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Trends and Variability in Precipitation Across Turkey: A Multi-Method Statistical Analysis

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Abstract

Analyzing trends in precipitation data is crucial for understanding the effects of climate change and making informed decisions about water management and crop patterns. The objective of the presented study was to investigate precipitation trends, analyze temporal and spatial variations, and identify potential change points in Turkey throughout the period from 1980 to 2019. Precipitation data were analyzed for both regional and 81 meteorological stations in Turkey on a monthly, seasonal and annual basis. Spearman rank correlation and Mann-Kendall tests were utilized to detect possible trends, and Sen's slope test to estimate the magnitude of change throughout the entire time series. The average precipitation amount of Turkey was determined 639.2 mm between 1980-2019 years. While Central Anatolian and Eastern Anatolian regions had below 639.2 mm, other regions were above. The range of seasonal precipitation values were found for winter 128.7-320.8 mm, 108.9-260.0 mm for spring, 43.9-109.3 mm for summer and 79.7-238.4 mm for autumn. The analysis of the data revealed no significant increase or decrease in annual values on a regional basis, with the greatest change on a seasonal basis being observed in the winter. The 40-yr trends of annual precipitation data belonging to 81 stations were decreasing in 23 provinces and increasing in 58 provinces, and 11 of them (14% of the total) were found to be statistically significant. Moreover, November was found to be a month of particular significance in terms of precipitation changes across the country, with a decrease observed in 80 out of 81 provinces. Spatial distribution analysis showed that the magnitude of variation in precipitation decreased as one moved from the southern to the northern regions of the country.

Keywords: Mann-Kendall test; Spearman rank correlation; rainfall trends; climate change

1. Introduction

Meteorological parameters such as precipitation, wind speed, humidity, temperature, vapor pressure and cloudiness can differ in a variety of ways depending on the region or the period. Climate change can be induced by alterations in atmospheric composition or land use attributed to human activities (Türkeş 2012) and has been cited as the primary reason for these differences in recent years (Leng et al. 2015; Tye et al. 2019; Danandeh Mehr et al. 2020; Radha et al. 2023). Precipitation is a variable that may be analyzed to get a sense of the consequences of climate change and to conduct studies on how to adapt to these changes. Climate change is causing the global hydrological cycle to accelerate and precipitation values to change due to higher evaporation rates and increased water vapor in the atmosphere from rising temperatures (Yang and Liu 2011). Examining the hydroclimatic variations and trends with the precipitation values yields both theoretical and practical benefits for managing agricultural and water resources.

One of the most significant resources on Earth and a fundamental human necessity is water. Any considerable variation in water distribution will have an impact on the local or national economy, accordingly on hydrologic functions. Precipitation affects agricultural productivity at the points of the hydrological cycle and the food supply chain is heavily reliant on available water amount (Chandniha et al. 2017; Panda and Sahu 2019). The types of crops that are able to grow in various parts of the world are largely influenced by the frequency and variability of precipitation (Panda et al. 2019; Sahu et al. 2020). The crop suffers significant yield losses as a result of the precipitation not intensifying throughout the sowing, emerging, and development stages but instead falling

as heavy showers at unforeseen times (Meshram et al. 2017). Understanding the past and recent distribution of precipitation came into prominence due to its effects on agricultural activities and indirectly on the national economy. Trend detection of long-term precipitation is crucial to understand the effects of climate changes on the availability of water, along with the danger of increasing occurrences of droughts and floods (Karpouzos et al. 2010; Pal et al. 2017).

The study of the time-dependent variation of precipitation worldwide is of increasing interest. Examining precipitation trends provides valuable information about accurate water resource assessment, drought-flood control and effective water management (Huang et al. 2013). The long-term precipitation data can be used to create government strategies to minimize the negative effects of climate change, particularly in the most impacted regions. Due to its significance, numerous studies have been conducted to investigate the variability and trends of precipitation across the world (Mohapl 2001; Feidas et al. 2007; Taschetto and England 2009; Mekis and Vincent 2011; Huang et al. 2013; Ali and Ahmad 2015; Beyene 2015; He and Gautam 2016; Türkeş 2019; et al. 2017; Gadedjisso-Tossou et al. 2021; Garg et al. 2022; Pawar and Rathnayake 2022). The increasing temperatures inside the intricate climatic system of Turkey make it one of the countries most affected by climate change. Drought impacts are expected to increase in the future, in particular for developing countries in the southern and eastern parts of the Mediterranean (Tramblay et al. 2020). Given that Turkey is geographically bordered by seas on three sides, has a dispersed topography, different regions will be impacted by climate change in different ways and to varying degrees (Türkeş 1998). Precipitation that is distributed unevenly is one of the primary issues Turkey's water resources management faces. The precipitation climatology of Turkey, along with the long-term variability, trends, and alterations in precipitation series, has been extensively examined in prior research conducted by Türkeş (1996, 1998, 1999, 2003), Türkeş and Erlat (2003, 2005, 2006), Türkeş and Tatlı (2009, 2011) and Türkeş et al. (2002, 2009, 2020). Türkeş (1996), stated that the average precipitation anomalies tend to change according to the regime regions. It is essential to analyze precipitation data from areas like Turkey in order to comprehend how various regimes have distinct consequences. In previous studies conducted in Turkey; Partal and Kahya (2006) used a framework approach to detect precipitation trends and discovered some important trends in Turkey and Bacanli (2017) compared the precipitation and drought trend analyses and reported parallel results. Türkeş (1996) examined the spatial and temporal characteristics of Turkey during the period 1930-1993, reporting decreasing trends in the area-averaged normalized rainfall series for the Black Sea and Mediterranean regions, as well as for Turkey as a whole. Despite the test statistics for these trends not reaching significance at the 5% level, the study observed a statistically significant decrease in annual rainfall at 15 stations across Turkey, including 7 within the Mediterranean rainfall region. Research conducted not only for the spesific regions but also encompassing the Turkey as a whole has identified a decline in overall precipitation levels since the 1970s, coupled with a heightened prevalence of arid conditions (Türkeş et al 2007; Türkeş 2012). Türkeş and Erlat (2003) conducted a comprehensive analysis on the historical and contemporary climatology of precipitation, its spatio-temporal variability, and its associations with large-scale and regional atmospheric circulations. Identification and quantification of trend analysis are required for the sustainability of Turkish agriculture; nevertheless, precipitation, as one of the hydro climatic variables, has not been examined in the aggregate for the period of the last 40 years. In this study, an in-depth analysis of precipitation variations in Turkey over the years 1980 to 2019 is undertaken, integrating diverse regions and applying a range of statistical methods. While previous research has delved into precipitation trends within Turkey, the work stands out by uniquely adopting the regional divisions established. This framework enables a comprehensive examination of precipitation patterns, allowing the uncovering of insights that were previously unexplored. To bolster the robustness of the findings, rigorous statistical tests including the Spearman rank correlation, Mann-Kendall test, and Sen's slope test are employed. By doing so, the study not only builds upon existing research but also brings a new perspective to the analysis of precipitation trends in Turkey.

The main objectives of the presented study were (i) to examine the precipitation variability of Turkey by coefficient of variation (ii) to investigate the most probable change years in precipitation data from 1980 to 2019 by the Pettitt Mann Whitney test (iii) to determine the precipitation trends and slopes of 81 meteorological stations in Turkey by Spearman rank correlation, Mann-Kendall method and Sen's Slope test.

2. Material and Methods

2.1 Study Site and Data

Turkey with 81 provinces (36°–42°N and 26°–45°E) is located in Western Asia and a small part of Southeast Europe (Fig. 1). The total land area is 783 562 km^2, of which 97% is in Asia and 3% in Europe Turkey.

The altitude of Turkey varies between 0 and 5137 m, and the highest city center (Erzurum) is located at an altitude of 1890 m while the lowest (Zonguldak) is at 8 m from the sea level. Turkey has diverse climates due to its geographical location and irregular topography. The southern and western parts of Turkey are mostly defined by a Mediterranean whereas the northern part has a mid-latitude moderate climate. In central and eastern parts, however, continental steppe and cold snowy climates predominate (Türkeş 2020). Most of the rainfall occurs in winter and spring in Turkey. In summer, the amount of precipitation decreases while the temperature and evaporation increase.

The monthly precipitation data were obtained from meteorological stations in 81 provinces by the Turkish State Meteorological Service for the period of 1980-2019 (TSMS, 2021). Türkeş (1996) reported the most probable change year for the beginning of the drier period as the early 1980s. Figure 1 shows the location of meteorological stations, the climatic zones and the mean annual precipitation from 1980 to 2019. Cluster analysis in climatology is used to define classes of synoptic types or climate regimes (Türkeş and Tatli 2011). In a previous studies conducted by Türkeş (1998) and Türkeş et al. (2002) the categorization of the meteorological stations of Turkey primarily relied on the seasonal rainfall patterns and their geographical influences. In present study, Turkey divided into climatic zones base on cluster analysis results reported by Unal et al. (2003). Annual rainfall averages ranged from 261.1 mm (Iğdır) to 2 244.9 mm (Rize) between 1980 and 2019. Türkeş et al. (2002) observed that precipitation exhibits distinct cycle lengths across different seasons. In light of this finding, an in-depth analysis of the seasonal variations in precipitation data was conducted. Seasonal trend of each station and region is calculated as follows December, January, and February for winter; March, April, and May for spring; June, July, and August for summer; and September, October, and November for autumn.

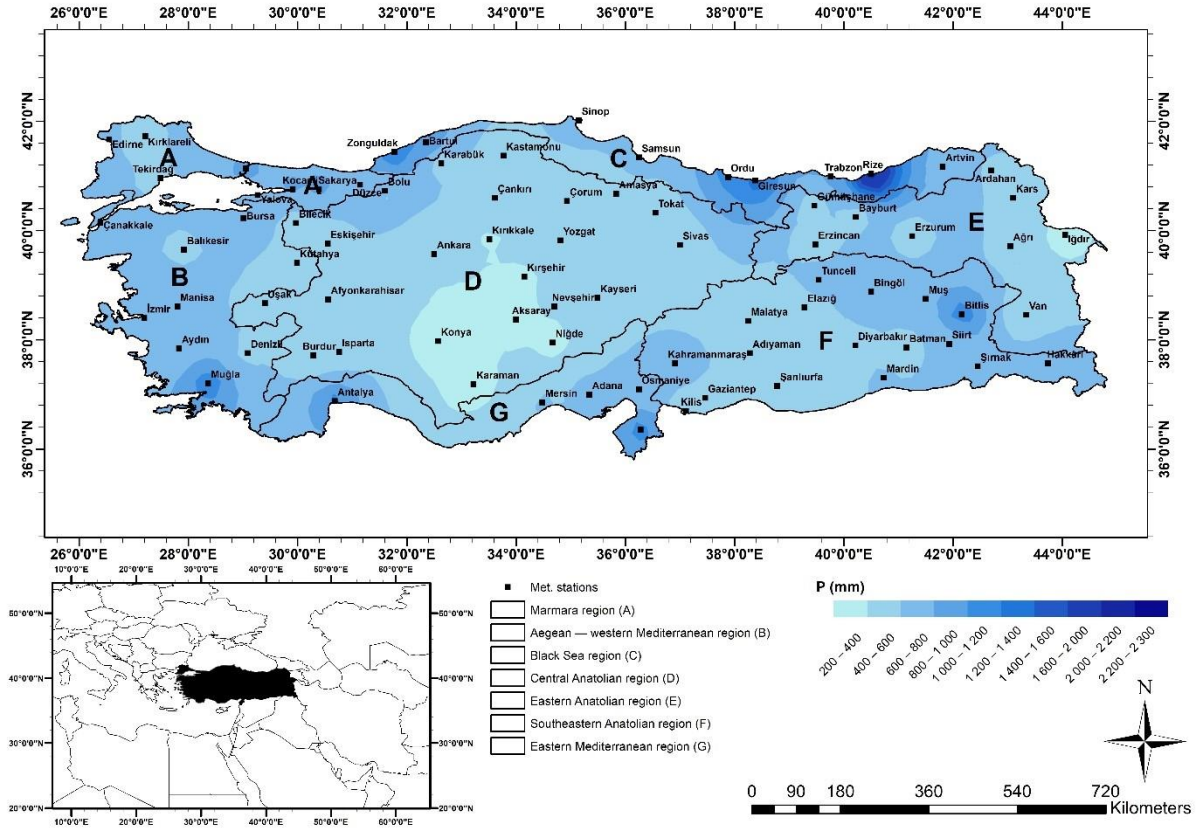

Fig. 1 Location of the study area, climate zones and spatial distribution of the mean annual precipitation of meteorological stations from 1980 to 2019.

2.2 Data Analysis

2.2.1 Homogeneity test and determination of possible change points of long-term data

The standard normal homogeneity test (SNHT) was used to determine the homogeneity of the long-term precipitation data of each station, and the Pettitt Mann Whitney test was used for the detection of possible change

points. The SNHT was applied at a 5% significance level using Equation 1 (Alexandersson 1986; Saina et al. 2020).

$$T_k = k z_1^2 + (n-k) z_2^2 \qquad k = 1,2,\dots,n \tag{1}$$

where; n is the number of total observations; z_1 and z_2 calculations are given in Equation 2 and Equation 3.

$$z_1 = \frac{1}{k}\sum_{i=1}^{k} \frac{x_i - \bar{x}}{\sigma_x} \tag{2}$$

$$z_2 = \frac{1}{k-1}\sum_{i=k+1}^{n} \frac{x_i - \bar{x}}{\sigma_x} \tag{3}$$

where; $\bar{x}$ is the mean; σ_x is the standard deviation and n is the number of total observations. The homogeneity hypothesis of precipitation data was rejected if the test statistic T0 = max(T(k)) is above the critical value 8.10 for the n=40 and the year with the maximum T_k value was considered as the change point (Vezzoli et al. 2012). The non-parametric rank test known as the Pettitt test was used to detect significant changes in precipitation data for each meteorological station (Pettitt 1979) (Equation 4).

$$U_k = 2\sum_{i=1}^{k} r_i - k(n+1) \quad k = 1,2,\dots,n \tag{4}$$

where; U_k is the determination point of significant change (maximum or minimum) and n is the number of total observations. The critical value of the Pettitt test is 167 for the n=40 at a 5% significance level (Vezzoli et al. 2012).

2.2.2. Spearman rank correlation

A nonparametric type of the Pearson product-moment correlation is the Spearman rank correlation (Siegel 1957). The correlation coefficient of Spearman (rS) calculated from a sample of data is an estimate of the Pearson correlation coefficient (ρS) (Artusi et al. 2002). A strong Spearman correlation of +1 or 1 happens when one variable is a relationship (R^2=1) of the other without repeated values (Zar 2005). In this regard, the rS was calculated to determine if the data series included serial correlations among two variables by Equation 5.

$$rS = 1 - \frac{6\sum {d_i}^2}{n(n^2-1)} \tag{5}$$

where; d_i is the significant difference between the two variables and n is the number of total observations.

The following criteria can be used to choose the proper rS significance test:

(a) When the sample size is larger than 50 (n>50), the significance can be assessed using t-statistic. At a significance level α, by comparing the absolute value of t in Equation 6 with the critical value t', which corresponds to the degrees of freedom (n - 2) in the t-value table, it can be determined whether rS is statistically significant.

$$t = rS\sqrt{\frac{n-2}{1-rS^2}} \tag{6}$$

(b) When the sample size is less than or equal to 50 (n ≤ 50), the significance of rS can be tested by referring to the boundary value table for Spearman's rank correlation coefficient, with degree is (n - 2).

2.2.3. Mann-Kendall and Sen's Slope Test

The MAKASENS 1.0 computer software was used to determine monthly, seasonal and annual precipitation data trends for 40 years (Sarkar and Ali 2009). The non-parametric Mann-Kendall statistical approach was employed to determine whether there is a statistically significant increase or decrease trend and Sen's slope test technique was utilized for slope estimates (Gilbert 1987). The Mann-Kendall test is a different version of Kendall's test known as Tau and is based on the rows rather than the size of the data. According to the H0 hypothesis, the time-ordered series (X_1, X_2……., X_n) in this test are similarly distributed, time-independent

random variables. The distribution of X_k and X_j successive data values in the series, as ($k \neq j$) and $n \geq k, j$ (n, data recording length), is not identical, according to the H1 alternative hypothesis (Mann 1945). To detect a sequence X (X_1, X_2……., X_n) of length n, the statistic S is defined as follows (Equation 7):

$$S = \sum_{i-1}^{n-1} \sum_{j=i+1}^{n} Sgn(x_j - x_i) \quad Sgn(\theta) = \begin{cases} 1 & \theta > 0 \\ 0 & \theta = 0 \\ -1 & \theta < 0 \end{cases} \tag{7}$$

When the sample size is larger than or equal to 10 ($n \geq 10$), the statistic S approximately follows a normal distribution with a mean of 0. The variance Var(S) is calculated as (Equation 8):

$$\mathrm{Var}\,(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i i(i-1)(2i+5)}{18} \tag{8}$$

The Mann–Kendall Z is given by (Equation 9):

$$Z = \begin{cases} (S-1)/\sqrt{Var\,(S)} & S>0 \\ 0 & S=0 \\ (S+1)/\sqrt{Var\,(S)} & S<0 \end{cases} \tag{9}$$

A negative value of Z indicates a decreasing trend, while a positive value indicates an increasing trend. When the absolute value of Z exceeds 1.64, 1.96, and 2.58, it passes the significance test with 90%, 95%, and 99% confidence, respectively.

The slope of trend lines was calculated using Sen's slope test, which is independent of distributions and unaffected by seasonal occurrences (Van Belle and Hughes 1984; Sen 1968). The slope m is an unbiased estimate of the trend and exhibits improved accuracy compared to regression statistics, as it mitigates the influence of outliers and missing data. For the sequence X (x1, x2, ..., xn), the value of m is determined by the following Equation 10:

$$m = median\,(\frac{x_j - x_k}{j-k}),\ \forall j < i \tag{10}$$

where; median is the median function.

2.2.4. The coefficient of variation (CV)

The coefficient of variation —a normalized statistical measure of spread for a probability distribution— was calculated based on seasonal and annual. CV values of 81 meteorological stations were calculated with the principles in Landsea and Gray (1992).

Resultant test statistics from Mann-Kendall and Sen's Slope tests and coefficient of variation (CV) results were shown on a GIS map. Inverse Distance Weighting (IDW) interpolation technique was used to analyze spatial distribution with the ArcMap 10.2.2.

3. Results

3.1 Descriptive Statistics

The variation of mean annual and seasonal total precipitation data of the period 1980-2019 are given in Figure 2. While the lowest precipitation value seen in the study region between 1980-2019 was measured in the year 1993 (501.01 mm), and the highest value was in the 2001 (759.06 mm). The ranges of precipitation values for the periods of winter, spring, summer and autumn were determined as 128.7-320.8 mm, 108.9-260.0 mm, 43.9-109.3 mm and 79.7-238.4 mm, respectively (Fig. 2).

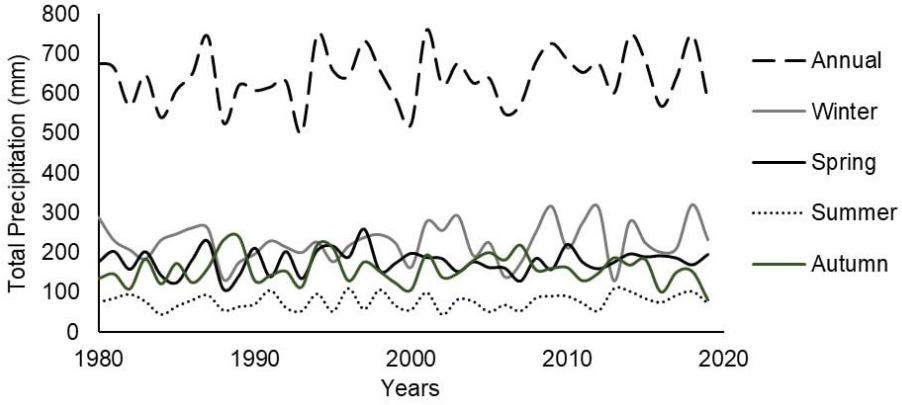

Fig. 2 Inter-annual variations in annual and seasonal precipitation totals in Turkey for the period of 1980-2019

Average precipitation values of regions and intra-regional statistics (standard error) are shown in Figure 3. The axis value in Figure 3 was determined as 639.2 mm, which is the average precipitation amount of Turkey between 1980-2019. Regions A, B, C, F and G had an average above 639.2 mm, while regions D and E were below.

The SNHT was applied to the precipitation data of different regions and Turkey at a significant level of 5% (Table 1). The results were supported by the Pettitt test ($p<0.05$) and all data were found to be homogeneous. The SNHT results of 81 meteorological stations in Turkey are presented in Supplementary Table 1. Meteorological data obtained from Balıkesir, Kars, Kastamonu and Ardahan were found to be heterogeneous, and then the breaking points were determined with the Pettitt test. Precipitation data trend analyzes were conducted by dividing the common breakpoints determined by SNHT and Pettitt. The new periods were 1980-2007 and 2008-2019 for Balıkesir; 1980-1999 and 2000-2019 for Kars; 1980-2006 and 2007-2019 for Kastamonu and 1980-2000 and 2001-2019 for Ardahan.

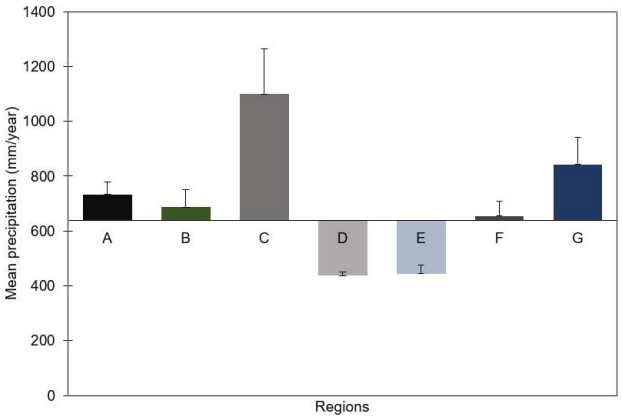

Fig. 3 Comparison of mean precipitation values in different regions with the average value of Turkey (632.1 mm)

3.2 The coefficient of variation (CV)

Understanding inter-seasonal and inter-annual variations of precipitation is crucial to calculate irrigation water requirements and to plan management of water resources for various purposes. When Figure 4 is examined, the season with the highest inter-annual variation for the study period is summer (28.9-152.9%). The province with the least variation in 4 of the 5 time periods —winter, spring, autumn and annually— was found to be Rize, which among 81 provinces had the greatest average precipitation. The biggest CV values in the summer months and annually were recorded in Mardin as 34.9% and 152.9%, respectively. Additionally, the CV values of 33.4% annually, 46.7% in winter, 56.9% in spring, 111% in summer and 76.9% in autumn make Antalya a province with the most erratic precipitation.

3.3 Trend Tests

3.3.1 Spearman rank correlation test

A Spearman rank correlation coefficient (rS) was used to detect the presence of trends in monthly, seasonal and annual precipitation data of regions and Turkey (Table 1). The highest rS for the mean annual precipitation was 0.283 in region A, while the lowest was -0.036 in region F ($p<0.05$). The strongest positive Spearman correlation was determined in the June in B region (0.406), and the strongest negative was determined in the November of F region (-0.418). The monthly, seasonal and annual rS values of 81 meteorological stations can be found in Supplementary Table 1. The strongest negative correlation was determined as -0.486 in Erzurum in November; very strong correlations of 1.000 ($R^2=1$) were determined in October in Ağrı and Amasya provinces. Considering both the Turkey region values in Table 1 and the average rS values of 81 provinces in Supplementary Table 1, it is revealed that the effects of climate change on precipitation data are most pronounced in November.

3.3.2 Mann-Kendall and Sen's slope test

The trend analysis at different significant levels (1%, 5% and 10%) of monthly, seasonal and annual precipitation data of different regions and Turkey are shown in Table 2. Although the annual precipitation trends of the A, B, C, D and E regions are increasing and the F and G regions are decreasing, no statistically significant changes were found. The trend of average values of Turkey was positive, but it was not statistically significant (Z=1.013). However, similar to rS values, there were statistically significant changes in both Turkey's averages and A, E, F and G regions in November. The changes in winter of region C were the only seasonal trend with statistically significant (10%). The determined Sen's slopes of trends for the monthly, seasonal and annual precipitation data are shown in Table 3 for different regions and Turkey. The highest negative trend was determined as -1.701 in the G region. The only regions with the negative slope in annual values were F and G, and regions A and B had the biggest positive slopes (2.607 and 2.595, respectively). Slope values of all the regions were positive in January, March, May, August and September on monthly basis and in Winter and Spring on seasonal basis. The slopes of each region were decreasing in November and increasing in January. Parallel findings were obtained with the Mann-Kendall test results for November and all slopes were found to be negative.

Mann-Kendall test results for 81 meteorological stations are given in Supplementary Table 2 and summarized in Table 4. The 40-yr change in annual precipitation of 11 provinces (14% of all stations) was found to be statistically significant and 23 provinces showed decreasing trend, 58 provinces showed increasing trend. All stations except Balıkesir (Z=0754) evaluated monthly had a declining trend in November, and 26 of them were statistically significant. It was revealed that precipitation in all provinces except Amasya, Balıkesir, Gaziantep (Z=0.000), Kars, Mardin, Ardahan and Batman had an increasing trend in September. In 81% of all provinces, average precipitation of January tended to increase and 15 trend was statistically significant. Sen's slope values of 81 provinces are given in Supplementary Table 3. Negative slopes in 19 provinces and positive slopes in 62 provinces were determined. The highest positive and negative slopes were determined in Rize and Bitlis as 5.528 and 6.405 mm $year^{-1}$, respectively (Stations with heterogeneous data sets were not taken into account due to the short period). The slope values in November were negative for all provinces expect Karabük (zero) and only Amasya had a positive slope in September. On the other hand, there are no positive or negative slopes at 25 stations in July and 31 stations in August (Supplementary Table 3).

Figure 5 displays the maps of seasonal and annual change trends and Sen's slope values determined by analyzing the provinces' 40-year average precipitation data. The only province to show a statistically significant decrease during the winter was Artvin, while statistically significant declines also happened in Trabzon and Malatya for the summer and in Muş, Kırklareli and Ardahan for the autumn. It was determined that no significant decreases were experienced in the spring season. The variation ranges of Sen's slope values for winter, spring, summer and autumn were determined as -2.109 - 2.846, -2.709 – 1.829, -1.701 - 2.407 and -2.083-2.407 mm $year^{-1}$, respectively (Fig. 5).

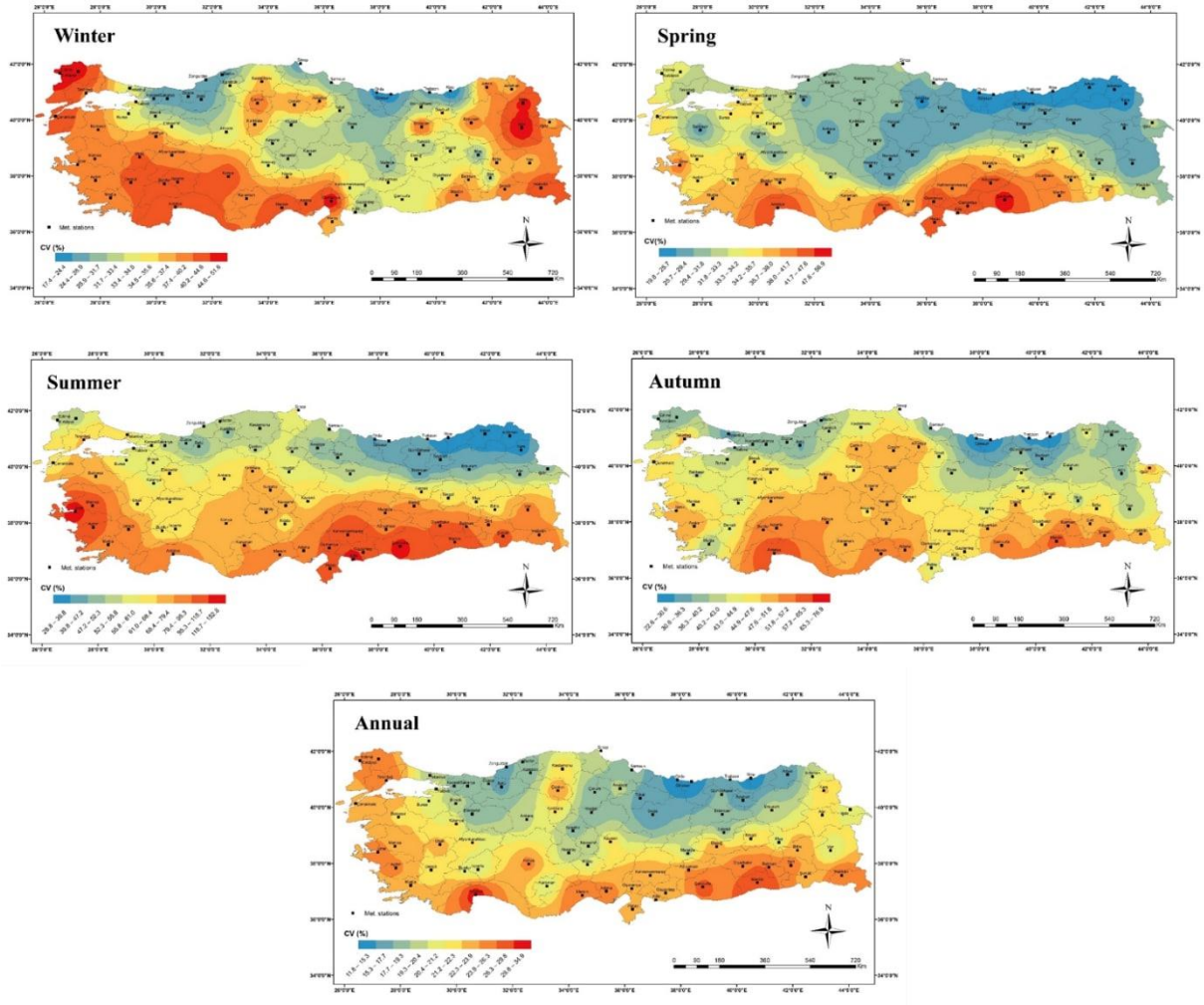

Fig. 4 Geographical distribution map of the coefficients of variation (%) of annual and seasonal precipitation totals over the period 1980 – 2019. In the map, circles display meteorological stations across Turkey, and colors represent the distribution of variation coefficients in percentages.

Table 1. The monthly and seasonal results of Standard Normal Homogeneity Test (SNHT), Pettitt Test and Spearman's rho for the climatic zones and Turkey

Region	SNHT	Pettitt	Spearman's rho															
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Spring	Summer	Autumn	Annual
Turkey	1993 (H_0)	1993 (H_0)	0.256	-0.038	0.172	-0.063	0.132	0.244	-0.164	0.121	0.272	0.126	-0.376	0.012	0.112	0.063	0.151	0.028	0.162
A	1993 (H_0)	1993 (H_0)	0.166	0.128	0.076	-0.058	0.157	0.286	-0.113	0.007	0.315	0.182	-0.376	0.028	0.192	0.045	0.133	0.148	0.283
B	2007 (H_0)	1993 (H_0)	0.213	0.095	0.029	-0.042	0.205	0.406	-0.140	0.186	0.309	0.232	-0.239	-0.136	0.042	0.078	0.268	0.097	0.187
C	1986 (H_0)	1986 (H_0)	0.246	-0.036	0.256	-0.069	0.182	0.039	-0.106	0.027	0.229	-0.006	-0.216	0.316	0.282	0.221	-0.010	0.087	0.141
D	2007 (H_0)	2007 (H_0)	0.222	0.041	0.214	-0.245	0.098	0.268	-0.332	0.118	0.248	0.085	-0.259	0.008	0.162	0.045	0.165	-0.028	0.126
E	2000 (H_0)	2000 (H_0)	0.226	-0.002	0.294	0.062	0.023	-0.010	0.182	0.163	0.125	0.080	-0.335	0.042	0.081	0.182	0.199	-0.048	0.203
F	2017 (H_0)	1997 (H_0)	0.226	-0.160	0.025	-0.044	-0.005	-0.145	0.092	0.213	0.136	0.046	-0.418	0.044	0.039	-0.004	-0.065	-0.205	-0.036
G	2018 (H_0)	1993 (H_0)	0.167	-0.133	0.061	0.023	0.158	0.097	-0.037	0.165	0.186	-0.088	-0.318	0.019	0.029	0.061	0.022	-0.171	-0.030

Table 2. Mann-Kendall test results on the monthly and seasonal basis for the climatic zones and Turkey

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Spring	Summer	Autumn	Annual
Turkey	**1.666^{+}**	-0.175	1.084	-0.524	0.897	1.223	-0.920	0.641	**1.806^{+}**	0.827	**-2.109***	0.012	0.734	0.384	0.897	0.128	1.013
A	1.410	0.781	0.361	-0.361	0.839	**1.805^{+}**	-0.851	0.105	**1.945^{+}**	1.153	**-2.249***	0.245	1.060	0.431	0.711	0.851	1.573
B	1.526	0.478	0.198	-0.198	1.177	**2.342***	-0.618	1.223	**1.922^{+}**	1.433	-1.433	-0.897	0.198	0.431	1.619	0.664	1.200
C	**1.667^{+}**	-0.151	1.619	-0.431	1.084	0.198	-0.571	0.361	1.456	0.004	-1.270	**1.852^{+}**	**1.689^{+}**	1.293	-0.082	0.384	0.618
D	1.526	0.245	1.340	-1.573	0.618	1.643	**-2.016***	0.664	1.619	0.524	-1.503	0.128	0.757	0.245	1.014	-0.151	0.687
E	1.293	-0.035	**1.689^{+}**	0.454	0.268	-0.035	1.177	1.014	0.781	0.431	**-1.946^{+}**	0.175	0.291	1.223	1.282	-0.361	1.270
F	1.340	-1.060	0.151	-0.361	0.082	-0.944	0.583	1.130	0.851	0.408	**-2.365***	0.221	0.245	0.012	-0.361	-1.084	-0.338
G	1.084	-0.897	0.501	0.210	1.014	0.536	-0.259	0.992	1.270	-0.618	**-2.016***	0.175	0.361	0.361	0.093	-1.153	-0.035

Numbers in bold indicate significant values, + significant at the 10 % level, * significant at the 5 % level, ** significant at the 1 % level

Table 3. The monthly and seasonal Sen's Slope values for the climatic zones and Turkey

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Spring	Summer	Autumn	Annual
Turkey	0.653	-0.026	0.306	-0.148	0.124	0.240	-0.104	0.080	0.392	0.292	-0.830	0.032	0.207	0.272	0.144	0.657	0.979
A	0.868	0.386	0.163	-0.130	0.248	0.711	-0.283	0.033	0.700	0.646	-1.064	0.148	0.998	0.279	0.310	0.730	2.607
B	1.402	0.268	0.106	-0.070	0.434	0.554	-0.094	0.137	0.403	0.700	-0.906	-0.821	0.248	0.246	0.576	0.575	2.595
C	0.775	-0.080	0.624	-0.130	0.271	0.068	-0.205	0.182	0.986	-0.008	-1.064	0.859	0.957	0.612	-0.047	0.479	1.140
D	0.432	0.071	0.291	-0.430	0.141	0.517	-0.252	0.074	0.185	0.104	-0.449	0.048	0.443	0.102	0.344	-0.057	0.634
E	0.195	-0.007	0.276	0.148	0.073	-0.021	0.266	0.149	0.139	0.092	-0.476	0.066	0.111	0.481	0.410	-0.125	0.999
F	0.544	-0.577	0.073	-0.252	0.036	-0.126	0.007	0.022	0.089	0.141	-1.141	0.170	0.293	0.032	-0.057	-0.689	-0.611
G	1.305	-0.589	0.356	0.113	0.541	0.085	0.000	0.025	0.352	-0.381	-1.701	0.295	0.882	0.437	0.044	-1.554	-0.159

Table 4. Number of trends at different significance level and directions by Mann-Kendall test (81 stations)

Period	Number of Trends										
	Increasing					0	Decreasing				
	n.s	1%	5%	10%	Total		n.s	1%	5%	10%	Total
January	51	2	8	5	66	1	14	0	0	0	14
February	35	0	0	1	36	1	40	1	1	2	44
March	43	2	7	5	57	1	23	0	0	0	23
April	26	0	0	1	27	0	47	2	4	1	54
May	44	1	2	5	52	0	28	0	0	1	29
June	43	2	5	5	55	1	22	1	1	1	25
July	24	0	0	0	24	3	45	0	5	4	54
August	50	0	2	2	54	1	25	0	1	0	26
September	62	1	8	3	74	1	5	0	1	0	6
October	43	1	5	2	51	2	28	0	0	0	28
November	1	0	0	0	1	0	54	2	14	10	80
December	34	1	1	2	38	0	41	0	1	1	43
Winter	48	2	1	6	57	1	22	0	0	1	23
Spring	43	1	2	1	47	2	31	1	0	0	32
Summer	45	1	3	2	51	0	28	0	1	1	30
Autumn	32	0	1	0	33	1	44	0	1	2	47
Annual	51	1	6	0	58	0	19	1	3	0	23

n.s.: non-significant

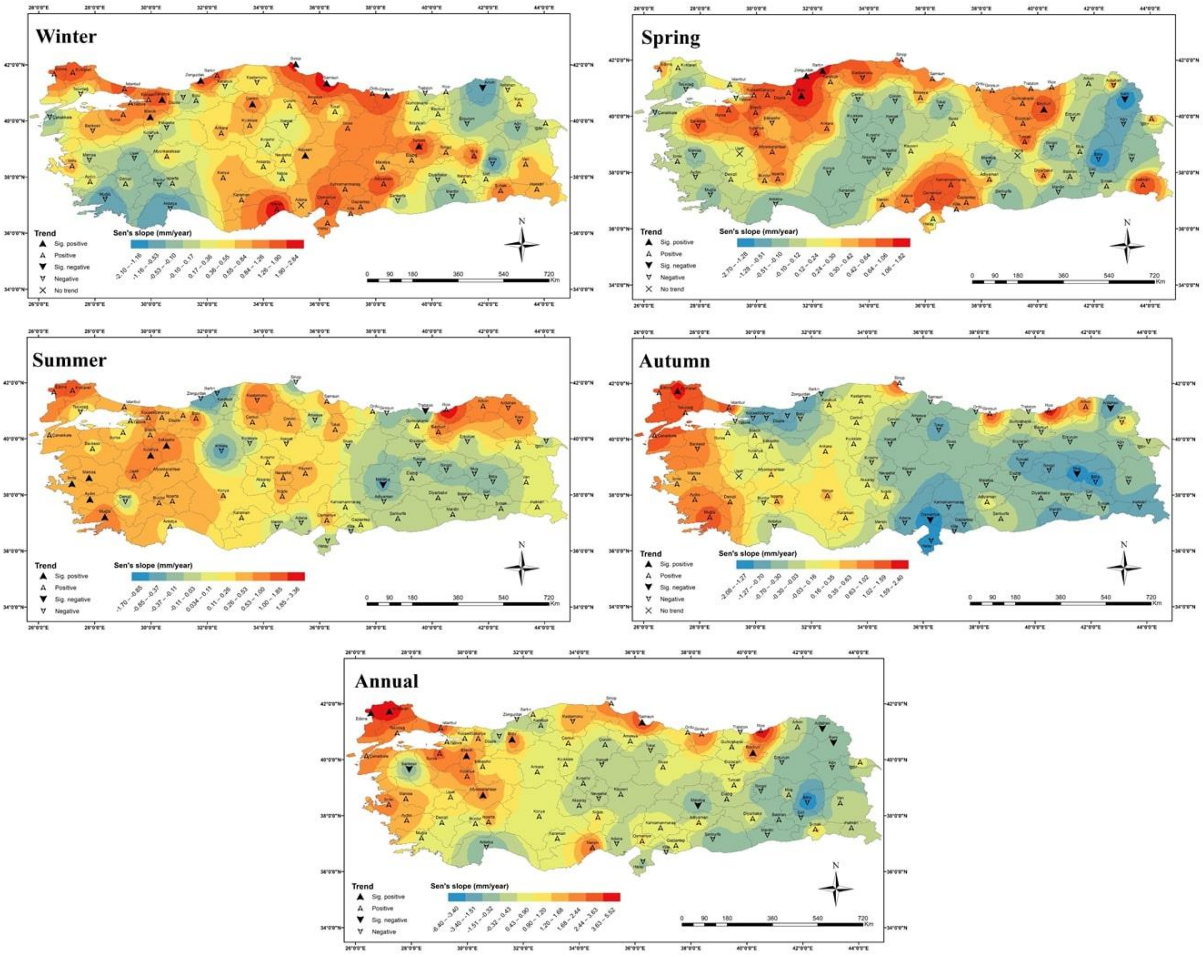

Fig. 5 The spatial distribution of Sen's slope values and trends (Man-Kendall test) for annual and seasonal precipitation over the period of 1980 – 2019. Upward and downward arrows display positive and negative trends of meteorological stations, with solid arrows denoting significance in both positive and negative trends and colors correspond to Sen's slope in mm/year.

The fact that Turkey has a large surface area and contains different climatic zones has caused the precipitation trends to change in different intensities and directions for regions and even for stations. In order to reveal these differences, a box plot of Sen's slope of 40-yr precipitation data of 81 provinces is given in Figure 6 (monthly) and Figure 7 (seasonally). The median values of slopes were negative for 5 months (February, April, July, November and December), positive for 6 months (January, March, May, June, September, October) and the median of August was zero (Fig. 6). The highest and lowest points were obtained in the month of September as 3.66 mm year^{-1} and 2.79 mm year^{-1} in November, respectively. All the median values of seasonal slopes except autumn were positive. While the highest negative slope was determined as -2,709 mm year^{-1} in the spring season, the highest positive slope was determined in summer as 3.366 mm year^{-1}.

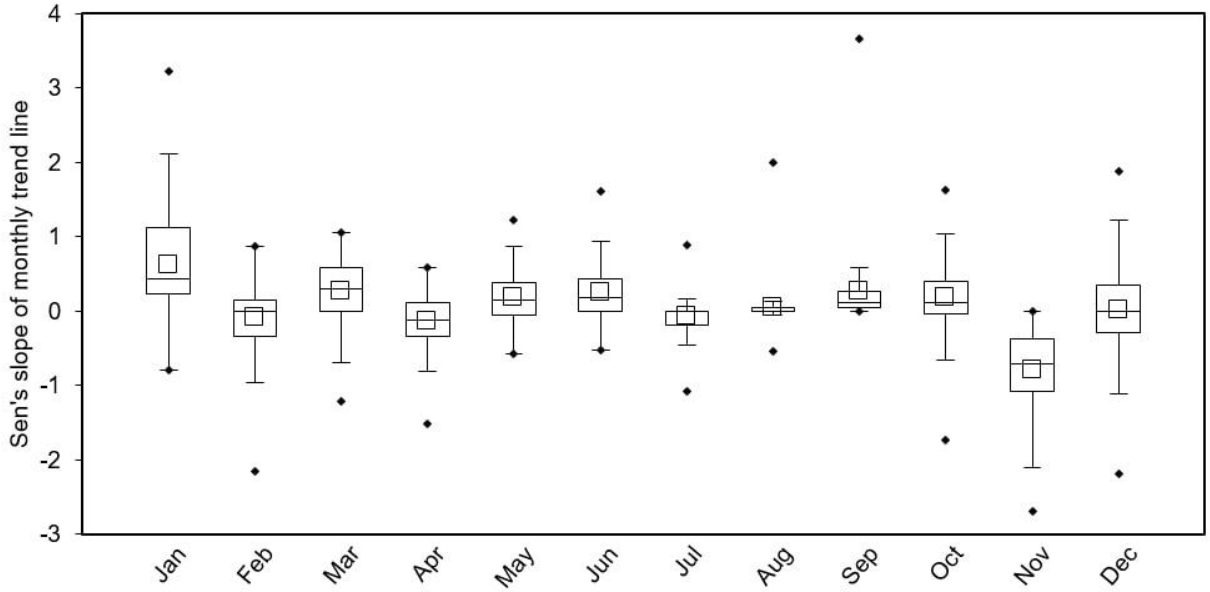

Fig. 6 Box plot of the Sen's slope for monthly precipitation data of Turkey (1980-2019)

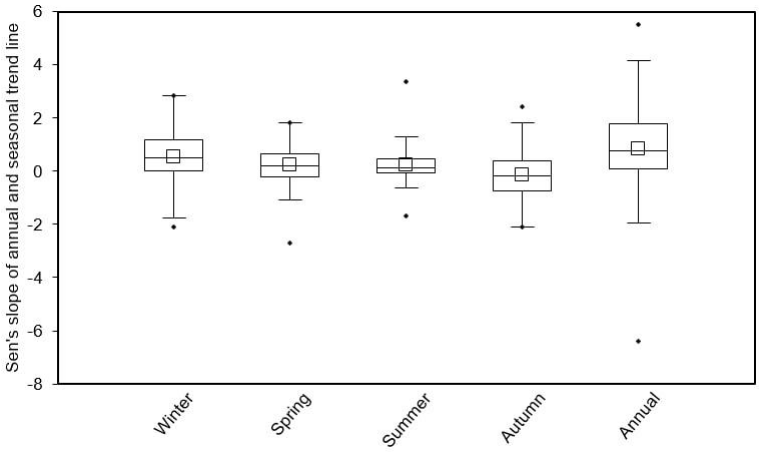

Fig. 7 Box plot of the Sen's slope for annual and seasonal precipitation data of Turkey (1980-2019)

4. Discussion

Climatic variability can be described as the annual difference in values of specific climatic variables within averaging periods such as a 30-year period (Aber and Melillo 1990). The magnitude, intensity, frequency, and type of precipitation vary from year to year, and variations in these factors have an impact on the environment and lifecycle. Precipitation and the hydrological cycle are all being impacted by climate change (Trenberth 2011). Turkey, currently characterized by a semi-arid climate, is expected to be affected by reduced precipitation and heightened drought conditions resulting from global climate change, rendering it more susceptible to increased occurrences of droughts (Türkeş 2020). It is crucial to identify differences in monthly, seasonal, and yearly historical data series and assess the trend since climate change has a significant impact on irrigation water

requirements. In this study, the variation of precipitation over Turkey was examined between 1980-2019 years, and the average precipitation was determined 639.2 mm. Another similar study which conducted by Toros (2012), the average annual precipitation of Turkey was reported as 654 mm from 1961 to 2008 and the maximum and minimum annual precipitation values of provinces were 2 227 mm and 258 mm, respectively. İçel and Ataol (2014) stated that the average amount of precipitation in Turkey between 1975 and 2009 was 668.1 mm, representing an increase in precipitation of 0.43 mm when yearly averages were taken into consideration. The results were found in present study was similar to resulted from previous studies.

The most significant climatological feature of precipitation, which falls to the Earth's surface in various forms of condensation such as drizzle, rain, snow, freezing rain, ice pellets, and hail, is the spatial and temporal variability it exhibits. While the broad-scale zonal distribution of precipitation is generally linked to latitude, the actual distribution pattern is complex and intertwined with numerous other factors (Türkeş 2014, 2021). In light of this information, regional assessments have been conducted and compared with the findings of previous studies. Region A (Marmara Region) stands out as the region where the variation of monthly rS and trend values were the highest. Koç (2001) analyzed the precipitation data of an area that includes the Marmara Region and determined the presence of erratic precipitation. Although the B region's (Aegean) precipitation levels increased, no statistically significant trend was determined. Koçman et al. (1996) analyzed the 48-year change in the Aegean Region and reported that they did not detect any significant changes, which is consistent with our findings. Both regional and national analysis showed an increase in precipitation in the winter months, which was explained by Aziz and Yücel (2021) as decreasing snowfall and increasing precipitation with the increase in air temperatures. The only statistically significant increase in the seasonal analysis was determined for the winter period of Region C (Black Sea Region). In another study conducted by İrdem (2005), examining the temporal and spatial characteristics of precipitation in Turkey, an increasing trend was found in winter precipitation in the Black Sea Region. The Central Anatolia Region (Region D) is one of the regions that will be most affected by future climate change scenarios due to its geographical location and has the potential to be exposed to natural disasters such as floods due to the deterioration of hydrology. Statistically significant ($p<0.05$) decreases determined in July of Region D were evaluated as the effects of climate change and are in line with the findings of previous studies (Altin et al. 2012; Çiçek and Duman 2015; Kızılelma et al. 2015). Both rS values and Mann-Kendall test results for November of all regions were negative. The trend analysis results of regions A, F and G were statistically significant at the level of 5%, and the decreasing trend of region E was statistically significant at the level of 10%. Şenocak and Emek (2019) reported similar results for region E. The effect of major weather systems linked to the large-scale atmospheric circulation can be used to explain that regions F and G had weaker correlations in rS values compared to other regions. The Mediterranean Region (G) showed a decrease in precipitation values, which is consistent with previous studies focused on the Mediterranean region conducted by Maheras et al. (2004) and Kutiel and Türkeş (2017). The Southeastern Anatolia area (Region F) also shown decreasing trend, and according to Türkeş (2003), this region features dry sections that are prone to desertification. In an overarching evaluation encompassing all regions, Türkeş (1998) examined the variations across the regions and highlighting the prominent wet areas like the Black Sea and Mediterranean regions.

The meteorological parameter that varies the most with time and place among others is the amount of precipitation (Panda and Sahu 2019). The lowest standard deviation of the slopes of the precipitation trends of 81 provinces between 1980 and 2019 was determined in August. August is a month that seldom experiences rain and accordingly, in the box plot, the lowest variation range was determined in August (Türkeş 1996, 1998, 2003; Kadioğlu 2000). Floods and droughts are more likely to occur in areas with more inter-annual fluctuation in precipitation (Türkeş 1996; Pandey and Ramasastri 2002). A significant part of Turkey has a coefficient over 20%. It is important to use water consciously in areas where the coefficient of variability for precipitation totals is high as excess precipitation variability means a lack of water, especially for agricultural activities because the higher the inter-annual variability, the higher the probability of drought occurrence is in Turkey (Türkeş 2022). The results of Sen's slope test appeared to be reasonably compatible with those of the Mann-Kendall test as in Partal and Kahya (2006). Region A was the region with the greatest positive annual trend slope (2.607 mm $year^{-1}$). Tayanç et al. (2009) attributed this fluctuation to the fact that the region is located in the interior and the lack of a coastline. Due to its geographical location, the Mediterranean Region is particularly vulnerable to variations in temperature and precipitation. Karaburun (2011) reported positive slopes for precipitation trends of the Marmara Region through the 1985-2006 period. However, the regions having negative slopes were Regions F and G. In Region F, seasonal trends have positive values in the winter and spring and negative values in the summer and autumn.

Negative slopes in annual precipitation in the Mediterranean area have been also detected by Longobardi and Villani (2010) and Rio et al. (2011). Furthermore, Zittis et al. (2021) simulated future precipitation for the Mediterranean region and revealed significant negative slopes (up to −10 mm decade^{-1}) as a result of climate change scenarios.

The spatial variation of 40-yr precipitation data was examined using the interpolation approach since meteorological stations dispersed throughout the national size might be ineffective in displaying the spatial distribution of precipitation (Guo et al. 2020). The annual value of CV often decreased from south to north, reaching a peak between Mardin and Şanlurfa of 36.6%. Ölgen (2010) stated that for the years 1950-2009, CV values in Turkey varied between 11.92% and 31.89% and the range of 19-25% CV value extending in the east-west line in Turkey acts as a zone separating the southern and northern regions. The reason for the great variability in the Mediterranean region is that the number and severity of the depressions that occur in the Mediterranean due to atmospheric oscillations vary greatly from year to year (Roberts et al. 2012). In annual and seasonal precipitation variability, winter showed a different distribution compared to other periods. The Mediterranean Region receives air masses from different regions after October. Low-pressure zones flow from the south to the eastern, or from the northern Aegean to the Black Sea. As a result of the combination of these air masses, depression transitions occur in the Marmara and Aegean regions in winter, which causes precipitation of unexpected magnitude (Koçman 1993). The distribution of winter precipitation tends to decrease from Central Anatolia to the Black Sea, with CVs of total winter precipitation higher than 30% over most of Turkey, except for the regions of Central Anatolia and Black Sea, lower values found in the eastern and western Black Sea, and the highest CV found at Iğdır station with a rate of 38% (Türkeş and Erlat 2005). The variability of the fall precipitation and the variability of the summer precipitation are quite comparable. However, the CV values have decreased since fall precipitation is far more steady than in summer months. Floods and droughts are more likely to occur in areas with more inter-annual fluctuation in precipitation (Türkeş 1996; Pandey and Ramasastri 2002). It is important to use water consciously in areas where the precipitation variability coefficient is high as excess precipitation variability means a lack of water, especially for agricultural activities, and a significant part of Turkey has a coefficient over 20%.

5. Conclusion

In the present study, trends for annual, seasonal and regional series were analyzed for 81 meteorological stations of Turkey between 1980-2019 years. Spearman rank correlation and Mann-Kendall tests were utilized to detect possible trends, and Sen's slope test to estimate the magnitude of change throughout the entire time series. Although the annual precipitation trends did not show any statistically significant changes, our findings reveal that certain regions and months are more susceptible to the impact of climate change. Notably, the regions; Marmara (A), Eastern Anatolia (E), Southeastern Anatolia (F), and Eastern Mediterranean Anatolia (G) demonstrated significant changes in the average precipitation during the month of November, while Black Sea (C) exhibited pronounced changes during the winter season. The highest rS for the mean annual precipitation was 0.283 in region Marmara (A), while the lowest was -0.036 in region Southeastern Anatolia (F). Moreover, the Mann-Kendall test and Sen's slope test showed that each region showed decreasing trends in November, while they were increasing in January. Furthermore, all stations except Balıkesir had a decreasing trend in November, and the precipitation tended to increase in January for 81% of all provinces. The coefficients of variation in annual precipitation ranged between 11.8 % - 34.9 %. The highest variation was observed in summer (28.9-152.9 %) within the seasons. For provinces, Mardin had the greatest coefficient of variation with the 34.9% for summer months, and 56.9% for annually. These findings underscore the importance of continuous monitoring and analysis of precipitation trends to better understand the impact of climate change on water resources in the region. In conclusion, the study provides new insights into the previously unknown trends and variability across Turkey, and emphasizes the need for further research to address the effects of climate change on water resources.

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Statements and Declarations

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Conflict of Interests

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

Ethical Approval

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted. This research did not contain any studies involving animal or human participants, nor did it take place on any private or protected areas.

Author Contributions

Ali Kaan Yetik designed the study and developed the conceptualization. Data receiving was done by Burak Şen. Production of the figures used as material and visualization was done by Bilge Arslan. Analysis and interpretation was performed by Ali Kaan Yetik, Bilge Arslan and Burak Şen. The first version of original draft was prepared by Ali Kaan Yetik and all authors commented on previous versions of the manuscript. All authors read and approved the final version of manuscript.

Data Availability

The precipitation datasets analyzed during the current study are not publicly available as they are the sole entity of the Turkish State Meteorological Service (TSMS). The data can only be used for research and other academic purposes and cannot be shared with third parties unless written permission is granted by the TSMS. The datasets can be available from the corresponding author upon reasonable request after informing the TSMS.

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