasing trend, a significant decrease is only found in a small number of stations and periods. However, in the ITA, the "decreasing" or "strong decreasing" trend is determined at low, medium, and high values in most stations.

Most of the low values of *WS* show a "strong decreasing" trend. In medium and high values, "strong increasing" trends are determined at two stations, while mostly "strong decreasing" trends are seen at all other stations. For *WS*, the number of stations with a "strong decreasing" trend in low, medium, and high values with the ITA is quite high. In contrast, the number of stations for which the MK test determines a significant trend is only four for different periods.

In a significant part of the low values of *P*, "increasing" trends are found in a limited number of stations, and "strong decreasing" or "strong increasing" trends are determined in only one station. The "strong increasing" trends are observed in the mean values of *P* only at four stations in the summer and one station in the autumn. At high values, which can also be considered extreme precipitation events, a "decreasing" or "strong decreasing" trend occurs in a remarkable part of the stations in the winter, spring, and annually. According to the monotonic trend results calculated with the MK test for precipitation values in the GAP region, only the Mardin station shows a significant trend (increasing for summer, decreasing annually). However, the ITA results show that the low values mostly did not change, and the medium values generally decreased or did not change, except for the summer season. The most notable difference is that high *P* values in the spring show a "decreasing" or "strong decreasing" trend at all stations except one.

4. Discussion

Kadioğlu (1997) determined the trends of seasonal and annual temperature (minimum and maximum) values in the years between 1929 and 1990 at 18 stations (including stations Sanliurfa and Diyarbakir in the GAP region) in different regions of Turkey using the MK test. For the minimum temperature data, significant increasing trends were observed at both stations in the spring and annual periods and only at the Diyarbakir station in the summer. For the maximum temperature data, significant increasing trends were calculated only at the Sanliurfa station in the summer and autumn seasons. The results of this study, in which data through 2020 were used, show that a significant increasing trend continued after 1990. In addition, significant increasing trends are determined in the other seasons, where no significant trend could be determined in the data until 1990 at the Sanliurfa station. Yenigun and Ecer (2013) determined the trend using the MK and Spearman's rho tests for annual temperature and relative humidity (minimum, maximum, and mean) and total and maximum precipitation values of many meteorological stations in the Euphrates River basin between 1960 and 2000. Five of the stations used in their study (Kilis, Gaziantep, Sanliurfa, Mardin, and Adiyaman stations, which are in the west, southwest, and southeast of the study area, respectively) are also included in the present study. The significant increasing trends were determined in the mean, maximum, and minimum temperature at the Gaziantep and Sanliurfa stations, mean and minimum temperature values at the Kilis station, and mean and maximum values at the Adiyaman and Mardin stations. In the present study, the significant increasing trends are determined in all these stations for annual T_{mean}, T_{min}, and T_{max} values. It can be concluded that the temperature values between 2000 and 2020 significantly increased at all stations.

Yenigun and Ecer (2013) determined annual *RH* trends using the MK test. The study results indicated that significant trends increased at the Sanliurfa station, decreased at the Mardin station, and there is “no trend” at the Kilis station, according to the data between 1960 and 2000. In the current study, which evaluated the data up to the year 2020, it is seen that the increasing trend at the Sanliurfa station changed to “no trend”, and the status that was “no trend” at the Kilis station changed to a decreasing trend. In addition, the Mardin station, which showed a “decreasing trend”, keeps its status the same based on this study’s findings.

Dadaser-Celik and Cengiz (2014) analyzed the trends of the wind speed data recorded at 206 meteorology stations across Turkey between 1975 and 2006 using the MK test. The result obtained from their study indicated that there is no significant trend in the regions as found in the present study in the annual, spring, summer, autumn, and winter periods. In addition, significant decreasing trends were determined in most of the annual and seasonal periods at stations except Diyarbakir and Batman. In the present study, which used the data up to 2020, no significant trends were found at the Diyarbakir and Batman stations, while significant decreasing trends were determined at the Kilis and Mardin stations. It is seen that all of the statistically significant decreasing trends in the study conducted by Dadaser-Celik and Cengiz (2014) changed to “no trend”.

A trend analysis study conducted by Partal and Kahya (2006) for Turkey’s precipitation data considered that only one station (Kilis) was included in the presented study area. They determined a significantly decreasing trend at the station, which used precipitation data until 1993. Based on the current study results, the trend is changed to “no trend” with adding new data. Yenigun and Ecer (2013) used the MK and Spearman’s rho tests to determine the trend of annual total precipitation values measured between 1960 and 2000 for the Gaziantep, Kilis, Adiyaman, Sanliurfa, and Mardin stations (W and S of the study area). They found no significant trend in precipitation values between 1960 and 2000 due to their analysis. In this study, which is done with recent data, no significant trend is found in most stations or studied periods.

The ITA has determined the occurrence of a trend in more stations than the MK test for *P* in the GAP region. The results of the present paper are in the same line as the studies carried out by Ay and Kisi (2014) and Kisi (2015). All these studies determined that the number of stations having the trend by the ITA is higher than the MK.

5. Conclusion

In this study, trend analysis of monthly mean, maximum, and minimum temperatures (T_{mean}, T_{min}, and T_{max}), monthly relative humidity (*RH*), monthly wind speed (*WS*), and monthly total precipitation (*P*) parameters in the GAP region of Turkey is conducted for seasonal and annual periods. The Mann-Kendall (MK) test and Innovative Trend Analysis (ITA) are used to determine the trend in annual and seasonal periods, and Sen's slope method and regression analysis are used to calculate the magnitude of the trend. The main results obtained from the study are summarised below.

The monotonic trends of the temperatures (T_{mean}, T_{min}, and T_{max}) are in the increasing direction (statistically significant) in the majority of the stations (both seasonal and annual) in the GAP region, according to the result of the MK test. Additionally, the trend results obtained by the MK test and ITA method are similar for temperature data.

Although *RH* values mostly show a decreasing trend in the MK test, the significant decreasing trends are determined in quite a limited number of stations and seasons. However, "decreasing" or "strong decreasing" trends are determined in most stations with ITA. Therefore, it is considered that the decrease in humidity values in the GAP region, whose relative humidity value is well below the Turkey average, may increase the risk of desertification in the future.

The MK test determines that the number of stations with significant trends is quite limited for *WS*, while the number of stations with "strong decreasing" trends determined by the ITA method is quite high.

A significant trend (increasing direction in the summer, decreasing direction in the annual) is determined in only one station by the MK test for *P*. Besides, the low and medium values mostly do not have a trend according to the ITA methods; however, the high *P* values show a "decreasing" or "strong decreasing" trend at most stations in the winter, spring, and annually.

The study results are expected to help understand the trends of climatic variables in the GAP region. In addition, these results can provide valuable information for water resources planning, development of agricultural activities, and the determination of wind energy potential.

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Data availability – The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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SAŽETAK

Procjena trendova meteoroloških vremenskih nizova u jugoistočnoj Anatoliji, Turska

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U ovom istraživanju analizirano je šest klimatskih varijabli (srednja, minimalna i maksimalna temperature, relativna vlažnost, brzina vjetra i oborina) za razdoblje 1966.–2020. u području jugoistočne Anatolije, koje se nalazi u fokusu turskog integralnog razvojnog projekta (GAP). Trendovi za sezonska i godišnja razdoblja određeni su pomoću Mann-Kendallovog (MK), a nagibi trendova određeni su metodom Senovog nagiba i regresijskom analizom. Nadalje, da se odrede promjene vremenskih nizova za niske, srednje i visoke vrijednosti, korištena je inovativna analiza trenda (ITA). Rezultati dobiveni objema metodama su pokazali da srednje, minimalne i maksimalne temperature u GAP području imaju uzlazne trendove. Značajni uzlazni trendovi su dobiveni pomoću MK testa za ograničen broj postaja za oborinu, relativnu vlažnost i brzinu vjetra, dok su primjenom ITA metode za većinu postaja dobiveni konzistentni opadajući trendovi.

Ključne riječi: analiza trenda, klimatske varijable, Mann-Kendallov test, inovativna analiza trenda, Senov nagib

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