



## Drought Trends in Türkiye Under Global Warming Conditions

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### ARTICLE INFO

Research Article

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Received: 06 September 2025 / Revised: 13 April 2026 / Accepted: 12 May 2026 / Online: 12 October 2026

[Cite this article](#)

Sekendur F, Ünlükara A (2026). Drought Trends in Türkiye Under Global Warming Conditions. *Journal of Agricultural Sciences (Tarım Bilimleri Dergisi)*, 32(4):1008-1029. DOI:10.15832/ankutbd.1779288

### ABSTRACT

The methods used in monitoring the increasing drought are vitally significant. In order to determine and monitor drought, many scientific studies have been carried out in our country, especially using the standardized precipitation index (SPI). However, due to increasing temperatures and evaporation, there is a need for studies showing the spatio-temporal change of drought at the country scale according to the standardized precipitation evapotranspiration index (SPEI), which also takes evaporation into account. The change in drought indices according to different evapotranspiration methods is also of interest. In this study, spatio-temporal comparison of drought trend and trend magnitude at 1, 6 and 12-month time scales according to SPI and SPEI indices was aimed by using meteorological observation data of 81 meteorological stations in Türkiye between 1980-2019. FAO-56 Penman-Monteith (PM) and Hargreaves (HG) reference evapotranspiration methods were used to

calculate the SPEI index. Temporal trend analyses were conducted by Modified Mann-Kendall method and drought slope magnitude analyses by Sen's Slope Estimator and spatial analyses by IDW method. According to the SPI index trend analysis for a 1, 6 and 12- month time scale, especially the drought in the Black Sea, the Marmara and Aegean Regions of Türkiye showed a significant downward trend while a significant upward trend of drought was seen in the other regions. The findings revealed that the humid periods were more prevailing than the dry periods in these areas that have downward drought trend. Unlike the SPI, the trend analysis of SPEI<sub>PM</sub> and SPEI<sub>HG</sub> index, downward trend of drought was only encountered in the coastal provinces of the Aegean region, the Central Black Sea, and the West Marmara Region. A significant upward trend of drought was observed in the majority of Central Anatolia, Eastern Anatolia, and Southeastern Anatolia Regions according to the SPEI<sub>PM</sub> and SPEI<sub>HG</sub> index.

Keywords: Drought, SPI, SPEI, FAO-56 Penman-Monteith, Hargreaves

### 1. Introduction

Drought is one of the most complex and devastating natural hazards, exerting profound impacts on ecosystems, water resources, and human societies. Unlike sudden-onset disasters, drought develops slowly and may persist over extended periods, making its detection, monitoring, and mitigation particularly challenging. It is commonly defined as a condition in which precipitation falls significantly below long-term averages, leading to disruptions in hydrological balance and adverse effects on land and water resources (Said et al. 2019).

Drought is inherently a multi-dimensional and multi-scale phenomenon. Previous studies have demonstrated that variables such as precipitation, soil moisture, groundwater levels, snow cover, and streamflow are critical components for drought assessment (McKee et al. 1993). Typically, drought evolution follows a sequential process, beginning with meteorological drought (precipitation deficit), progressing to agricultural drought (soil moisture deficiency), and eventually leading to hydrological drought (reduced surface and groundwater availability) (Tran et al. 2019). At the global scale, drought poses severe risks to food security, potentially resulting in famine and large-scale socio-economic losses (Heim 2002). Therefore, improving drought monitoring and assessment methodologies remains a critical research priority (Philip et al. 2017).

The complexity of determining drought characteristics and severity makes it difficult to monitor and assess (Tirivarambo et al. 2018; Wang et al. 2019; Shaker Sureh 2024). Therefore, many drought indices have been developed to monitor and assess drought events (Vicente-Serrano et al. 2010; Wable et al. 2019). Examples of these are Standardized Precipitation Index (SPI) (McKee et al. 1993), Palmer Drought Severity Index (PDSI) (Palmer 1965), Reconnaissance Drought Index (RDI) (Tsakiris et al. 2007), Composite Meteorological Drought Index (CI) (Guo et al. 2017).

To address some of these limitations, the Standardized Precipitation Evapotranspiration Index (SPEI) was introduced by Vicente-Serrano et al. (2010). Unlike SPI, SPEI incorporates the effects of temperature-driven evapotranspiration, enabling a more comprehensive representation of drought under changing climatic conditions. Although SPEI has been widely applied and

validated in various climatic regions (Beguería et al., 2014), its performance is strongly influenced by the method used to estimate reference evapotranspiration ( $ET_0$ ). Estimating  $ET_0$  is inherently complex, as it requires multiple meteorological variables, including temperature, wind speed, solar radiation, and humidity (Allen et al. 1998; Çetin 2020).

The Thornthwaite method, which relies solely on temperature data, has been commonly used in SPEI calculations due to its simplicity and low data requirements (Thornthwaite 1948). However, this method neglects key climatic variables and assumes zero evapotranspiration at temperatures below 0 °C, limiting its applicability in regions with cold winters (Selling 1996; Van der Schrier et al. 2011). In contrast, physically based approaches such as the FAO-56 Penman–Monteith method, recommended by the Food and Agriculture Organization (FAO), provide more robust estimates but require extensive meteorological data (Allen et al. 1998). Alternatively, the Hargreaves method offers a compromise by estimating  $ET_0$  using temperature-based inputs with improved sensitivity compared to Thornthwaite (Hargreaves & Samani 1985).

Previous studies have highlighted that the choice of  $ET_0$  method can significantly influence SPEI-based drought assessments (Tsakiris et al. 2007; Dai 2011; Sheffield et al. 2012; Ortiz-Gómez et al. 2022). In particular, the FAO-56 Penman–Monteith method has been shown to be more sensitive in detecting drought variability compared to simpler temperature-based methods. However, despite these findings, there remains a lack of comprehensive, region-specific evaluations comparing drought indices derived from different  $ET_0$  methods, particularly for countries with diverse climatic conditions such as Türkiye.

This gap is especially critical for Türkiye, where significant spatial variability in climate and the occurrence of sub-zero temperatures during winter limit the applicability of certain evapotranspiration models. While previous studies have applied individual drought indices or single  $ET_0$  methods, comparative assessments integrating multiple indices (SPI and SPEI) and different  $ET_0$  estimation approaches (FAO-56 Penman–Monteith and Hargreaves) at a national scale remain limited.

Therefore, the main contribution of this study is to systematically evaluate spatial drought trends across Türkiye by employing multiple drought indices (SPI,  $SPEI_{PM}$ , and  $SPEI_{HG}$ ) and to quantify the differences arising from the choice of evapotranspiration method. By addressing this gap, the study can provide a more robust understanding of drought dynamics and contribute to the improvement of drought monitoring and water resources management strategies under variable climatic conditions.

## 2. Material and Methods

### 2.1. Study area, meteorological station data and average climate data

Meteorological observation data of the central meteorological stations of 81 provinces of Türkiye between 1980-2019 were obtained from Turkish State Meteorological Service. Meteorological data include monthly precipitation (mm), wind speed ( $m.s^{-1}$ ), maximum and minimum air temperature (°C), sunshine duration (hours), solar radiation ( $MJ.m^{-2}.day^{-1}$ ), maximum and minimum relative humidity (%).

The stations located in the provincial centers were classified according to 7 geographical regions in letter order to examine the research more easily and to avoid confusion. Each geographical region has a similar topographic structure as well as similar vegetation and climate characteristics. For this reason, it was thought that it would be more appropriate to present the study data and findings based on 7 geographical regions.

Meteorological station data of the Mediterranean, Eastern Anatolia, Aegean, Southeastern Anatolia, Central Anatolia, Black Sea, and Marmara Region provinces are shown in Tables 1 to 7 respectively.

**Table 1- Meteorological station data of the Mediterranean Region**

| <i>Station Name</i> | <i>Station Number</i> | <i>Latitude</i> | <i>Longitude</i> | <i>Elevation (m)</i> |
|---------------------|-----------------------|-----------------|------------------|----------------------|
| Adana               | 17351                 | 37° 00' 15" N   | 35° 20' 40" E    | 23                   |
| Antalya             | 17300                 | 36° 54' 23" N   | 30° 47' 56" E    | 64                   |
| Burdur              | 17238                 | 37° 43' 19" N   | 30° 17' 38" E    | 957                  |
| Hatay               | 17372                 | 36° 14' 13" N   | 36° 07' 59" E    | 104                  |
| Isparta             | 17240                 | 37° 47' 05" N   | 30° 34' 04" E    | 997                  |
| K.Maraş             | 17255                 | 37° 34' 34" N   | 36° 54' 54" E    | 572                  |
| Mersin              | 17340                 | 36° 46' 51" N   | 34° 36' 11" E    | 7                    |
| Osmaniye            | 17355                 | 37° 06' 08" N   | 36° 15' 14" E    | 94                   |

**Table 2- Meteorological station data of the Eastern Anatolia Region**

| <i>Station Name</i> | <i>Station Number</i> | <i>Latitude</i> | <i>Longitude</i> | <i>Elevation (m)</i> |
|---------------------|-----------------------|-----------------|------------------|----------------------|
| Ağrı                | 17099                 | 39° 43' 31" N   | 43° 03' 08" E    | 1646                 |
| Ardahan             | 17046                 | 41° 06' 22" N   | 42° 42' 20" E    | 1827                 |
| Bingöl              | 17203                 | 38° 53' 05" N   | 40° 30' 03" E    | 1139                 |
| Bitlis              | 17207                 | 38° 28' 30" N   | 42° 09' 45" E    | 1785                 |
| Elazığ              | 17201                 | 38° 38' 40" N   | 39° 15' 22" E    | 989                  |
| Erzincan            | 17094                 | 39° 45' 08" N   | 39° 29' 13" E    | 1216                 |
| Erzurum             | 17096                 | 39° 57' 10" N   | 41° 11' 23" E    | 1758                 |
| Hakkari             | 17285                 | 37° 34' 28" N   | 43° 44' 20" E    | 1727                 |
| Iğdır               | 17100                 | 39° 55' 22" N   | 44° 03' 08" E    | 856                  |
| Kars                | 17097                 | 40° 36' 22" N   | 43° 06' 43" E    | 1777                 |
| Malatya             | 17199                 | 38° 20' 12" N   | 38° 13' 02" E    | 950                  |
| Muş                 | 17204                 | 38° 45' 03" N   | 41° 30' 08" E    | 1322                 |
| Tunceli             | 17165                 | 39° 06' 21" N   | 39° 32' 27" E    | 981                  |
| Van                 | 17172                 | 38° 28' 10" N   | 43° 20' 46" E    | 1675                 |

**Table 3- Meteorological station data of the Aegean Region**

| <i>Station Name</i> | <i>Station Number</i> | <i>Latitude</i> | <i>Longitude</i> | <i>Elevation (m)</i> |
|---------------------|-----------------------|-----------------|------------------|----------------------|
| A.Karahisar         | 17190                 | 38° 44' 17" N   | 30° 33' 37" E    | 1034                 |
| Aydın               | 17234                 | 37° 50' 25" N   | 27° 50' 16" E    | 56                   |
| Denizli             | 17237                 | 37° 45' 43" N   | 29° 05' 32" E    | 425                  |
| İzmir               | 17220                 | 38° 23' 40" N   | 27° 04' 56" E    | 29                   |
| Kütahya             | 17155                 | 39° 25' 02" N   | 29° 59' 21" E    | 969                  |
| Manisa              | 17186                 | 38° 36' 55" N   | 27° 24' 18" E    | 71                   |
| Muğla               | 17292                 | 37° 12' 34" N   | 28° 22' 01" E    | 646                  |
| Uşak                | 17188                 | 38° 40' 16" N   | 29° 24' 15" E    | 919                  |

**Table 4- Meteorological station data of the Southeastern Anatolia Region**

| <i>Station Name</i> | <i>Station Number</i> | <i>Latitude</i> | <i>Longitude</i> | <i>Elevation (m)</i> |
|---------------------|-----------------------|-----------------|------------------|----------------------|
| Adıyaman            | 17265                 | 37° 45' 19" N   | 38° 16' 39" E    | 672                  |
| Batman              | 17282                 | 37° 51' 49" N   | 41° 09' 22" E    | 610                  |
| Diyarbakır          | 17280                 | 37° 53' 50" N   | 40° 12' 10" E    | 674                  |
| Gaziantep           | 17261                 | 37° 03' 31" N   | 37° 21' 04" E    | 854                  |
| Kilis               | 17262                 | 36° 42' 30" N   | 37° 06' 43" E    | 640                  |
| Mardin              | 17275                 | 37° 18' 37" N   | 40° 43' 42" E    | 1040                 |
| Siirt               | 17210                 | 37° 55' 55" N   | 41° 56' 07" E    | 895                  |
| Şanlıurfa           | 17270                 | 37° 09' 39" N   | 38° 47' 11" E    | 550                  |
| Şırnak              | 17287                 | 37° 31' 13" N   | 42° 26' 42" E    | 1350                 |

**Table 5- Meteorological station data of the Central Anatolia Region**

| <i>Station Name</i> | <i>Station Number</i> | <i>Latitude</i> | <i>Longitude</i> | <i>Elevation (m)</i> |
|---------------------|-----------------------|-----------------|------------------|----------------------|
| Aksaray             | 17192                 | 38° 22' 14" N   | 33° 59' 55" E    | 970                  |
| Ankara              | 17130                 | 39° 58' 22" N   | 32° 51' 49" E    | 891                  |
| Çankırı             | 17080                 | 40° 36' 30" N   | 33° 36' 37" E    | 755                  |
| Eskişehir           | 17124                 | 39° 46' 52" N   | 30° 34' 47" E    | 801                  |
| Karaman             | 17246                 | 37° 11' 36" N   | 33° 13' 13" E    | 1018                 |
| Kayseri             | 17196                 | 38° 41' 13" N   | 35° 30' 00" E    | 1094                 |
| Kırıkkale           | 17135                 | 39° 50' 36" N   | 33° 31' 05" E    | 751                  |
| Kırşehir            | 17160                 | 39° 09' 50" N   | 34° 09' 22" E    | 1007                 |
| Konya               | 17244                 | 37° 59' 01" N   | 32° 34' 26" E    | 1031                 |
| Nevşehir            | 17193                 | 38° 36' 59" N   | 34° 42' 09" E    | 1260                 |
| Niğde               | 17250                 | 37° 57' 30" N   | 34° 40' 46" E    | 1211                 |
| Sivas               | 17090                 | 39° 44' 37" N   | 37° 00' 07" E    | 1294                 |
| Yozgat              | 17140                 | 39° 49' 28" N   | 34° 48' 57" E    | 1301                 |

**Table 6- Meteorological station data of the Black Sea Region**

| <i>Station Name</i> | <i>Station Number</i> | <i>Latitude</i> | <i>Longitude</i> | <i>Elevation (m)</i> |
|---------------------|-----------------------|-----------------|------------------|----------------------|
| Amasya              | 17085                 | 40° 40' 01" N   | 35° 50' 07" E    | 409                  |
| Artvin              | 17045                 | 41° 10' 30" N   | 41° 49' 07" E    | 613                  |
| Bartın              | 17020                 | 41° 37' 29" N   | 32° 21' 25" E    | 33                   |
| Bayburt             | 17089                 | 40° 15' 17" N   | 40° 13' 15" E    | 1584                 |
| Bolu                | 17070                 | 40° 43' 58" N   | 31° 36' 08" E    | 743                  |
| Çorum               | 17084                 | 40° 32' 46" N   | 34° 56' 10" E    | 776                  |
| Düzce               | 17072                 | 40° 50' 37" N   | 31° 08' 56" E    | 146                  |
| Giresun             | 17034                 | 40° 55' 22" N   | 38° 23' 16" E    | 38                   |
| Gümüşhane           | 17088                 | 40° 27' 35" N   | 39° 27' 55" E    | 1216                 |
| Karabük             | 17078                 | 41° 12' 16" N   | 32° 37' 58" E    | 400                  |
| Kastamonu           | 17074                 | 41° 22' 16" N   | 33° 46' 32" E    | 800                  |
| Ordu                | 17033                 | 40° 59' 02" N   | 37° 53' 09" E    | 5                    |
| Rize                | 17040                 | 41° 02' 24" N   | 40° 30' 05" E    | 3                    |
| Samsun              | 17030                 | 41° 20' 39" N   | 36° 15' 23" E    | 4                    |
| Sinop               | 17026                 | 42° 01' 48" N   | 35° 09' 16" E    | 32                   |
| Tokat               | 17086                 | 40° 19' 52" N   | 36° 33' 28" E    | 611                  |
| Trabzon             | 17037                 | 40° 59' 55" N   | 39° 45' 54" E    | 25                   |
| Zonguldak           | 17022                 | 41° 26' 57" N   | 31° 46' 41" E    | 135                  |

**Table 7- Meteorological station data of the Marmara Region**

| <i>Station Name</i> | <i>Station Number</i> | <i>Latitude</i> | <i>Longitude</i> | <i>Elevation (m)</i> |
|---------------------|-----------------------|-----------------|------------------|----------------------|
| Balıkesir           | 17150                 | 39° 37' 57" N   | 27° 55' 12" E    | 102                  |
| Bilecik             | 17120                 | 40° 08' 29" N   | 29° 58' 38" E    | 539                  |
| Bursa               | 17116                 | 40° 13' 51" N   | 29° 00' 48" E    | 100                  |
| Çanakkale           | 17112                 | 40° 08' 28" N   | 26° 23' 58" E    | 6                    |
| Edirne              | 17050                 | 41° 40' 36" N   | 26° 33' 03" E    | 51                   |
| İstanbul            | 17638                 | 40° 54' 41" N   | 29° 09' 21" E    | 18                   |
| Kırklareli          | 17052                 | 41° 44' 18" N   | 27° 13' 04" E    | 232                  |
| Kocaeli             | 17066                 | 40° 45' 59" N   | 29° 55' 02" E    | 74                   |
| Sakarya             | 17069                 | 40° 46' 03" N   | 30° 23' 36" E    | 30                   |
| Tekirdağ            | 17056                 | 40° 57' 31" N   | 27° 29' 47" E    | 4                    |
| Yalova              | 17119                 | 40° 39' 37" N   | 29° 17' 12" E    | 4                    |

The long-term average climate data of the Mediterranean, Eastern Anatolia, Aegean, Southeastern Anatolia, Central Anatolia, Black Sea, and Marmara Region provinces between 1980-2019 are shown in Tables 8 to 14 respectively.

**Table 8- Long-term average climate data of the Mediterranean Region**

| <i>Station name</i> | <i>U<sub>2</sub></i> | <i>T<sub>avg</sub></i> | <i>T<sub>max</sub></i> | <i>T<sub>min</sub></i> | <i>Rh<sub>max</sub></i> | <i>Rh<sub>min</sub></i> | <i>N</i> | <i>Nrd</i> | <i>P<sub>avg</sub></i> |
|---------------------|----------------------|------------------------|------------------------|------------------------|-------------------------|-------------------------|----------|------------|------------------------|
| Adana               | 0.97                 | 19.2                   | 25.4                   | 13.9                   | 96.2                    | 17.8                    | 7.5      | 85.8       | 664.6                  |
| Antalya             | 2.09                 | 18.8                   | 24.2                   | 13.8                   | 95.0                    | 17.5                    | 8.2      | 85.4       | 1102.6                 |
| Burdur              | 1.42                 | 13.3                   | 19.4                   | 7.6                    | 91.8                    | 22.0                    | 7.5      | 101.6      | 421.1                  |
| Hatay               | 2.09                 | 18.3                   | 23.2                   | 14.1                   | 94.0                    | 22.1                    | 7.2      | 99.4       | 1124.2                 |
| Isparta             | 1.42                 | 12.3                   | 18.4                   | 6.2                    | 94.3                    | 23.8                    | 7.1      | 112.2      | 538.4                  |
| K.Maraş             | 1.12                 | 16.7                   | 23.0                   | 11.5                   | 92.8                    | 16.3                    | 6.8      | 83.4       | 724.0                  |
| Mersin              | 1.42                 | 19.2                   | 23.4                   | 14.8                   | 90.8                    | 33.0                    | 7.5      | 79.0       | 603.2                  |
| Osmaniye            | 1.27                 | 18.6                   | 24.9                   | 12.7                   | 93.8                    | 17.9                    | 6.6      | 83.3       | 823.8                  |

U<sub>2</sub>: Wind speed of 2 meters (m.s<sup>-1</sup>), T<sub>avg</sub>, T<sub>max</sub> and T<sub>min</sub>: Average, maximum and minimum temperature, respectively (°C), Rh<sub>max</sub> and Rh<sub>min</sub>: Maximum and minimum relative humidity (%), n: Sunshine duration (hour), Nrd: Number of rainy days, P<sub>avg</sub>: Average precipitation (mm).

**Table 9- Long-term average climate data of the Eastern Anatolia Region**

| <i>Station name</i> | <i>U<sub>2</sub></i> | <i>T<sub>avg</sub></i> | <i>T<sub>max</sub></i> | <i>T<sub>min</sub></i> | <i>Rh<sub>max</sub></i> | <i>Rh<sub>min</sub></i> | <i>n</i> | <i>Nrd</i> | <i>P<sub>avg</sub></i> |
|---------------------|----------------------|------------------------|------------------------|------------------------|-------------------------|-------------------------|----------|------------|------------------------|
| Ağrı                | 1.20                 | 6.2                    | 13.0                   | -0.4                   | 94.8                    | 31.6                    | 6.3      | 117.3      | 525.9                  |
| Ardahan             | 1.35                 | 3.6                    | 10.9                   | -2.5                   | 95.0                    | 33.2                    | 5.5      | 129.0      | 556.5                  |
| Bingöl              | 0.97                 | 12.1                   | 18.6                   | 6.5                    | 90.9                    | 21.7                    | 6.2      | 107.4      | 942.5                  |
| Bitlis              | 1.50                 | 9.0                    | 14.0                   | 3.9                    | 95.3                    | 26.9                    | 6.0      | 108.0      | 1046.6                 |
| Elazığ              | 1.72                 | 13.1                   | 19.0                   | 7.5                    | 88.5                    | 22.3                    | 7.1      | 98.6       | 409.6                  |
| Erzincan            | 1.05                 | 10.9                   | 17.3                   | 4.7                    | 93.4                    | 26.4                    | 6.6      | 107.7      | 378.6                  |
| Erzurum             | 1.94                 | 5.7                    | 11.9                   | -0.5                   | 96.6                    | 27.3                    | 6.9      | 128.1      | 402.9                  |
| Hakkari             | 1.20                 | 10.3                   | 15.5                   | 5.5                    | 88.5                    | 24.5                    | 7.7      | 99.8       | 791.2                  |
| Iğdır               | 0.90                 | 12.2                   | 19.0                   | 5.6                    | 92.3                    | 19.0                    | 6.3      | 93.6       | 259.7                  |
| Kars                | 1.87                 | 4.7                    | 11.6                   | -1.7                   | 95.2                    | 30.9                    | 6.5      | 120.8      | 497.4                  |
| Malatya             | 1.05                 | 13.7                   | 19.0                   | 8.4                    | 88.4                    | 20.5                    | 7.7      | 92.7       | 382.5                  |
| Muş                 | 0.90                 | 9.7                    | 15.9                   | 4.2                    | 91.0                    | 26.7                    | 6.6      | 113.0      | 761.5                  |
| Tunceli             | 0.90                 | 12.7                   | 19.6                   | 6.8                    | 91.2                    | 22.7                    | 7.1      | 109.7      | 856.5                  |
| Van                 | 1.57                 | 9.4                    | 15.0                   | 3.7                    | 90.5                    | 24.9                    | 7.9      | 98.5       | 388.9                  |

**Table 10- Long-term average climate data of the Aegean Region**

| <i>Station name</i> | <i>U<sub>2</sub></i> | <i>T<sub>avg</sub></i> | <i>T<sub>max</sub></i> | <i>T<sub>min</sub></i> | <i>Rh<sub>max</sub></i> | <i>Rh<sub>min</sub></i> | <i>n</i> | <i>Nrd</i> | <i>P<sub>avg</sub></i> |
|---------------------|----------------------|------------------------|------------------------|------------------------|-------------------------|-------------------------|----------|------------|------------------------|
| A.Karahisar         | 1.50                 | 11.3                   | 17.4                   | 5.1                    | 95.3                    | 23.0                    | 6.8      | 116.6      | 424.4                  |
| Aydın               | 1.12                 | 17.7                   | 24.6                   | 11.9                   | 95.3                    | 21.0                    | 6.5      | 91.0       | 638.6                  |
| Denizli             | 0.90                 | 16.2                   | 22.5                   | 10.8                   | 93.1                    | 23.7                    | 7.3      | 95.5       | 567.7                  |
| İzmir               | 2.24                 | 17.9                   | 22.7                   | 13.5                   | 90.8                    | 29.8                    | 8.1      | 91.4       | 699.6                  |
| Kütahya             | 1.20                 | 10.8                   | 17.0                   | 4.9                    | 94.9                    | 22.9                    | 6.1      | 123.5      | 569.0                  |
| Manisa              | 1.27                 | 16.9                   | 22.9                   | 11.0                   | 92.1                    | 25.0                    | 6.5      | 93.7       | 739.7                  |
| Muğla               | 1.42                 | 15.1                   | 21.2                   | 9.6                    | 95.3                    | 21.3                    | 7.3      | 100.9      | 1186.3                 |
| Uşak                | 1.35                 | 12.5                   | 18.5                   | 6.8                    | 94.9                    | 22.6                    | 7.5      | 98.0       | 546.1                  |

**Table 11- Long-term average climate data of the Southeastern Anatolia Region**

| <i>Station name</i> | <i>U<sub>2</sub></i> | <i>T<sub>avg</sub></i> | <i>T<sub>max</sub></i> | <i>T<sub>min</sub></i> | <i>Rh<sub>max</sub></i> | <i>Rh<sub>min</sub></i> | <i>n</i> | <i>Nrd</i> | <i>P<sub>avg</sub></i> |
|---------------------|----------------------|------------------------|------------------------|------------------------|-------------------------|-------------------------|----------|------------|------------------------|
| Adıyaman            | 1.27                 | 17.3                   | 23.1                   | 12.0                   | 88.1                    | 17.8                    | 7.6      | 95.4       | 712.7                  |
| Batman              | 1.26                 | 15.9                   | 23.8                   | 8.9                    | 88.2                    | 23.4                    | 7.5      | 88.2       | 485.6                  |
| Diyarbakır          | 1.94                 | 15.9                   | 22.6                   | 8.8                    | 87.2                    | 19.3                    | 7.9      | 99.6       | 500.1                  |
| Gaziantep           | 0.82                 | 15.2                   | 21.6                   | 9.4                    | 92.8                    | 19.8                    | 7.1      | 92.2       | 570.9                  |
| Kilis               | 1.87                 | 17.2                   | 23.4                   | 11.8                   | 93.7                    | 13.5                    | 7.7      | 90.3       | 494.6                  |
| Mardin              | 2.77                 | 16.1                   | 20.1                   | 12.3                   | 86.1                    | 17.8                    | 8.1      | 84.0       | 670.5                  |
| Siirt               | 0.97                 | 16.2                   | 21.7                   | 11.0                   | 85.0                    | 20.5                    | 7.5      | 106.5      | 695.9                  |
| Şanlıurfa           | 1.20                 | 18.5                   | 24.4                   | 12.7                   | 90.4                    | 18.2                    | 8.1      | 80.6       | 460.2                  |
| Şırnak              | 1.42                 | 15.1                   | 19.3                   | 10.9                   | 73.2                    | 14.5                    | 7.3      | 75.7       | 720.8                  |

**Table 12- Long-term average climate data of the Central Anatolia Region**

| <i>Station name</i> | $U_2$ | $T_{avg}$ | $T_{max}$ | $T_{min}$ | $Rh_{max}$ | $Rh_{min}$ | $n$ | $Nrd$ | $P_{avg}$ |
|---------------------|-------|-----------|-----------|-----------|------------|------------|-----|-------|-----------|
| Aksaray             | 1.80  | 12.1      | 18.7      | 6.2       | 91.7       | 23.4       | 7.4 | 92.5  | 346.2     |
| Ankara              | 1.65  | 11.9      | 17.9      | 6.3       | 93.5       | 23.6       | 6.8 | 134.0 | 412.5     |
| Çankırı             | 0.90  | 11.3      | 18.1      | 5.0       | 96.7       | 26.5       | 6.3 | 112.0 | 417.0     |
| Eskişehir           | 1.42  | 11.3      | 17.5      | 5.4       | 96.4       | 24.0       | 6.2 | 102.4 | 378.8     |
| Karaman             | 1.57  | 12.0      | 18.8      | 5.5       | 91.8       | 20.3       | 7.9 | 83.8  | 335.5     |
| Kayseri             | 1.20  | 10.7      | 18.1      | 3.0       | 95.2       | 20.7       | 7.0 | 107.9 | 392.2     |
| Kırıkkale           | 1.42  | 12.5      | 18.5      | 6.9       | 93.9       | 25.5       | 7.0 | 103.8 | 388.1     |
| Kırşehir            | 2.02  | 11.5      | 17.8      | 5.4       | 95.0       | 24.5       | 7.3 | 105.5 | 384.9     |
| Konya               | 1.72  | 11.7      | 18.0      | 5.4       | 93.0       | 21.3       | 7.4 | 102.8 | 328.8     |
| Nevşehir            | 1.50  | 10.7      | 16.5      | 5.4       | 94.7       | 21.7       | 7.1 | 97.5  | 415.2     |
| Niğde               | 1.94  | 11.2      | 17.6      | 5.1       | 93.4       | 20.4       | 7.4 | 111.2 | 335.0     |
| Sivas               | 0.90  | 9.0       | 15.4      | 2.9       | 94.7       | 23.2       | 6.8 | 112.0 | 438.6     |
| Yozgat              | 1.50  | 9.2       | 14.7      | 4.0       | 96.7       | 26.1       | 6.7 | 115.8 | 587.5     |

**Table 13- Long-term average climate data of the Black Sea Region**

| <i>Station name</i> | $U_2$ | $T_{avg}$ | $T_{max}$ | $T_{min}$ | $Rh_{max}$ | $Rh_{min}$ | $n$ | $Nrd$ | $P_{avg}$ |
|---------------------|-------|-----------|-----------|-----------|------------|------------|-----|-------|-----------|
| Amasya              | 1.20  | 13.5      | 20.1      | 8.0       | 92.7       | 18.1       | 5.7 | 111.7 | 459.8     |
| Artvin              | 1.27  | 12.3      | 17.3      | 8.5       | 95.8       | 21.2       | 4.9 | 147.7 | 703.1     |
| Bartın              | 0.97  | 12.8      | 19.1      | 7.7       | 98.1       | 29.2       | 5.8 | 148.9 | 1043.9    |
| Bayburt             | 1.27  | 7.0       | 13.8      | 1.3       | 92.0       | 23.3       | 5.6 | 110.8 | 442.4     |
| Bolu                | 0.97  | 10.5      | 17.1      | 4.7       | 97.3       | 26.1       | 5.5 | 138.1 | 561.4     |
| Çorum               | 1.27  | 10.8      | 17.6      | 4.3       | 96.9       | 23.5       | 6.1 | 122.9 | 446.9     |
| Düzce               | 0.75  | 13.1      | 19.4      | 8.6       | 97.0       | 29.0       | 5.1 | 143.9 | 830.7     |
| Giresun             | 0.90  | 14.8      | 18.0      | 11.7      | 94.5       | 34.8       | 2.8 | 171.2 | 1268.0    |
| Gümüşhane           | 1.27  | 9.5       | 16.5      | 4.4       | 93.9       | 20.8       | 5.7 | 128.9 | 459.9     |
| Karabük             | 0.75  | 13.4      | 20.8      | 7.9       | 95.4       | 22.3       | 5.7 | 136.3 | 479.9     |
| Kastamonu           | 0.97  | 9.8       | 16.4      | 4.1       | 96.4       | 25.5       | 5.8 | 146.5 | 503.1     |
| Ordu                | 1.12  | 14.5      | 18.4      | 11.2      | 93.4       | 35.7       | 4.5 | 163.9 | 1045.3    |
| Rize                | 0.90  | 14.5      | 18.1      | 10.4      | 98.4       | 36.3       | 4.2 | 183.9 | 2245.0    |
| Samsun              | 1.65  | 14.6      | 18.3      | 11.1      | 94.7       | 31.6       | 5.3 | 154.0 | 716.9     |
| Sinop               | 2.17  | 14.3      | 17.3      | 11.6      | 96.6       | 34.7       | 5.4 | 138.3 | 689.3     |
| Tokat               | 1.65  | 12.5      | 18.8      | 7.1       | 94.5       | 24.4       | 5.9 | 126.8 | 429.9     |
| Trabzon             | 1.72  | 14.7      | 18.1      | 11.8      | 93.9       | 33.1       | 4.5 | 149.8 | 816.9     |
| Zonguldak           | 1.80  | 13.7      | 17.1      | 10.5      | 96.0       | 30.8       | 5.5 | 159.5 | 1218.5    |

**Table 14- Long-term average climate data of the Marmara Region**

| <i>Station name</i> | $U_2$ | $T_{avg}$ | $T_{max}$ | $T_{min}$ | $Rh_{max}$ | $Rh_{min}$ | $n$ | $Nrd$ | $P_{avg}$ |
|---------------------|-------|-----------|-----------|-----------|------------|------------|-----|-------|-----------|
| Balıkesir           | 1.20  | 14.7      | 21.2      | 8.8       | 95.8       | 26.3       | 6.8 | 103.0 | 583.5     |
| Bilecik             | 1.57  | 12.5      | 17.8      | 8.1       | 95.0       | 27.8       | 6.4 | 117.4 | 462.1     |
| Bursa               | 1.50  | 14.6      | 20.4      | 9.1       | 97.1       | 24.4       | 6.3 | 123.2 | 694.8     |
| Çanakkale           | 2.77  | 15.1      | 19.7      | 10.8      | 95.5       | 38.0       | 7.2 | 92.9  | 618.9     |
| Edirne              | 1.35  | 13.7      | 19.7      | 8.4       | 96.5       | 29.5       | 6.0 | 115.2 | 603.8     |
| İstanbul            | 1.35  | 16.2      | 20.8      | 12.7      | 96.6       | 27.4       | 6.3 | 125.1 | 652.7     |
| Kırklareli          | 1.12  | 13.2      | 18.9      | 8.8       | 96.1       | 29.9       | 5.3 | 112.1 | 578.3     |
| Kocaeli             | 1.05  | 14.8      | 19.8      | 10.8      | 96.8       | 30.9       | 5.7 | 150.1 | 816.5     |
| Sakarya             | 1.12  | 14.6      | 20.0      | 10.1      | 97.6       | 30.1       | 5.4 | 140.5 | 850.6     |
| Tekirdağ            | 1.94  | 14.1      | 17.9      | 10.4      | 96.5       | 41.4       | 5.7 | 110.1 | 582.3     |
| Yalova              | 1.20  | 14.6      | 19.1      | 10.4      | 95.4       | 35.2       | 5.4 | 121.0 | 748.7     |

## 2.2. Homogeneity analysis

Determining whether the data used in drought analyses, trend analyses, etc., based on climate parameters is homogeneous increases the reliability of the results of the analyses.

Drought assessment based on the SPI index is performed solely using rainfall data, whereas drought analyses using the SPEI index incorporate combinations of rainfall and meteorological data (temperature, humidity, wind, sunshine duration, and sunshine intensity) (Vicente-Serrano et al., 2010). Vicente-Serrano et al. (2010) performed their calculations based on climatic water balance ( $D_i$ ) series created for different time scales in the SPEI drought index they developed. They used the equation  $D_i = P_i - ET_{0i}$  to calculate SPEI values for different time scales. This equation, as clearly stated by Keskiner et al. (2020), is an indicator of the basin water deficit. As can be understood from this, in order to find the climatic water balance, the reference evapotranspiration ( $ET_0$ ) value must be subtracted from the measured precipitation amount ( $P_i$ ). Precipitation amount is the most important climate parameter for calculations based on SPI and SPEI indices (Vicente-Serrano et al., 2010).

In this study, homogeneity tests were applied only to monthly total precipitation data; no additional homogeneity tests were conducted for the climate data combinations (temperature, humidity, wind, sunshine duration, and sunshine intensity) to be used in  $ET_0$  calculations. Monthly total precipitation amounts for the period 1980–2019 from 81 meteorological stations located in provincial centres across Türkiye were subjected to homogeneity tests to ensure reliable drought analyses based on SPI and SPEI indices.

### 2.2.1. Homogeneity test methods

Statistical approaches with methodologies provided by Wijngaard et al. (2003) include the Standard Normal Homogeneity Test (SNHT) and the Buishand Range Test (Buishand 1982). The Pettitt Test (Pettitt 1979) and the Von Neumann Test (Von Neumann 1941) were used as homogeneity tests. Homogeneity tests were applied to monthly total precipitation data. Monthly total precipitation amounts were entered into Microsoft Excel 2019 and subsequently transferred to the XLSTAT 2018 programme for the relevant homogeneity tests to be performed. The homogeneity of the data series was investigated at a 5% significance level using the four relevant homogeneity tests in the XLSTAT 2018 programme.

### 2.2.2. Classification of homogeneity tests for meteorological time series

In the study conducted by Wijngaard et al. (2003), homogeneity tests, which were also considered in this study, were used to analyse the homogeneity of meteorological data. According to the method adopted by Wijngaard et al. (2003), the classification was carried out in two parts. In the first part, meteorological data were checked according to these four homogeneity tests, and in the second part, a classification was created to determine the usability of the homogeneity test results for each station. The classification created by Wijngaard et al. (2003) was used in the study and is shown in Table 15.

**Table 15- Homogeneity test classification of meteorological time series**

| <i>Clas.</i> | <i>Explanation</i>                                                                                                                                                      | <i>Evaluation</i> |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|
| <b>1</b>     | At most, one test has rejected the $H_0$ hypothesis at the 5% error level. It can be used in time series climate studies.                                               | <b>Useful</b>     |
| <b>2</b>     | At most two tests rejected the $H_0$ hypothesis at the 5% error level. As the time series is relatively heterogeneous, it should not be disregarded in climate studies. | <b>Uncertain</b>  |
| <b>3</b>     | Three or four tests have rejected the $H_0$ hypothesis at the 5% error level. Time series should be homogenised or not used in climate studies.                         | <b>Doubtful</b>   |

## 2.3. Calculation of SPI and SPEI

### 2.3.1. Standardized precipitation index (SPI)

Monthly total precipitation data are used for drought analysis according to the SPI index. SPI is designed to assess drought conditions based on the probability distribution of long-term precipitation using the gamma function (McKee et al. 1993). SPI index is one of the most preferred methods for monitoring drought and determining its severity and can be used both temporally and spatially. If the data to be used in the study are normally distributed, the most general relationship of the SPI index is based on the simulation fact that the difference of precipitation ( $x_i$ ) from the mean precipitation ( $\bar{x}_i$ ) of a station  $i$  for a certain time scale can be obtained by dividing the standard deviation ( $\sigma_i$ ). If mean and standard deviation of the available data are known, the SPI value is hypothetically calculated as shown in equation (1) (Çetin et al. 2018; Aksoy et al. 2021).

$$SPI = \frac{x_i - \bar{x}_i}{\sigma_i} \quad (1)$$

When calculating according to the SPI index, continuous and error-free precipitation series of at least 30 years should be used. However, as justified by Said et al. (2019), drought analyses can be performed with rainfall series of shorter record lengths when necessary. Each rainfall series is then fitted to the Gamma distribution. The Gamma distribution is considered to be the most appropriate distribution for rainfall series (Thom 1958). This distribution is defined as the distribution frequency or probability density function.

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}, \text{ for } x > 0 \quad (2)$$

$\alpha > 0$ ,  $\alpha$  is the shape parameter,  $\beta > 0$  is the scale parameter,  $x > 0$ ;  $x$  is the amount of precipitation and  $\Gamma(\alpha)$  is the gamma function.  $\alpha$  and  $\beta$  are the parameters of the gamma theoretical probability distribution model. The calculations of  $\alpha$  and  $\beta$  are given in equation (3).

$$\alpha = \frac{1}{4A} \left( 1 + \sqrt{1 + \frac{4A}{3}} \right) \text{ ve } \beta = \frac{\bar{x}}{\alpha} \quad (3)$$

The value of  $A$  found in equation (3) is defined in equation (4).

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad (4)$$

$n$  denotes the number of precipitation observations. The cumulative probability value of any data is obtained from the Gamma cumulative probability distribution function whose relation is given below.

$$G(x) = \int_0^x g(x) dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-\frac{x}{\beta}} dx \quad (5)$$

Since the gamma function is undefined for  $x=0$ , if the precipitation data is zero, equation (5) is adjusted as in equation (6).

$$H(x) = q + (1 - q) \cdot G(x) \quad (6)$$

In equation (6),  $q$  is used to express the probability for zero (0) value.

### 2.3.2. Standardized precipitation evapotranspiration index (SPEI)

SPEI has a multi-scale and multi-numerical characteristic that includes other meteorological parameters along with precipitation. The index developed by Vicente-Serrano et al. (2010) is based on the variation of the monthly climatic water balance ( $D$ ) at different time scales. The SPEI calculation algorithm requires estimating the reference evapotranspiration ( $ET_0$ ), determining the climatic water balance deficit ( $D_i = P_i - ET_{0i}$ ) at different time scales, and normalizing the climatic water balance with a log-logistic probability distribution. The climatic water balance deficit is given in Equation (7).

$$D_i = P_i - ET_{0i} \quad (7)$$

$D_i$  represents climatic water balance deficit (mm),  $P_i$  represents total precipitation (mm),  $ET_{0i}$  represents reference evapotranspiration (mm). For the calculation of SPEI values, a three-parameter Log-logistic theoretical probability distribution model is used for time scales. The SPI index uses a two-parameter distribution ( $0 < x < \infty$ ) and  $x$  can only take positive values.

On the other hand, in the three-parameter distributions used in SPEI ( $\gamma < x < \infty$ ),  $x$  can also take negative values (Vicente-Serrano et al. 2010). Here,  $\gamma$  represents the initial parameter of the distribution. Therefore, the log-logistic distribution is preferred in SPEI calculation since it fits extreme negative values better (Hernandez & Uddameri 2014). The climatic water balance for different time scales is calculated using Equation (8).

$$D_n^k = \sum_{i=0}^{k-1} (P_{n-i} - ET_{0n-i}), \quad n \geq k \quad (8)$$

In the equation (8),  $k$  represents the chosen time scale (months) and  $n$  represents the account frequency. The probability density function of the three-parameter log-logistic distribution is shown in Equation (9).

$$f(x) = \frac{\beta}{\alpha} \left( \frac{x-\gamma}{\alpha} \right)^{\beta-1} \left( 1 + \left( \frac{x-\gamma}{\alpha} \right)^\beta \right)^{-2} \quad (9)$$

In the equation (9), D values are the scale, shape, and origin parameters  $\alpha, \beta$  ve  $\gamma$  respectively, for  $\gamma > D < \infty$ . Vicente-Serrano et al. (2010) determined  $\alpha, \beta$  ve  $\gamma$  parameters by L-moments method in their SPEI calculation studies. In this study,  $\alpha, \beta$  ve  $\gamma$  parameters are estimated according to the L-moments method.

$$\alpha = \frac{(w_0 - 2w_1)\beta}{\Gamma(1 + \frac{1}{\beta})\Gamma(1 - \frac{1}{\beta})} \quad (10)$$

$$\beta = \frac{2w_1 - w_0}{6w_1 - w_0 - 6w_2} \quad (11)$$

$$\gamma = w_0 - \alpha\Gamma(1 + \frac{1}{\beta})\Gamma(1 - \frac{1}{\beta}) \quad (12)$$

Where;  $\Gamma(1 + \frac{1}{\beta})$ , is the gamma function of  $(1 + \frac{1}{\beta})$ , and  $w_s$  is the ordered probability density function. It is calculated according to Equation (13) and takes the values  $s = 0, 1, 2$ .

$$w_s = \frac{1}{n} \sum_{i=1}^n (1 - \frac{j-0.35}{n})^s D_i \quad (13)$$

In Equation (13), n represents the number of data points and j represents the interval of observations in ascending order. For the transformation of  $D_i$  series on time scales into a standard normal distribution, the cumulative probabilities based on the log-logistic distribution are determined by Equation (14) below.

$$F(x) = \left[ 1 + \left( \frac{\alpha}{x - \gamma} \right)^\beta \right]^{-1} \quad (14)$$

SPEI value is calculated as the standardized value of  $F(x)$  as in Equation (15).

$$SPEI = W - \frac{c_0 + c_1 W + c_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \quad (15)$$

$$W = \sqrt{-2 \ln(P)}, P \leq 0.5 \quad (16)$$

P stands for the probability of exceeding a specified value of D. If  $P > 0.5$ ,  $1 - P$  is replaced and the resulting SPEI sign is reversed. Where P is the probability of exceeding a given value of  $D_i$  for equality of  $P = 1 - F(x)$ ;  $P > 0.5$ ,  $P = 1 - P$  and the coefficients are as shown below (Yang et al. 2016).

$$\begin{aligned} c_0 &= 2.515517 \\ c_1 &= 0.802853 \\ c_2 &= 0.010328 \\ d_1 &= 1.432788 \\ d_2 &= 0.189269 \\ d_3 &= 0.001308 \end{aligned}$$

## 2.4. Calculation of reference evapotranspiration

### 2.4.1. FAO 56 Penman-Monteith method

Reference evapotranspiration ( $ET_0$ ) is the amount of plant water consumption indicating the evaporation demand of the atmosphere. To obtain the reference evapotranspiration ( $ET_0$ ) by the FAO56 Penman-Monteith method, the following equation (17) from Allen et al. (1998) was used.

$$ET_{0PM} = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (17)$$

$ET_0$ : Reference evapotranspiration ( $\text{mm.day}^{-1}$ ),  $Rn$ : Net radiation at the reference plant surface ( $\text{MJ.m}^{-2}.\text{day}^{-1}$ ),  $G$ : Soil heat flux density ( $\text{MJ.m}^{-2}.\text{day}^{-1}$ ),  $T$ : Average daily air temperature at 2 m height ( $^{\circ}\text{C}$ ),  $u_2$ : Wind speed at 2 m height ( $\text{m.s}^{-1}$ ),  $e_s$ : Saturated vapor pressure (kPa),  $e_a$ : Actual vapor pressure (kPa),  $\Delta$ : Slope of the vapor pressure curve ( $\text{kPa.}^{\circ}\text{C}^{-1}$ ) and  $\gamma$ : represents the psychrometric constant ( $\text{kPa.}^{\circ}\text{C}^{-1}$ ).

#### 2.4.2. Hargreaves method

An alternative empirical approach to calculate  $ET_0$  was proposed by Hargreaves and Samani (1985). The calculation is based on Equation (18).

$$ET_{0HG} = C_H 0.408 R_0 (T + 17.8) \sqrt{T_{max} - T_{min}} \quad (18)$$

T: mean temperature ( $^{\circ}\text{C}$ ),  $R_0$ : extraterrestrial (from the outer surface of the atmosphere) solar radiation,  $T_{max}$  and  $T_{min}$  are the maximum and minimum temperatures ( $^{\circ}\text{C}$ ) respectively and  $C_H$ : Hargreaves coefficient. A value of 0.0023 was used for the  $C_H$  coefficient.

SPI and SPEI indices at 1-, 6-, and 12-months' time scales were calculated with R Studio.

#### 2.5. Modified Mann-Kendall trend test

In time series-based studies such as hydro-meteorological data, serial correlations may occur. The presence of serial correlations in data sets may cause results as if there is a trend even if there is no trend in the data. The trend values found with the classical Mann-Kendall trend test can sometimes give erroneous results. With the modified Mann-Kendall trend test, the effect of serial correlation is included in the calculated variance value (Cox & Stuart 1955). The Modified Mann-Kendall trend test by Hamed & Rao (1998), which considers the presence of autocorrelation, is used in the study.

In the modified Mann-Kendall trend test, the same S statistic calculation equation (19) used in the Mann-Kendall trend test is used.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \quad (19)$$

$$\begin{aligned} \text{sgn}(x_j - x_k) &= 1 & \text{if } x_j - x_k > 0 \\ &= 0 & \text{if } x_j - x_k = 0 \\ &= -1 & \text{if } x_j - x_k < 0 \end{aligned} \quad (20)$$

The variance of the S statistic for the modified Mann-Kendall trend test is calculated by Equation (21) below.

$$\text{Var}(S) = \left[ \frac{n(n-1)(2n+5)}{18} \right] \frac{n}{n_S^*} \quad (21)$$

$\frac{n}{n_S^*}$  denotes the correction factor for serial correlation (autocorrelation).

$$\frac{n}{n_S^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-i)(n-i-1)(n-i-2)\rho(i) \quad (22)$$

Equation (22) shows the autocorrelation function of the  $\rho(i)$  time series ranking.

In time series with or without serial correlation (autocorrelation), the statistical significance of the trend is calculated based on the adjusted  $Z_{cal}$  value and compared to the critical Z values.

$$Z_{cal} = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (23)$$

The  $Z_{cal}$  values are compared with the  $Z_{\alpha/2}$  value determined in the Z standard normal distribution table at  $\alpha=0.05$  level of significance. If  $|Z_{cal}| > Z_{\alpha/2}$ ,  $H_0$  hypothesis is rejected, and it is accepted that there is a statistically significant trend in the time series. If the Z value is positive, it is accepted that there is an upward trend, and if it is negative, it is accepted that there is a downward trend.

#### 2.6. Sen's slope estimator

Sen (1968) developed this nonparametric method to estimate the magnitude of trend in time series. Sen's slope method is a

statistical method that is not affected by outliers and is frequently used in parallel with the Mann-Kendall trend test (Sen 1968). For example, the Mann-Kendall trend test determines the trend of the analyzed climate parameter or drought index, while Sen's slope method determines the magnitude of this trend. The World Meteorological Organization (WMO) recommends the use of Sen's slope method as part of trend analysis based on hydro-meteorological data (WMO 2018). Sen's slope method has been widely used in hydro-meteorological time series (Lettenmaier et al. 1994; Yue & Hashino 2003; El-Nesr et al. 2010; Ülke & Özkoca 2018; Collaud Coen et al. 2020; Topçu & Karaçor 2020). It provides information about the magnitude of the trend in time series using a linear model (Sen 1968; Salmi et al. 2002; Keskiner & Çetin 2022).

In Equation (24),  $n$  is the number of data, and  $N$  is the number of slopes of Sen to be calculated in the time series to represent the observed data ( $x_j$  ve  $x_k$ ) at times  $j$  and  $k$  (Tonkaz et al. 2007; Kaur et al. 2021).

$$N = \frac{n(n-1)}{2} \quad (24)$$

Sen's slope statistic ( $Q_i$ ) for  $N$  number of sample pairs is calculated by Equation (25).

$$Q_i = \frac{(x_j - x_k)}{(j - k)}, j > k; i = 1, 2, 3, \dots, N \quad (25)$$

$Q_i$  values obtained with Equation (25) are ranked from smallest to largest and the median value is found. Depending on whether the number  $N$  is odd or even, the median of the  $Q_i$  values ( $Q_{median}$ ) is calculated with equation (26).

$$Q_{median} = \begin{cases} Q_{[(n+1)/2]}, & N \text{ odd} \\ \frac{Q_{[n/2]} + Q_{[(n+2)/2]}}{2}, & N \text{ even} \end{cases} \quad (26)$$

$Q_{medyan}$  value gives the change per unit time of the relevant observations. When this value is positive, there is an increasing slope and when it is negative, there is a decreasing slope (Gocic & Trajkovic 2013).  $Q_{median}$  value is statistically tested at 5% significance level and the analysis is completed (Sen 1968; Salmi et al. 2002).

## 2.7. Spatial analysis

In the study, the trends found by the Modified Mann-Kendall trend test and the slopes found by Sen's slope method at 1,6- and 12-months' time scales for 81 provincial central stations were projected to the entire surface of Türkiye by Inverse Distance Weighted Interpolation (IDW) method. ArgGIS 10.5 software was used to create drought trend and magnitude maps according to IDW method.

## 3. Results and Discussion

### 3.1. Homogeneity test results

Stations located in provincial centres have been classified according to Türkiye's seven geographical regions to facilitate the examination of research findings and avoid confusion. In the Tables 16 - 22 presenting the homogeneity results of the monthly average precipitation data for stations based on geographical region, the test results are given with  $H_0$  (null hypothesis) and  $H_a$  (alternative hypothesis). Test results for stations shown with  $H_0$  indicate that the data is homogeneous, while those shown with  $H_a$  indicate that the data is not homogeneous. In the classification section, 1 and 2 correspond to "Useful" or "Uncertain" status, respectively, based on the homogeneity test results for monthly total rainfall amounts included in climate studies.

**Table 16- Mediterranean Region homogeneity test results**

| Station  | Pettitt | SNHT                    | Buishand | Von Neumann | Classification |
|----------|---------|-------------------------|----------|-------------|----------------|
| Adana    | $H_0$   | $H_0$                   | $H_0$    | $H_0$       | 1              |
| Antalya  | $H_0$   | $H_0$                   | $H_0$    | $H_0$       | 1              |
| Burdur   | $H_0$   | $H_0$                   | $H_0$    | $H_0$       | 1              |
| Hatay    | $H_0$   | $H_0$                   | $H_0$    | $H_0$       | 1              |
| Isparta  | $H_0$   | <b><math>H_a</math></b> | $H_0$    | $H_0$       | 1              |
| K.Maraş  | $H_0$   | $H_0$                   | $H_0$    | $H_0$       | 1              |
| Mersin   | $H_0$   | $H_0$                   | $H_0$    | $H_0$       | 1              |
| Osmaniye | $H_0$   | <b><math>H_a</math></b> | $H_0$    | $H_0$       | 1              |

$H_0$ : Homogeneous,  $H_a$ : Not homogeneous, 1: 'Useful', 2: 'Uncertain'.

**Table 17- Eastern Anatolia Region homogeneity test results**

| <i>Station</i> | <i>Pettitt</i>       | <i>SNHT</i>          | <i>Buishand</i>      | <i>Von Neumann</i>   | <i>Classification</i> |
|----------------|----------------------|----------------------|----------------------|----------------------|-----------------------|
| Ağrı           | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Ardahan        | <b>H<sub>a</sub></b> | <b>H<sub>a</sub></b> | H <sub>0</sub>       | H <sub>0</sub>       | 2                     |
| Bingöl         | <b>H<sub>a</sub></b> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Bitlis         | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | <b>H<sub>a</sub></b> | 1                     |
| Elazığ         | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Erzincan       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Erzurum        | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Hakkari        | H <sub>0</sub>       | <b>H<sub>a</sub></b> | <b>H<sub>a</sub></b> | H <sub>0</sub>       | 2                     |
| Iğdır          | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Kars           | H <sub>0</sub>       | <b>H<sub>a</sub></b> | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Malatya        | H <sub>0</sub>       | <b>H<sub>a</sub></b> | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Muş            | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Tunceli        | H <sub>0</sub>       | <b>H<sub>a</sub></b> | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Van            | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |

**Table 18- Aegean Region homogeneity test results**

| <i>Station</i> | <i>Pettitt</i>       | <i>SNHT</i>    | <i>Buishand</i> | <i>Von Neumann</i> | <i>Classification</i> |
|----------------|----------------------|----------------|-----------------|--------------------|-----------------------|
| A.Karahisar    | H <sub>0</sub>       | H <sub>0</sub> | H <sub>0</sub>  | H <sub>0</sub>     | 1                     |
| Aydın          | H <sub>0</sub>       | H <sub>0</sub> | H <sub>0</sub>  | H <sub>0</sub>     | 1                     |
| Denizli        | H <sub>0</sub>       | H <sub>0</sub> | H <sub>0</sub>  | H <sub>0</sub>     | 1                     |
| İzmir          | H <sub>0</sub>       | H <sub>0</sub> | H <sub>0</sub>  | H <sub>0</sub>     | 1                     |
| Kütahya        | <b>H<sub>a</sub></b> | H <sub>0</sub> | H <sub>0</sub>  | H <sub>0</sub>     | 1                     |
| Manisa         | H <sub>0</sub>       | H <sub>0</sub> | H <sub>0</sub>  | H <sub>0</sub>     | 1                     |
| Muğla          | H <sub>0</sub>       | H <sub>0</sub> | H <sub>0</sub>  | H <sub>0</sub>     | 1                     |
| Uşak           | H <sub>0</sub>       | H <sub>0</sub> | H <sub>0</sub>  | H <sub>0</sub>     | 1                     |

**Table 19- Southeast Anatolia Region homogeneity test results**

| <i>Station</i> | <i>Pettitt</i> | <i>SNHT</i>          | <i>Buishand</i> | <i>Von Neumann</i>   | <i>Classification</i> |
|----------------|----------------|----------------------|-----------------|----------------------|-----------------------|
| Adıyaman       | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Batman         | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Diyarbakır     | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Gaziantep      | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Kilis          | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Mardin         | H <sub>0</sub> | <b>H<sub>a</sub></b> | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Siirt          | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Şanlıurfa      | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Şırnak         | H <sub>0</sub> | <b>H<sub>a</sub></b> | H <sub>0</sub>  | <b>H<sub>a</sub></b> | 2                     |

**Table 20- Central Anatolia Region homogeneity test results**

| <i>Station</i> | <i>Pettitt</i> | <i>SNHT</i>          | <i>Buishand</i>      | <i>Von Neumann</i>   | <i>Classification</i> |
|----------------|----------------|----------------------|----------------------|----------------------|-----------------------|
| Aksaray        | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Ankara         | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Çankırı        | H <sub>0</sub> | <b>H<sub>a</sub></b> | <b>H<sub>a</sub></b> | H <sub>0</sub>       | 2                     |
| Eskişehir      | H <sub>0</sub> | H <sub>0</sub>       | <b>H<sub>a</sub></b> | H <sub>0</sub>       | 1                     |
| Karaman        | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Kayseri        | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Kırıkkale      | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Kırşehir       | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Konya          | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>       | <b>H<sub>a</sub></b> | 1                     |
| Nevşehir       | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Niğde          | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Sivas          | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Yozgat         | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |

**Table 21- Black Sea Region homogeneity test results**

| <i>Station</i> | <i>Pettitt</i>       | <i>SNHT</i>          | <i>Buishand</i>      | <i>Von Neumann</i>   | <i>Classification</i> |
|----------------|----------------------|----------------------|----------------------|----------------------|-----------------------|
| Amasya         | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Artvin         | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Bartın         | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Bayburt        | <b>H<sub>a</sub></b> | <b>H<sub>a</sub></b> | H <sub>0</sub>       | H <sub>0</sub>       | 2                     |
| Bolu           | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Çorum          | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Düzce          | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Giresun        | <b>H<sub>a</sub></b> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Gümüşhane      | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Karabük        | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | <b>H<sub>a</sub></b> | 1                     |
| Kastamonu      | H <sub>0</sub>       | H <sub>0</sub>       | <b>H<sub>a</sub></b> | H <sub>0</sub>       | 1                     |
| Ordu           | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Rize           | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Samsun         | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Sinop          | <b>H<sub>a</sub></b> | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Tokat          | H <sub>0</sub>       | H <sub>0</sub>       | <b>H<sub>a</sub></b> | H <sub>0</sub>       | 1                     |
| Trabzon        | H <sub>0</sub>       | <b>H<sub>a</sub></b> | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |
| Zonguldak      | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | H <sub>0</sub>       | 1                     |

**Table 22- Marmara Region homogeneity test results**

| <i>Station</i> | <i>Pettitt</i> | <i>SNHT</i>          | <i>Buishand</i> | <i>Von Neumann</i>   | <i>Classification</i> |
|----------------|----------------|----------------------|-----------------|----------------------|-----------------------|
| Balıkesir      | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | <b>H<sub>a</sub></b> | 1                     |
| Bilecik        | H <sub>0</sub> | <b>H<sub>a</sub></b> | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Bursa          | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Çanakkale      | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Edirne         | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| İstanbul       | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Kırklareli     | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Kocaeli        | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Sakarya        | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Tekirdağ       | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |
| Yalova         | H <sub>0</sub> | H <sub>0</sub>       | H <sub>0</sub>  | H <sub>0</sub>       | 1                     |

Based on the homogeneity classification and assessment proposed by Wijngaard et al. (2003), stations falling into the 1. “Useful” and 2. “Uncertain” classes in the homogeneity test results tables should be classified as homogeneous. The research findings in this study were evaluated based on this criterion. Since none of the 81 provincial centre meteorological stations used in the study fell into the third “Doubtful” category according to the homogeneity test results, there was no need to homogenise the rainfall data. When the results were evaluated collectively, the monthly average rainfall data for 81 provinces were used in the SPI and SPEI calculations.

### 3.2. Spatial distribution of precipitation and reference evapotranspiration amounts

Annual average amounts for the period 1980-2019 for 81 meteorological stations in 81 provincial centers of Türkiye were taken into consideration. Precipitation (P) spatial distribution map is shown in Fig. 1, reference evapotranspiration spatial distribution map according to FAO-56 PM method is shown in Fig. 2, reference evapotranspiration spatial distribution map according to Hargreaves method is shown in Fig. 3.

Looking at the map of the areal distribution of Türkiye's average annual precipitation (Fig. 1), it is seen that the average precipitation varies between 259 mm and 2243 mm across the provinces. The lowest average precipitation belongs to Iğdır province (259 mm) and the highest average precipitation belongs to Rize province (2243 mm). According to the average precipitation data published by Turkish State Meteorological Service between 1991 and 2020, the normal (average) precipitation in Türkiye was reported as 573.4 mm. In regions with topographically variable structures, meteorological parameters and related

variables vary significantly over very short distances (Akacak & Taş 2021). In a study conducted across Türkiye, it was reported that rainfall variability was more than 25% in the Mediterranean and Southeastern Anatolia Regions and the least variability was reported in the Eastern Black Sea region. Due to the large variability in precipitation over many years, droughts are frequently experienced (Ölgen 2010). The fact that the average precipitation across the provinces is above and below Türkiye's average indicates how meticulously drought studies should be carried out. According to Fig. 1, the regions receiving the least precipitation are almost all of the Central Anatolia Region, the interior of the Aegean Region, the Southeastern Anatolia Region, and around Iğdır, Kars, Ağrı and Van in the Eastern Anatolia Region. The regions receiving the most precipitation are the Eastern and Western Black Sea Region, Hatay, Osmaniye, Antalya, Muğla and Manisa in the Mediterranean and Aegean Regions, Tunceli, Bingöl, Bitlis and Hakkari in the Eastern and Southeastern Anatolia Region.

When Türkiye's annual average FAO-56 PM reference evapotranspiration spatial distribution map (Fig. 2) is analyzed; it is seen that the average reference evapotranspiration amount varies between 765 mm and 1482 mm. The areas where reference evapotranspiration is considerably higher compared to other provinces are Southeastern Anatolia, the Mediterranean Region, the south of the Central Anatolia Region, and around Manisa, İzmir and Aydın in the Aegean Region. The areas with the lowest reference evapotranspiration are generally the east and north of the Eastern Anatolia Region, the coastline of the Black Sea Region and the north-east of the Marmara Region. Fig. 3 shows the areal distribution map of Türkiye's annual average reference evapotranspiration calculated according to the Hargreaves method. Accordingly, it is seen that the average reference evapotranspiration varies between 790 mm and 1474 mm. It is understood that these range values are close to the  $ET_0$  range values calculated according to the FAO-56 PM method shown in Fig. 2. When these two figures are compared, it is seen that according to the Hargreaves method (Fig. 3), more areas in Türkiye have high  $ET_0$  values. The highest reference evapotranspiration values are found in the Southeastern Anatolia Region, the south of the Eastern Anatolia Region, the Iğdır regions, the Central Anatolia Region, and the Mediterranean Region.

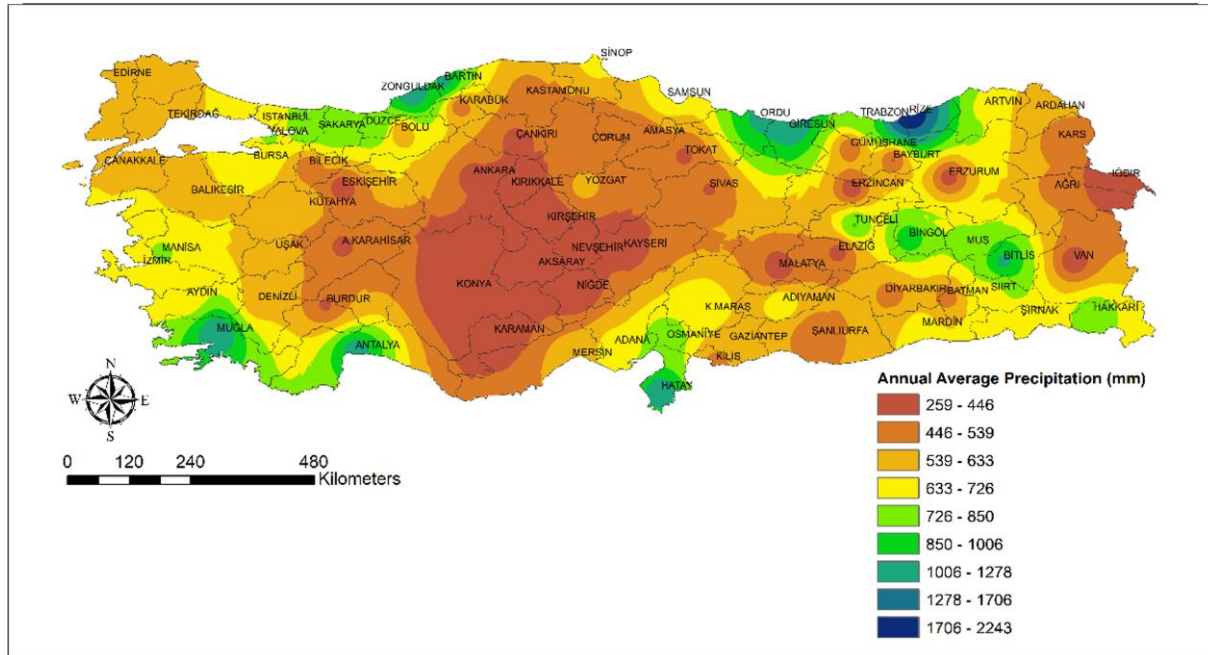


Figure 1- Spatial distribution map of annual average precipitation

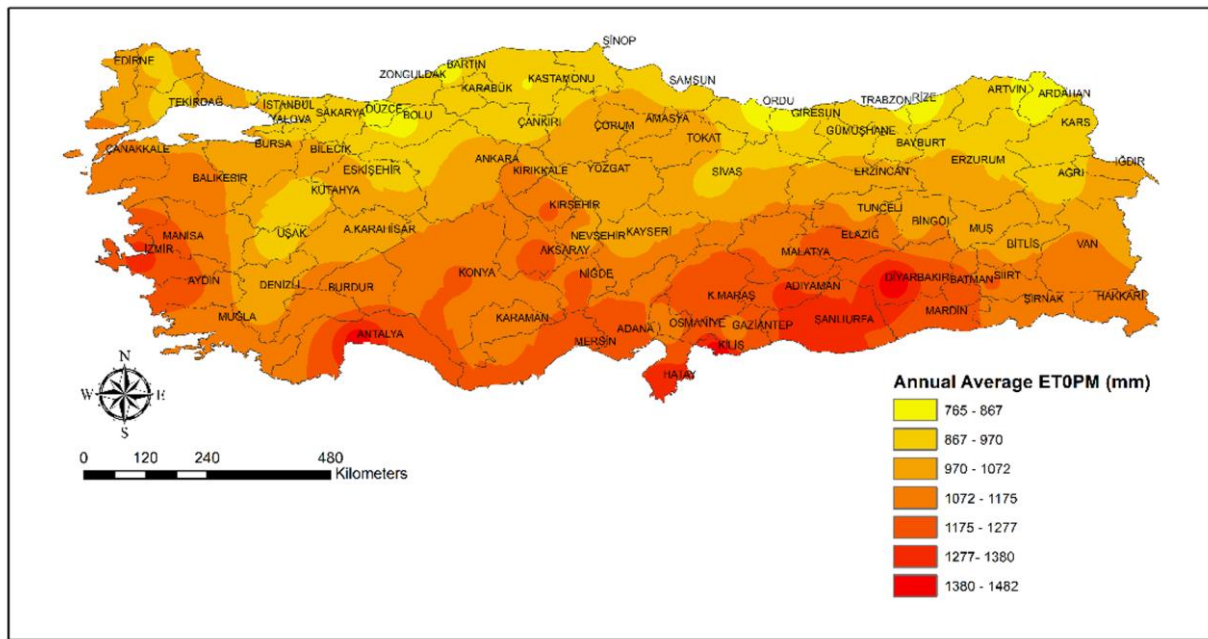


**Figure 2- Spatial distribution map of annual average FAO-56 PM reference evapotranspiration**

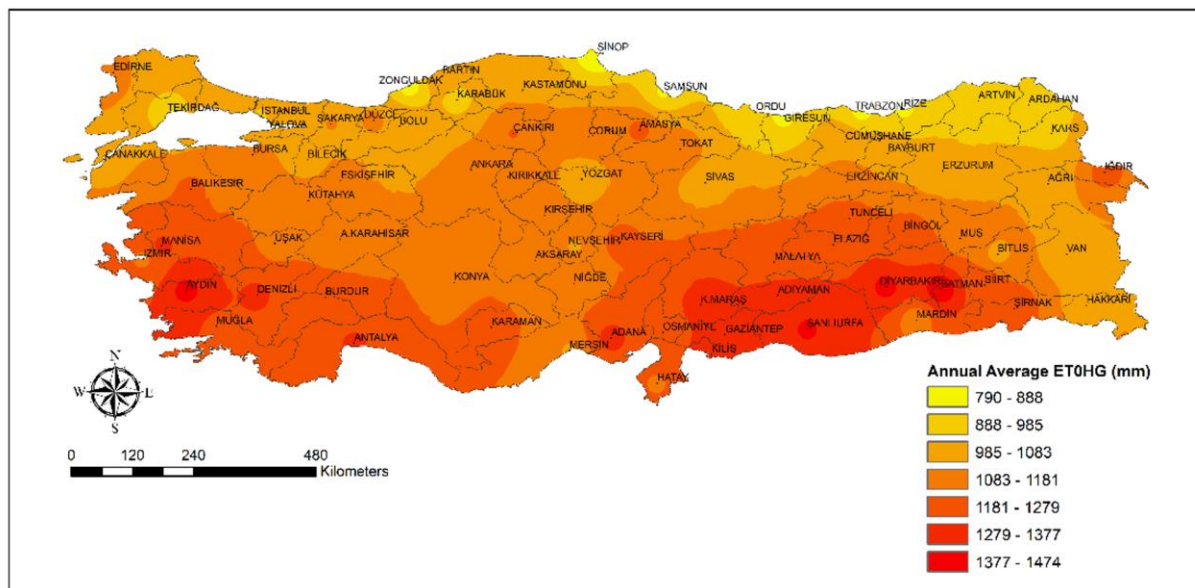


**Figure 3- Spatial distribution map of annual average Hargreaves reference evapotranspiration**

### 3.3. Spatial distribution of drought trend and magnitude

Certain symbols are used to indicate the drought trend status of the provinces. Blue triangle indicates statistically significant increasing trend ( $Z > +1.96$ ), blue dot indicates statistically non-significant increasing trend ( $0 < Z < +1.96$ ). The red triangle is used to indicate a statistically significant decreasing trend ( $Z < -1.96$ ) and the red dot is used to indicate a statistically non-significant decreasing trend ( $-1.96 < Z < 0$ ). The trend magnitudes determined according to Sen's slope method are given in the Sen's Slope legend on the maps.

$SPI_1$ ,  $SPEI_{1PM}$ ,  $SPEI_{1HG}$ ,  $SPI_6$ ,  $SPEI_{6PM}$ ,  $SPEI_{6HG}$ ,  $SPI_{12}$ ,  $SPEI_{12PM}$  and  $SPEI_{12HG}$  in the figures and explanations below represent the trend and trend magnitudes of the SPI and SPEI index values calculated according to the SPI, FAO-56 Penman-Monteith and Hargreaves method at 1-, 6- and 12-months' time scales, respectively.

When Figures 4, 5 and 6 are compared; most of the areas with increasing trend magnitudes according to the  $SPI_1$  index are transformed into areas with decreasing trend magnitudes in the  $SPEI_{1PM}$  and  $SPEI_{1HG}$  maps.

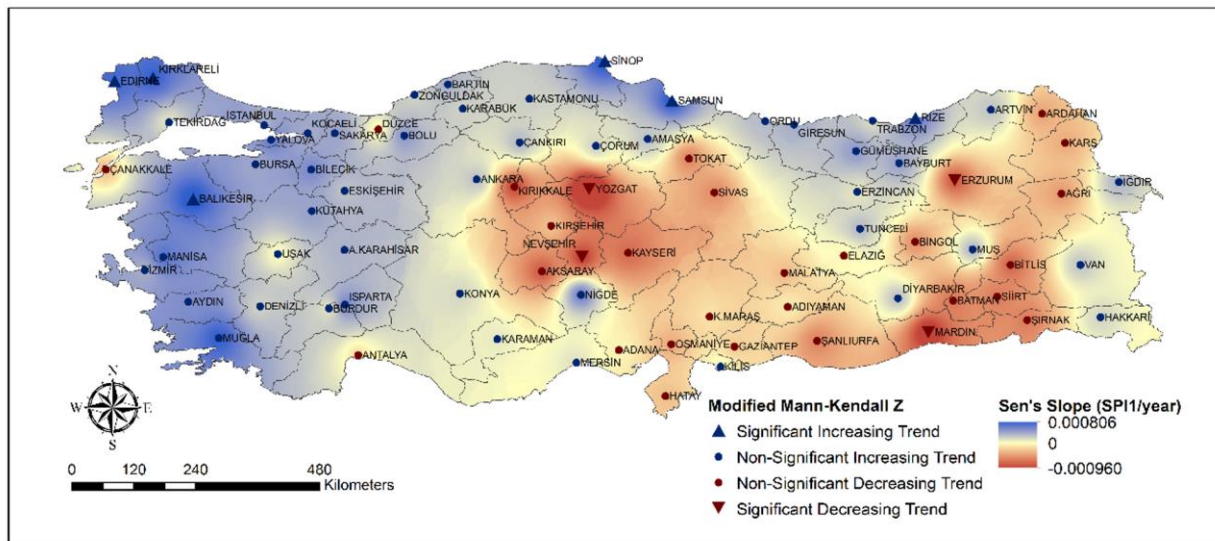


Figure 4- SPI<sub>1</sub> Modified Mann-Kendall trend and Sen's Slope map

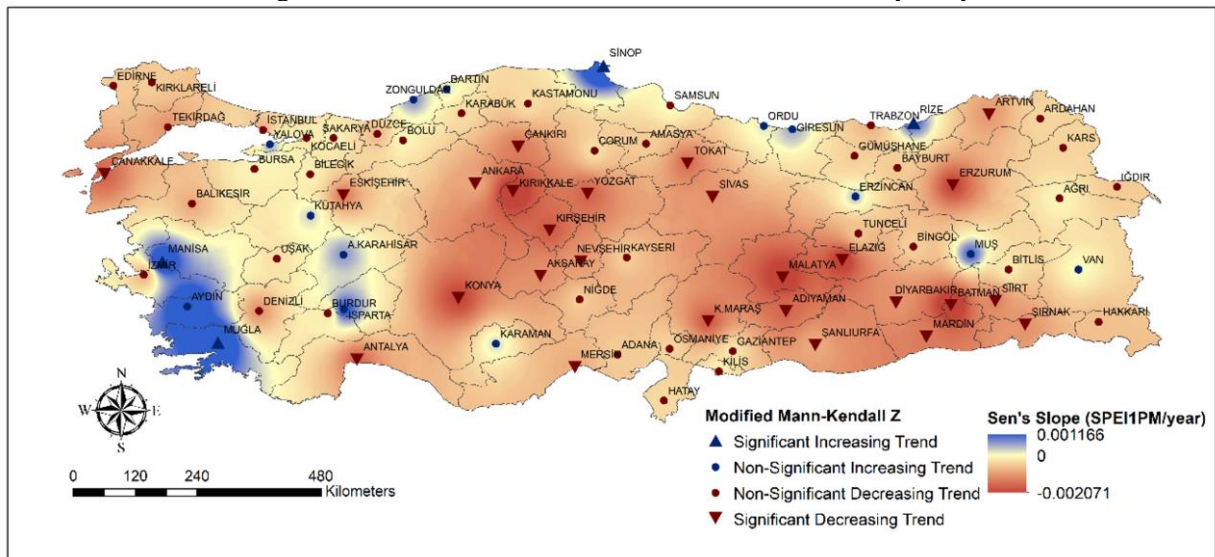


Figure 5- SPEI<sub>1PM</sub> Modified Mann-Kendall trend and Sen's Slope map

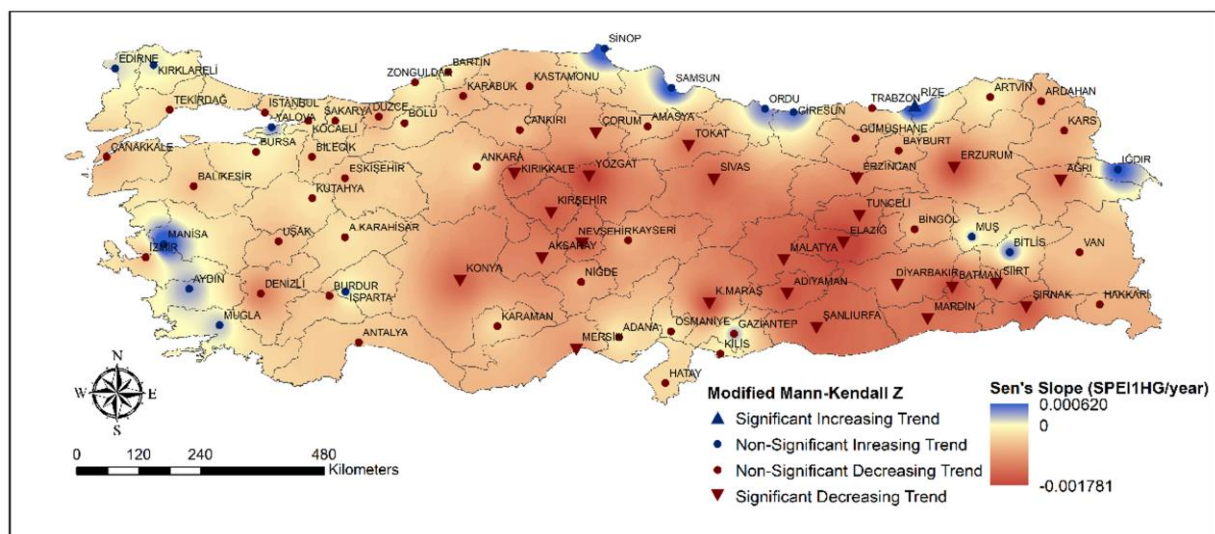


Figure 6- SPEI<sub>1HG</sub> Modified Mann-Kendall trend ve Sen's Slope map

In terms of trend magnitudes, Figures 7, 8 and 9 are analyzed together, the increase in the decreasing direction was seen more in SPI<sub>6HG</sub>.

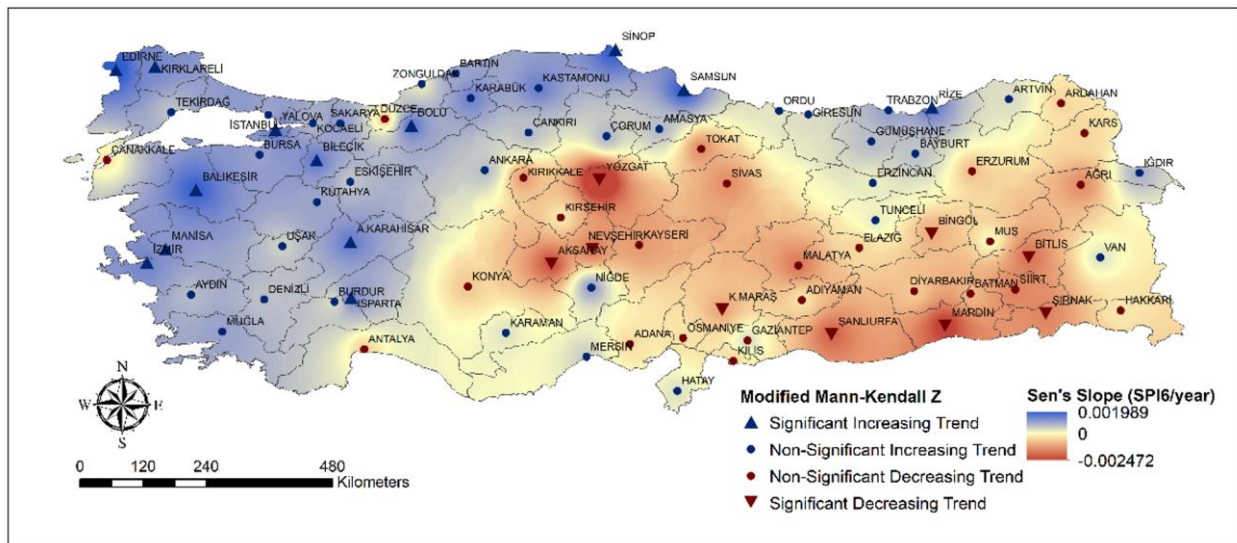


Figure 7- SPI<sub>6</sub> Modified Mann-Kendall trend and Sen's Slope map

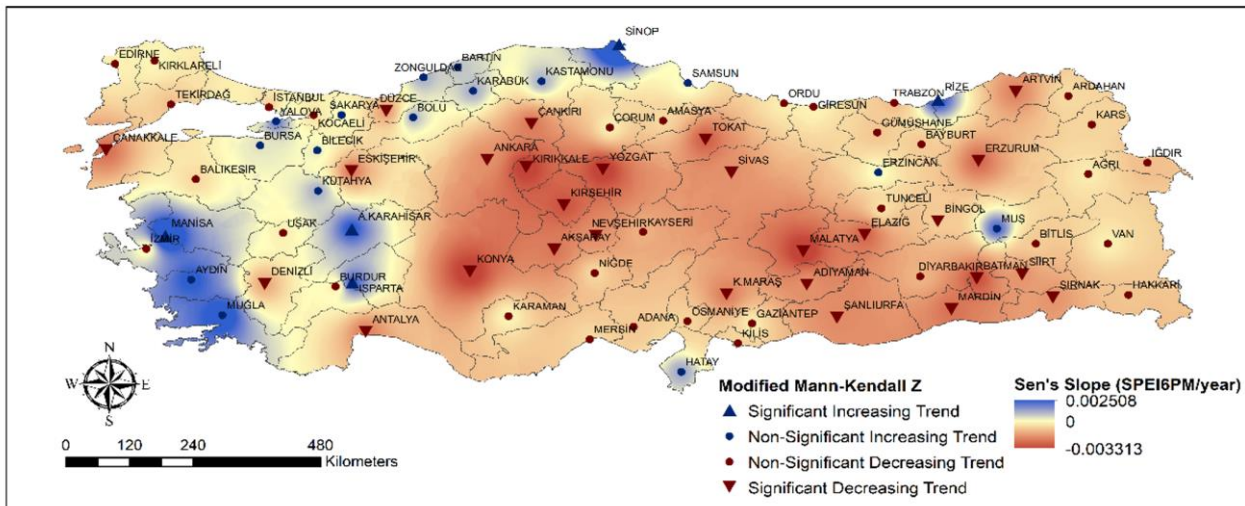


Figure 8- SPI<sub>6PM</sub> Modified Mann-Kendall trend and Sen's Slope map

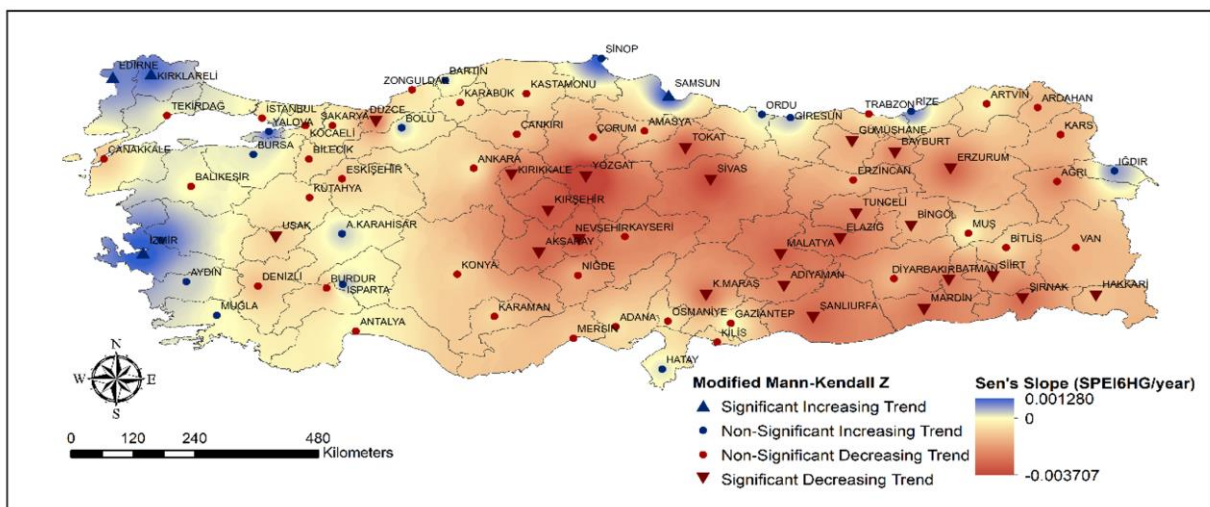


Figure 9- SPI<sub>6HG</sub> Modified Mann-Kendall trend and Sen's Slope map

In terms of trend magnitudes, Figures 10, 11 and 12 are analyzed together, the increase in the decreasing direction was seen more in SPI<sub>12HG</sub>.

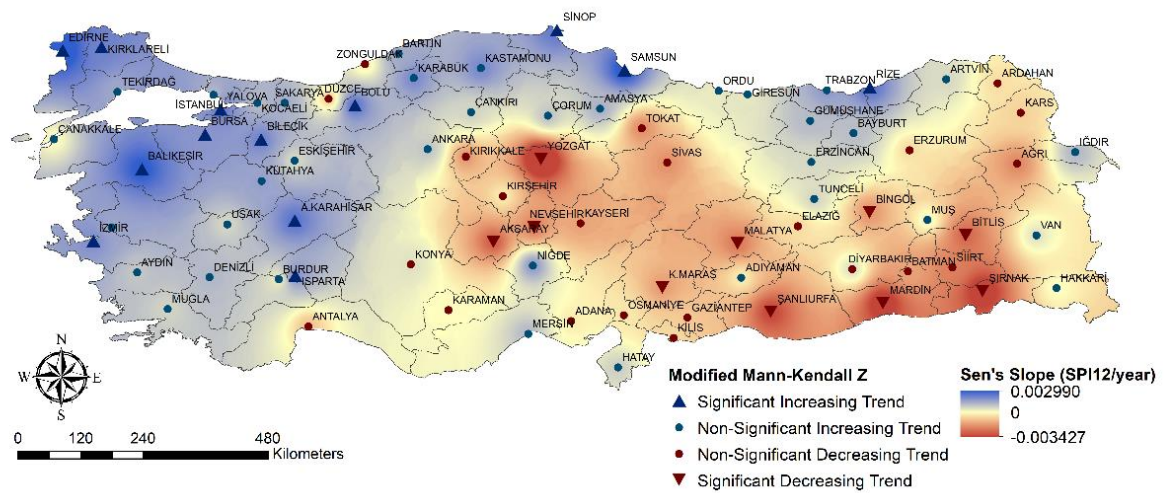


Figure 10- SPI<sub>12</sub> Modified Mann-Kendall trend and Sen's Slope map

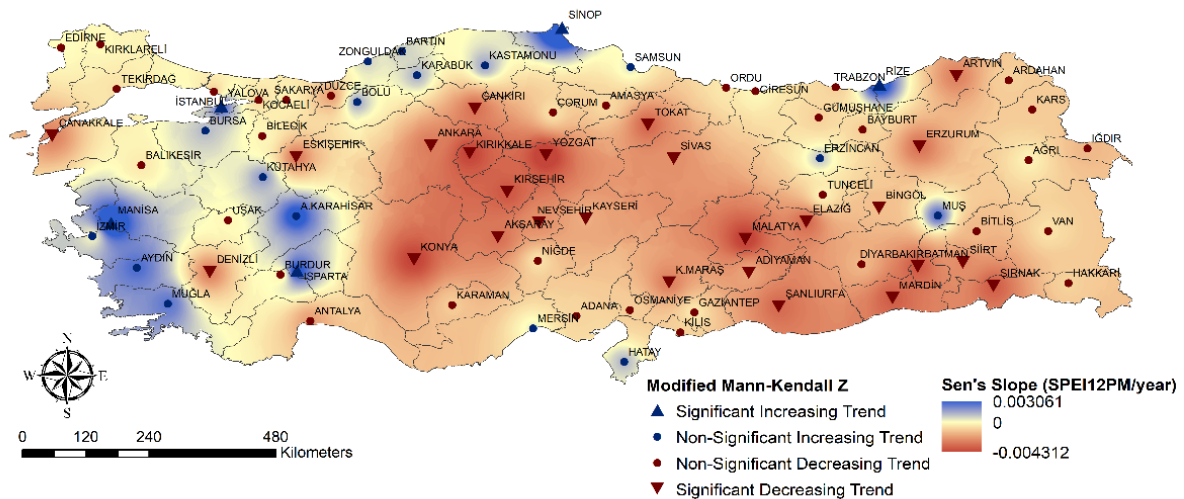


Figure 11- SPEI<sub>12PM</sub> Modified Mann-Kendall trend and Sen's Slope map

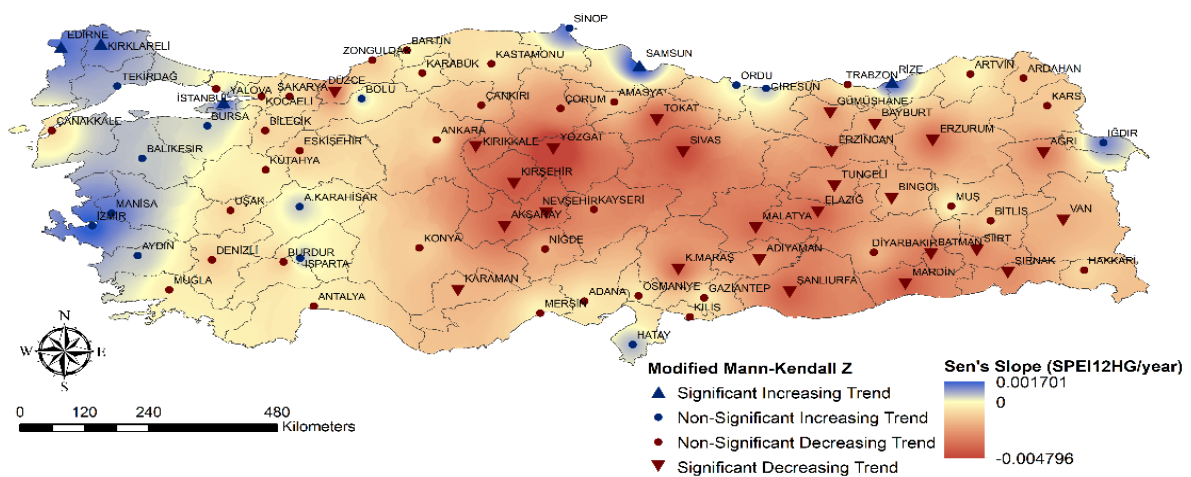


Figure 12- SPEI<sub>12HG</sub> Modified Mann-Kendall trend and Sen's Slope map

An overall assessment was made at 1-, 6- and 12-months' time scales. Compared to SPI, more statistically significant decreasing trends were found in SPEI<sub>PM</sub> and SPEI<sub>HG</sub> time series calculated with Hargreaves and FAO-56 PM reference evapotranspiration methods. This indicates that compared to SPI time series, SPEI<sub>PM</sub> and SPEI<sub>HG</sub> time series have more dry periods, i.e. dry conditions are more dominant than humid conditions. Compared to the Hargreaves method; the use of more meteorological parameters in the FAO-56 PM method can make the calculation of drought trend more sensitive (Bera et al. 2021).

In this study, wind speed, temperature, relative humidity, sunshine duration, and solar radiation data were used for the FAO-56 Penman-Monteith method. For Hargreaves method, only temperature data were used. According to the research findings, SPEI<sub>HG</sub> found arid conditions more dominant than SPEI<sub>PM</sub> when analyzed spatially at 1-, 6- and 12-month time scales. Beyond this comparison, the relative similarity of the spatial distribution of drought in SPEI<sub>HG</sub> and SPEI<sub>PM</sub> has attracted attention. It is recommended to use air temperature, wind speed, relative humidity, sunshine duration, and solar radiation data for a comprehensive ET<sub>0</sub> calculation (Allen et al. 1998). Studies have been conducted in different parts of the world to find out how these meteorological parameters influence ET<sub>0</sub>. To give a few sample studies; Zhang et al. (2009); Yin et al. (2010a, 2010b); Jhajharia et al. (2012) investigated the effect of solar radiation and wind speed, Yin et al. (2010a, 2010b), Tabari et al. (2011) investigated the effect of temperature and Liu & Zhang (2013) investigated the effect of wind speed on ET<sub>0</sub> calculation. Dadaşer Çelik et al. (2016) conducted trend analyses of reference evapotranspiration according to FAO-56 Penman-Monteith method using meteorological parameters of 77 meteorological stations in Türkiye between 1975 and 2006. According to the study, the increasing trend in temperature was shown as one of the most important main driving forces of the increasing trend in ET<sub>0</sub>. In addition, increases in wind speeds, decreases in relative humidity and changes in solar radiation were shown as factors directly affecting the ET<sub>0</sub> change. In this study, the temperature data used in the calculation of reference evapotranspiration (ET<sub>0</sub>) is considered to have an important role in the similarity between SPEI<sub>PM</sub> and SPEI<sub>HG</sub>. In addition, the fact that other meteorological parameters used in the SPEI<sub>PM</sub> calculation contribute to a more precise evaluation of the evaporative situation can be justified by the fact that less arid conditions, i.e. less dry periods, occur in SPEI<sub>PM</sub> compared to SPEI<sub>HG</sub> in this study. A study was conducted in the Aegean Region using meteorological data from 1975 to 2014 at time scales of 1, 3, 6, 12 and 24 months according to the SPEI<sub>PM</sub> index. According to the findings of temporal and spatial analyses, it was stated that there are statistically significant decreasing trends in the inland parts of the Aegean Region as the time scale increases (Özçelik 2019). These changes in the Aegean region were found similarly in this study and it was determined that the increase in the downward trends of SPEI<sub>PM</sub> and SPEI<sub>HG</sub> was high especially in Denizli and Uşak regions.

Yürekli & Ünlükara (2013) used 35 years of meteorological data of Kayseri province between 1975-2009 in their study in which they compared SPI and SPEI indices according to FAO-56 Penman-Monteith method for 1-, 3-, 6-, 12-, 18- and 24-months' time scales to evaluate the effects of global warming on drought. The researchers assumed that the temperature data of Kayseri province would increase by 3 °C and 5 °C in the 35-year period according to the first and second scenarios, respectively. When they made a comparison between the actual SPEI and scenario SPEI values, it was reported that if the temperature increases by 3-5 °C in Kayseri, drought will gradually increase in severity after the 1990s. Similar drought periods were found in SPI and SPEI indices for the 35-year period, but it was reported that a significant drought was experienced according to SPEI, especially in the 12-month time scale, but this was not visible in SPI. As a result, the researchers reported that SPEI index has superiority in determining the effects of temperature increase on drought compared to SPI index in determining drought according to different time scales. Kızılelma et al. (2015), investigated the trends of temperature and precipitation in the Central Anatolia Region with meteorological data between 1970-2010. They reported that there were statistically significant increases in maximum and minimum temperature trends in all stations except Ürgüp station. It was also reported that the increases in the maximum temperature trend are higher in the summer season. When the results of the studies are analyzed together, the trend and Sen's slope values of the Central Anatolia Region provinces support each other. In Kayseri and other provinces of the Central Anatolia Region, statistically significant downward trends in SPEI<sub>PM</sub> and SPEI<sub>HG</sub> compared to SPI and accordingly more drought tendency was detected. Increases in temperature trends in Central Anatolia may be effective in SPEI<sub>PM</sub> and SPEI<sub>HG</sub> to detect more drought conditions than SPI.

## 4. Conclusions and Recommendations

### 4.1. Conclusions

According to the SPI index trend analyses at 1-, 6- and 12-months' time scale, drought showed a downward trend behavior especially in the Black Sea Region, northern parts of Eastern Anatolia, Marmara and Aegean Regions. In these areas, as the time scale increased, the statistically significant downward trend behavior of drought increased. This situation indicates that humid periods are more frequent. In addition, it was determined that the trend magnitudes in these areas increased in the upward as the time scale increased. According to SPI at 1-, 6- and 12-months' time scales, Central Anatolia, Mediterranean, Eastern Anatolia and Southeastern Anatolia regions showed statistically significant upward trend behaviors of drought. In these areas, it was determined that the trend magnitudes increased in decreasing direction as the time scale increased. According to SPEI<sub>PM</sub> and SPEI<sub>HG</sub> index trend analyses, drought in the coastal provinces of the Aegean region, Central Black Sea and West Marmara regions showed a decreasing trend, while drought in other regions showed an increasing trend. According to SPEI<sub>PM</sub> and SPEI<sub>HG</sub> index, drought showed a statistically significant increasing trend in Central Anatolia, Eastern Anatolia, and Southeastern Anatolia. This situation shows that dry periods are more than humid periods in SPEI<sub>PM</sub> and SPEI<sub>HG</sub> time series. In addition, it

was determined that the trend magnitudes in these regions increased in decreasing direction as the time scale increased. Compared to the 1-month time scale, it was determined that drought trends in the 6 and 12-month time scales, SPEI<sub>PM</sub> and SPEI<sub>HG</sub> were more in the increasing direction. When SPI, SPEI<sub>PM</sub> and SPEI<sub>HG</sub> were compared, the most arid period was found in SPEI<sub>HG</sub> time series and secondly in SPEI<sub>PM</sub> time series.

The amount of climatic water balance and the meteorological parameters used in the calculations may have caused changes in drought trends according to SPEI<sub>PM</sub> and SPEI<sub>HG</sub>. The reference evapotranspiration amounts, and climatic water deficit calculated according to the Hargreaves method were found to be higher than the reference evapotranspiration and climatic water deficit values calculated according to the FAO-56 PM method. This can be justified by the fact that SPEI<sub>HG</sub> found a higher drought trend than SPEI<sub>PM</sub> on the time scale of 1, 6 and 12 months. This may be a justification for the occurrence of more drought periods in drought assessments using SPEI<sub>HG</sub>.

#### 4.2. Recommendations

Drought is one of the most important natural disasters affecting life. Drought must be evaluated in the most sensitive way to use water resources correctly, identify regions at risk of drought, and obtain more efficient results from irrigation practices. Drought indices are the most important methods used in determining, monitoring, and evaluating drought.

While the Standardized Precipitation Index (SPI) is a rainfall-based index, the Standardized Precipitation Evapotranspiration Index (SPEI) is a rainfall and evapotranspiration-based index. In this study, drought trends found by SPI showed significant differences compared to drought trends found by SPEI index (SPEI<sub>PM</sub> and SPEI<sub>HG</sub>), especially as the time scale increased. The SPEI index, which uses meteorological parameters and climatic water balance data, gave more accurate results in determining drought status. To determine drought more precisely, meteorological parameters and evapotranspiration should be used as much as possible. When the literature is examined, the FAO-56 Penman-Monteith method can provide more precise results in determining the drought situation since it uses more meteorological parameters. On the other hand, Hargreaves method utilizes only temperature data. In this study, it is understood that the SPEI trends and magnitudes found according to FAO-56 Penman-Monteith and Hargreaves methods are similar. Considering Türkiye in particular, if there are no missing meteorological parameters, SPEI drought studies according to FAO-56 Penman-Monteith method may give more precise results. With the SPEI index, the handicap of the SPI index (climatic water balance) can be completed. In this way, regional and national decision makers can formulate more accurate policies for future drought projections.

Considering the increasing trend of aridification in Türkiye, to prevent significant water shortages that may occur in the future, it is necessary to establish water policies that are supported by the state and whose infrastructure is prepared by laws.

Assuming that climate change may worsen the drought situation, effective drought management plans should be developed and implemented in order not to be caught unprepared for this disaster situation. To carry out drought management programs effectively and functionally, sensitive drought indices that can best reflect the hydro-meteorological situation should be used in drought analysis, monitoring and evaluation. The values of these indices can be mapped, spatially analyzed and interpreted.

## Acknowledgments

The authors are thankful for Turkish State Meteorological Service for providing all necessary meteorological parameters.

### Author Declarations

**Authors' contributions:** Study conception and design: Ali Ünlükara; data collection: Fatih Sekendur; analysis and interpretation of results: Fatih Sekendur, Ali Ünlükara; draft manuscript preparation: Fatih Sekendur. All authors reviewed and approved the final version of the manuscript.

**Conflict of interest/Competing interests:** The author(s) declare no conflict of interest.

**Ethics approval/declarations:** No need/ Not applicable.

**Funding:** This research received no external funding.

**Consent to participate:** No need/ Not applicable.

**Consent for publication:** No need/ Not applicable.

**Data availability:** Data are available on request due to privacy or other restrictions.

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