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MONITORING THE VARIABILITY OF METEOROLOGICAL DROUGHT CHARACTERISTICS AT MULTIPLE TIME SCALES

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Abstract: Meteorological drought is frequently defined as an extended interval of sub-normal precipitation persisting over a duration of months to multiple years. Drought severity and duration is two important parameters to characterize droughts. In this study, the aim is to monitor the variability of meteorological drought characteristics for selected 3 stations in Mediterranean Region, Türkiye. Initially by taking the mean monthly temperature and monthly total precipitation data for 1950-2024 period from General Directorate of Meteorology of Türkiye, Standardized Precipitation index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) have been used to predict drought events at multiple time scales of 1-month and 3-month. For a comprehensive monitoring of meteorological drought, spatial distribution of drought categories has been analyzed using Inverse Distance Weighting (IDW). Secondly, drought characteristics which are severity and duration have been obtained by Theory of Runs. Possible trends in these characteristics have been examined by Mann-Kenndal Test (MKT), Spearman's Rho (SRT), Wilcoxon Test (WT), Sen's Slope Test (SST), Innovative Trend Analysis (ITA) and Combination of Wilcoxon Test and Scatter Diagram (CWTSD). Results have shown that many drought events have been observed that indicates many parts of the region were experienced with different drought. Among all categories Normal and Wet (combination of all wet categories) have been most prevalent in the selected stations. Among all determined severity and duration series, the highest drought severity and the longest drought duration have been observed as 58.044 and 49 months during 2019(4)- 2023(4) that have been obtained with SPEI-3 of 17300 station. Trend results by MKT, SRT and WT test considering α=0.01 significance level have put forth that a big part of the series of drought characteristics have been detected with increasing trends. Decreasing trends have been obtained with less amount. However, these trends have been significant only in 9 series out of 24. SST results have shown that there has been mostly increasing trends in severity, while all duration series have shown no trend. The results of ITA and NO-ITA have demonstrated that trends of the characteristics have been increasing in many times. Unlike the MKT, SRT and WT, no trend cases have been observed in a small amount of severity series. In severity series, MKT, SRT, WT, SST, ITA and NO-ITA techniques have a good agreement in 21 series out of 24, in terms of trend type. The findings of this study are expected to be beneficial for local authorities for effective drought action plans in order to keep life, water resources, environment and sustainability.

Keywords: Meteorological drought, Trend, SPI, SPEI, Mediterranean region, Türkiye

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1. Introduction

Water constitutes an indispensable and irreplaceable resource for the sustenance of all biological life. Beside of this fact, water and water resources has a huge impact on environment, energy, sustainable development of the countries. Drought which is not only water threaten factor but also have huge influences on agriculture, economy has been described as a natural hazard that can be formed in many climatic regions of the world (Zhang et al., 2025).

In many studies such as (Gond et al., 2023; Kartal and Nones, 2024; Liu et al., 2024; Deger et al., 2025a; Esit et al., 2025a) drought has been classified into meteorological, agricultural, hydrological and socio-economic classes. Among these classes the term meteorological drought that is the subject matter of this study has been defined as an extended interval of sub-normal precipitation persisting over a duration of months to multiple years (Hadri et al., 2024).

It has been stated by Ipek et al. (2025) that drought analysis relies frequently on the application of drought indices specifically formulated to evaluate drought for different time scales and parameters. Niemeyer (2008) has reported a set of drought indices for monitoring and assessing drought events. Developed by McKee et al. (1993) Standardized Precipitation Index (SPI) is a frequently utilized index that is used for meteorological drought monitoring. The index which has a simple application needs only precipitation data. Beside of SPI, Standardized Precipitation Evapotranspiration Index (SPEI) that has been introduced by Vicente-Serrano et al. (2010) is also well known and commonly used for

meteorological drought monitoring. Its computation relies on potential evapotranspiration that needs temperature and precipitation data. Earlier in many meteorological drought monitoring studies such as (Bacanlı and Akşan, 2019; Salimi et al., 2021; Yuce and Esit, 2021; Fuentes et al., 2022; Yuce et al., 2022; Gumus, 2023; Kartal and Nones, 2024; Yaşa and Partal, 2024a; Filipović et al., 2025) at least one of these two indices have been used for different parts of the world. As a part of drought monitoring, when index values are known, then it is possible to associate these values with drought categories for spatial distribution analysis. For this purposes, Inverse Distance Weighting (IDW) spatial interpolation technique that has been used in (I. H. Deger et al., 2025b; Katipoğlu and Acar, 2022) is used.

Earlier many studies for drought monitoring such as (Shiau, 2006; Mishra and Singh, 2010; Mirabbasi et al., 2012; Avsaroglu and Gumus, 2022; Esit and Yuce, 2023; Deger et al., 2025a) have shown that drought characteristics such as severity and duration are two important parameters in the characterization of drought events as these parameters have an impact. In the computation of these characteristics based on computed index values the Theory of Runs that has been proposed by Yevjevich (1967) is commonly used.

In the drought monitoring, tracking possible variabilities by trend detection techniques by classical and innovative techniques provides significant information for future conditions. For this aim Mann-Kenndal Test (MKT) (Mann, 1945; Kendall, 1975), Spearman's Rho (SRT) (Spearman, 1904), Wilcoxon Test (WT) (Wilcoxon, 1945), Sen's Slope Test (SST) (Sen, 1968), Innovative Trend Analysis (ITA) (Şen, 2012) and recently Combination of Wilcoxon Test and Scatter Diagram (CWTSD) (Saplıoğlu and Güçlü, 2022) is frequently utilized techniques.

In the literature there has been great interest in applying trend techniques to determined index values in order to detect temporal variabilities in different time scales. A set of studies such as (Güner Bacanli, 2017; Byakatonda et al., 2018; Zarei, 2019; Gumus et al., 2021; Swain et al., 2022; Ullah et al., 2023; Kesgin et al., 2024; Robleh et al., 2024; Serkendiz et al., 2024; Jamalzi et al., 2025; Öllükçü and Katipoğlu, 2025). However, the number of studies in which trends of drought characteristics have been examined is quite less. For example, Yaşa and Partal (2024b) have made a study based on trend detection in severity series that has been derived from SPI for Southeast Region of Türkiye at multiple time scales. Recently Akbas et al. (2026) have performed a study for Lower Tigris-Euphrates Basin Türkiye using SPEI and examined the trends using classical and innovative techniques for drought severity, duration and magnitude at multiple time scales.

In the context of drought and its characteristics, climate and water resources are quite critical subjects for the agriculture, sustainability and water resources management processes of the regions as climate and water may be affected from several factors such as accelerated anthropogenic factors, variabilities in meteorological parameters such temperature and precipitation. In this case, drought early warning systems can provide information for future drought conditions, policy making, updating or planning strategies in the mitigation of the drought. To do so, monitoring variability conditions of drought characteristics with updated data and new approaches become significant. Therefore, in the main of object, this study aims to monitor the variability of drought characteristics derived by multiple drought indices via different trend techniques at multiple time scales that would be later used in future studies considering meteorological or other types of droughts.

The Mediterranean Region is one the 7 regions in Türkiye. Based on the climate models, the mediterranean basin has been reported as "the hot spot of climate change" by (Lionello and Scarascia, 2018; Lange, 2020; Öz et al., 2024). In addition to this, it has been emphasized by (Simsek et al., 2025; Vicente-Serrano et al., 2022) that global climate change is amplifying the probability of more intense and recurrent droughts in the basin that is a globally critical region.

In this research, the aim of this study is to monitor the variability of drought characteristics which are severity duration for selected 3 stations of 17300-Antalya Havalimanı, 17340-Mersin and 17351-Adana Bölge which are in Mediterranean Region. To do so, at first mean monthly temperature and monthly total precipitation data during 1950-2024 that have been taken from General Directorate of Meteorology of Türkiye, SPI and SPEI are used to predict drought events at 1-month and 3-month time scales. Spatial distribution of drought categories is investigated by Inverse Distance Weighting (IDW) spatial interpolation technique using licensed version of ArcGIS software. Secondly, the drought characteristics are obtained by using Theory of Runs. Possible trends in these characteristics are examined by Mann-Kenndal Test (MKT), Spearman's Rho (SRT), Wilcoxon Test (WT), Sen's Slope Test (SST), Innovative Trend Analysis (ITA) and Combination of Wilcoxon Test and Scatter Diagram (CWTSD). The findings of this study are expected to beneficial for local authorities as Mediterranean Region of Türkiye has a huge potential for the country in care of agriculture, tourism, ecology and biodiversity. Based on the literature review research, there has not been any study for trend detection in meteorological drought characteristics considering stations in Mediterranean Region and using multiple drought indices at multiple time scales.

2. Materials and Methods

2.1. Methodology

2.1.1. Drought indices

SPI that has been developed by (McKee et al., 1993) is one of the most widely used index utilizing only precipitation data for monitoring meteorological

droughts. For examining the droughts by SPI, the application procedure of the index with gamma distribution that is used in this study is available comprehensively in many studies such as (Esit and Yuce, 2023; Aktürk et al., 2024; Kartal and Nones, 2024; Robleh et al., 2024; Jamalzi et al., 2025; Sunusi and Auliana, 2025).

SPEI that has been introduced by Vicente-Serrano et al. (2010) is a well-known drought index for monitoring of meteorological drought (Dikshit et al., 2021). As the index utilizes precipitation and temperature records for its calculation, it assures more detailed assessment of drought (Öllükçü and Katipoğlu, 2025). A detailed determination procedure of the SPEI including the potential evapotranspiration (PET) by Thornthwaite (1948) has been well documented in (Tirivarombo et al., 2018; Esit et al., 2025b).

For a comprehensive investigation of meteorological drought in the study area, each calculated SPI and SPEI value is associated with a drought class that is given with Table 1. In addition to this, in order to capture the spatial influences of these categories in the study area spatial distribution of these categories based on percentage of occurrences are examined by Inverse Distance Weighting (IDW) interpolation technique using a licensed version of ArcGIS software program. Recently, IDW has been utilized in many studies such as (Deger et al., 2025b; İslam and Turgay, 2025) for examining the different variables in hydrology.

Table 1. Dry and wet classifications (Yuce and Esit, 2021)

Drought Class	SPI, SPEI
Extremely Wet	≥ 2
Very Wet	1.5-1.99
Moderately Wet	1.00-1.49
Normal	0.99 to -0.99
Moderately Dry	-1.00 to -1.49
Very Dry	-1.5 to -1.99
Extremely Dry	≤ -2

2.1.2. Drought characteristics

Drought severity (DS) and drought duration (DD) are two parameters for characterizing of drought (Mishra and Singh, 2010). The definition of these two characteristics have been done by Dracup et al. (1980) as DS describes cumulative summation of index values and DD means to period between end and start of a drought event. The graphical representation of DS and DD characteristics have been demonstrated by Figure 1. For the determination of these characteristics the Theory of Runs that has been proposed by Yevjevich (1967) is used.

In the study the severity for SPI and SPEI has been determined from equation 1 (McKee et al., 1993; Mirabbasi et al., 2012; Shiau, 2006) and equation 2 respectively.

$$S = -\sum_{i=1}^{D} SPI_i \quad (1)$$

$$S = -\sum_{i=1}^{D} SPEI_i \quad (2)$$

where D is drought duration.

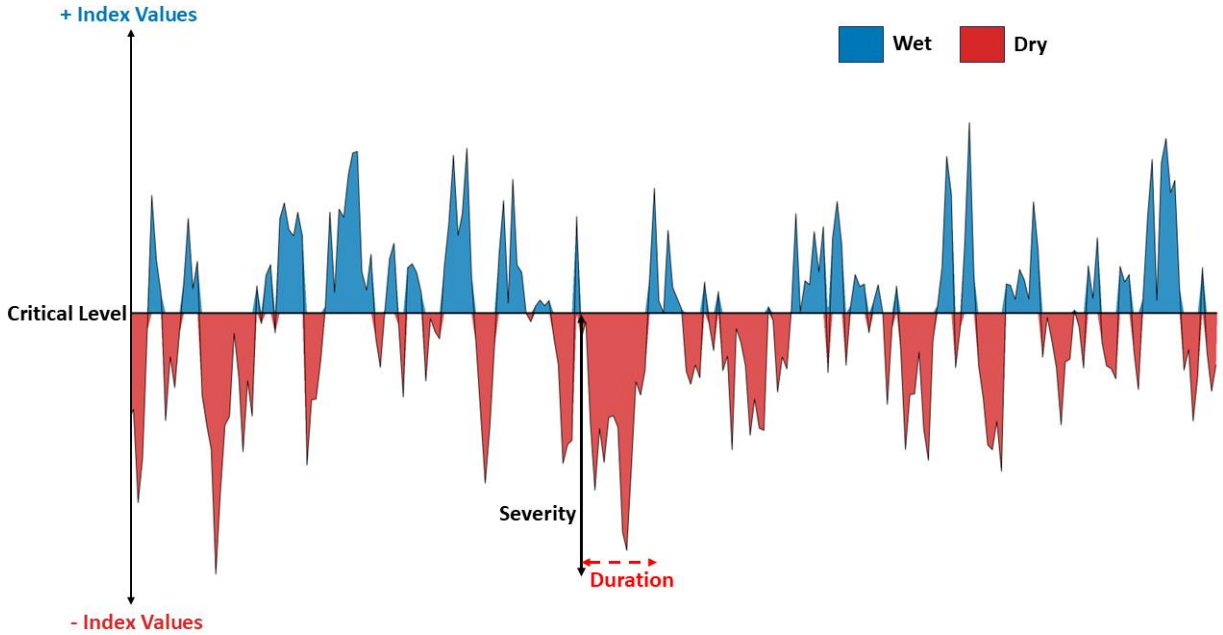

Figure 1. Graphical description of drought characteristics.

2.1.3. Trend Detection Techniques

In the study, multiple techniques which are MKT, SRT, WT, SST, ITA and CWTSD have been applied for trend detection to decrease uncertainty. Although assessment of trends in MKT, SRT and WT seem similar, each test differs in the determination of Z number under different sensitivities. ITA and CWTSD have similarities as both of the tests provide assessing trends graphically but techniques applied to data differs. A basic assumption of MKT and SRT is based on the independence of the data

points within the time series but unlike the MKT and SRT, ITA does not have any assumptions such as requiring the independent structure of time series data, normality of the distribution and data length (Şen, 2012).

2.1.3.1. Mann-Kendall test (MKT)

As a non-parametric and rank based test introduced by (Mann, 1945; Kendall, 1975) MKT is widely applied in the determination of trends of time series in many studies such as (Güçlü et al., 2025; Akbas et al., 2026; Deger, 2026). In the test, the test statistics is determined via quation 3.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (3)$$

where n is the data length, x_i and x_j show the data points in the years of j and k (j>k). Then the sign equation is calculated by equation 4.

$$sgn(x_j - x_k) = \begin{cases} 1 & (x_j - x_k) > 0 \\ 0 & (x_j - x_k) = 0 \\ -1 & (x_j - x_k) < 0 \end{cases} \quad (4)$$

When there are ties, the variance of S is described by equation 5.

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_i^m t_k(t_k-1)(2t_k+5)}{18} \quad (5)$$

where n demonstrates number of data points, t_i represents the number of ties for i value and r shows the number of tied values (Kenabatho, 2025). Then Z which is the standard normal test statistics is calculated from equation 6. For interpretation of the trend results, while Z <0 express a decreasing trend Z>0 shows an increasing trend. In the study, trends are assessed considering the significance level of α=0.01 that corresponds to Z=±2.576.

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \quad (6)$$

2.1.3.2 Spearman's Rho Test (SRT)

As an another non-parametric and rank based test that has been developed (Spearman, 1904) SRT is continuously used for trend detection (Rahman et al., 2017; Esit et al., 2024; Tuğrul and Hinis, 2024). In the test correlation coefficient r_s and the test statistic Z are determined by equation 7 and 8 respectively.

$$r_s = 1 - \frac{[6 \sum_{i=1}^{n} (Rx_i - i)^2)]}{n(n^2-1)} \quad (7)$$

$$z = r_s\sqrt{n-1} \quad (8)$$

Where R_{xi} describes the rank of i_{th} observation and n presents the data length. In the test, the evaluation of z values is similar to MKT test. Therefore, the significance level of α=0.01 that corresponds to Z=±2.576 is considered for evaluation of trends.

2.1.3.3. Sen's slope test (SST)

Introducing by Sen (1968) SST is one another continuously utilized test for trend detection (Ogunrinde et al., 2025; Sahu et al., 2025; Zarei, 2025) In the test, the slope (S) for n pair data can be calculated via equation 9 and equation 10 (Deger et al., 2025b).

$$S = \frac{Q_2 - Q_1}{T_2 - T_1} \quad (9)$$

$$S = \begin{cases} S_{\frac{n+1}{2}} & n = even \\ ve & \\ S_{\frac{n}{2}} & n = odd \end{cases} \quad (10)$$

where Q describes the data and T is time and n denotes the data length.

2.1.3.4. Innovative trend analysis (ITA)

ITA that has been proposed by Şen (2012) is widely used in many studies such as (Hallouz et al., 2024; Kartal et al., 2024; Yaşa and Partal, 2024a; Deger et al., 2025b; Akbas et al., 2026). A typical ITA template (red plaid) has been given in Figure 2. While applying this technique, initially the data is divided into two equal parts in ascending order and then first and second data divisions are plotted in x and y-axis respectively. Secondly, a 1:1 line which is no trend line is drawn. According to the technique, any point below the 1:1 line describes the presence of decreasing trend while any point above the 1:1 line express increasing trend. When the data is concentrated on 1:1 line, it indicates the existence of no trend.

2.1.3.5. Wilcoxon test and scatter diagram combination (CWTSD)

CWTSD that has been suggested by Saplıoğlu and Güçlü (2022) has been utilized in trend detection many studies such as (Koycegiz and Buyukyildiz, 2024; Akbas et al., 2026). The CWTSD technique enables to assess the trends both visually and statistically. For statistical assessments, the test used a Wilcoxon Test (WT) (Wilcoxon, 1945) which examines the scatter of two variables is the same by assuming the differences in the two-half data. The test statistics Z_w can be determined via following manner. Firstly, the difference between first half (X_i) and second half (Y_i) which is D_i can be determined by equation 11 by obtaining absolute values in equation 12.

$$D_i = X_i - Y_i \quad (11)$$

$$|D_i| = |X_i - Y_i| \quad (12)$$

In the next step, the absolute values are ordered in ascending order by assigning sequence numbers. The summation of marked rows demonstrating the summation of plus (minus) is considered as $T^+(T^-)$ is computed by equation 13.

$$T = T^+ - T^- \quad (13)$$

Then the test Z_w is determined from equation 14.

$$Z_w = \frac{T - \mu_T}{\sigma_T} = \frac{T}{\sigma_T} \quad (14)$$

Where μ_T is arithmetic mean and σ_T is standard deviation that is determined via equation 15. In the study the significance level of α=0.01 that corresponds to Z=±2.576 is considered for evaluation of trends.

$$\sigma_T = \sqrt{\frac{n(n+1)(2n+1)}{6}} \quad (15)$$

In CWTSD, the data set is divided into equal part similar to ITA but unlike the ITA the data divisions are not ordered. A typical template has been presented in by Figure 2 (black triangular) as NO-ITA. If the data falls below the 1:1 line it demonstrates a decreasing trend while the data falls above the 1:1 line express an increasing trend. When there is an equal amount of data points in two triangular regions it indicates a no trend case.

2.2. Study Area and Data

Mediterranean Region which is one of the 7 geographical regions of Türkiye displays a mediterranean climate in coastal areas, whereas its interior areas are dominated by a semi-arid continental climate (Soylu Pekpostalci et al., 2023). The region is characterized by hot and dry summers and mild, rainy winters (Simsek et al., 2025). In the study three stations in the region have been selected for performing analysis. The locations and information of these stations have been given in Figure 3 and Table 2 respectively. Precipitation and temperature data of these stations for the data record of 1950-2024 have been taken from General Directorate of Meteorology of Türkiye. As it can be seen from Table 2 during data record, mean monthly temperatures are ranged in the stations as 17300-Antalya Havalimanı (6.8-31.6℃), 17340-Mersin (5.7-30.9 ℃) and 17351-Adana Bölge (5.6-30.8 ℃). Although there is not much difference between stations the highest mean temperature during data record is observed in 17340-Mersin station. Based on the table monthly total precipitation data is ranged in the stations as (0-907.2mm), 17340-Mersin (0-677.4mm) and 17351-Antalya (0-416 mm) that also indicates the highest precipitation amounts are seen in 17300-Antalya Havalimanı station.

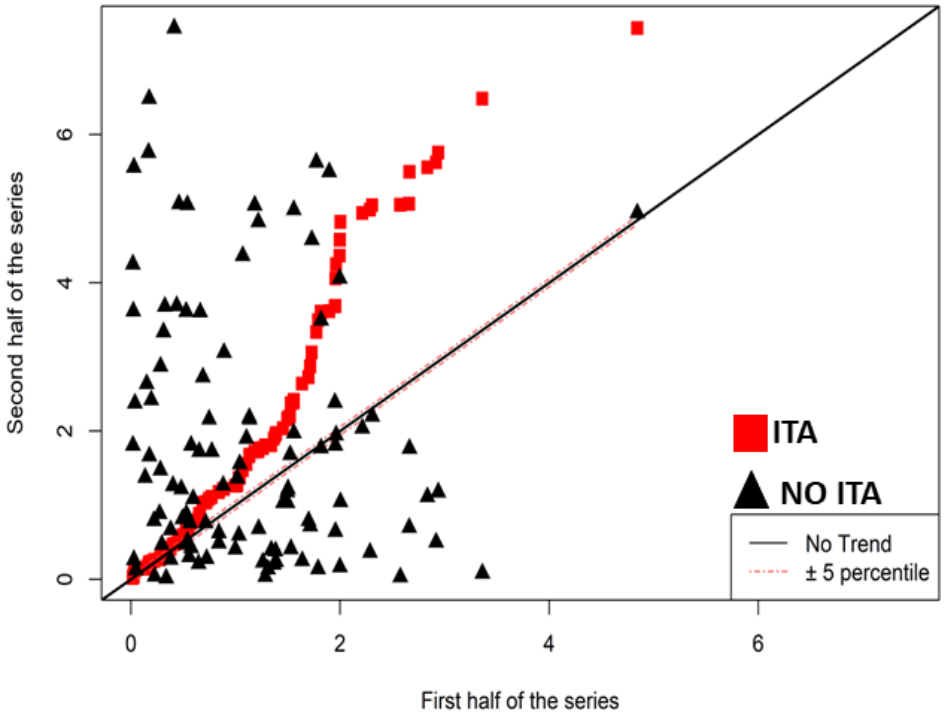

Figure 2. Graphical representation of ITA by Şen (2012) (red) and NO-ITA by Saplıoğlu and Güçlü (2022) (black).

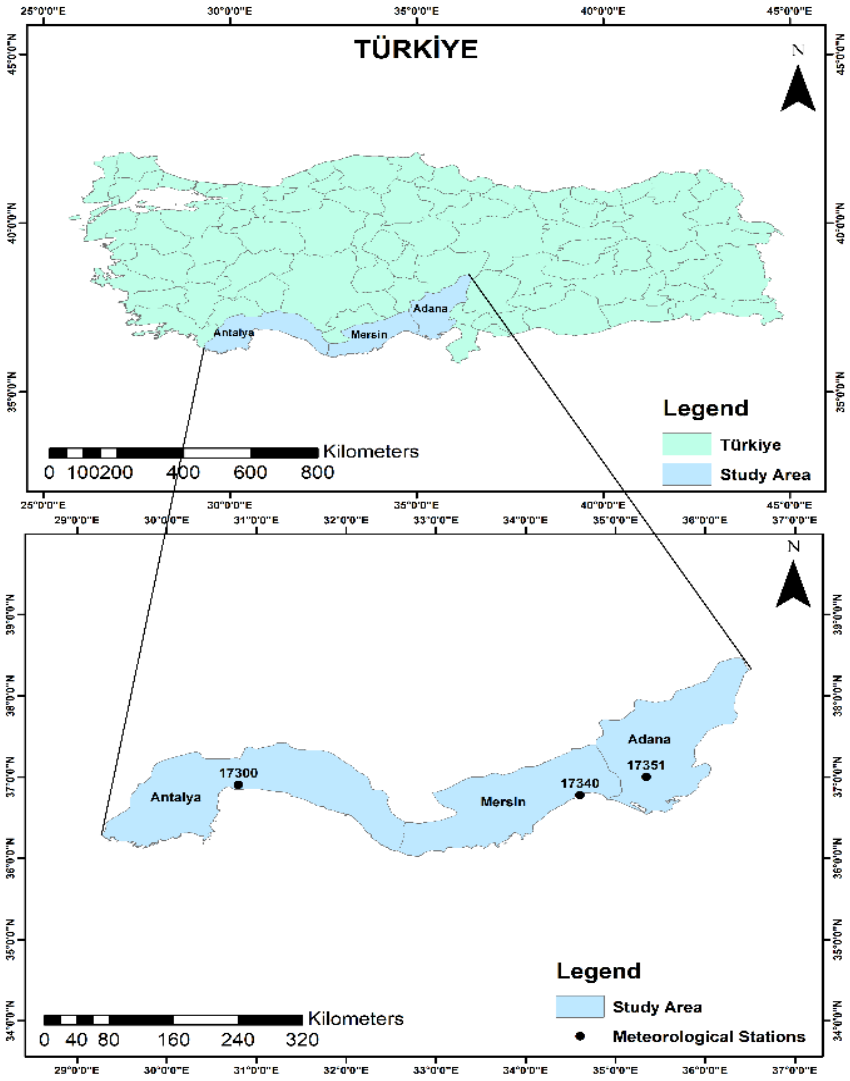

Figure 3. Study area and location of meteorological stations.

Table 2. Information of selected meteorological stations

Station	Latitude (N)	Longitude (E)	Height (m)	Meteorological Parameters	Data Range	Minimum	Maximum	Mean
17300 Antalya Havalimanı	36.9063	30.799	64	Mean Monthly Temperature (°C)	1950-2024	6.8	31.6	18.8
				Monthly Total Precipitation (mm)		0	907.2	85.6
17340 Mersin	36.7808	34.6031	7	Mean Monthly Temperature (°C)	1950-2024	5.7	30.9	19.4
				Monthly Total Precipitation (mm)		0	677.4	50.7
17351 Adana Bölge	37.0041	35.3443	23	Mean Monthly Temperature (°C)	1950-2024	5.6	30.8	19.3
				Monthly Total Precipitation (mm)		0	416	56.3

3. Results

3.1. Analyzing SPI, SPEI values, drought and wet categories

In the study, two indices have been used considering multiple time scales for a comprehensive drought assessment of the stations. At first, determined SPI and SPEI values at 1 and 3-month time scales have been presented by Figure 4. As it can be seen from the figure that many dry and wet events have been taken place in the data record. Based on these charts, many times dry conditions based on Table 1, have happened even in near today with variable severities and variable durations.

Many times, in both time scales of both indices close values in 3 stations can be observed. These charts provide a summarize information about obtained SPI and SPEI values within the time in a certain time scale.

After obtaining SPI and SPEI values in time scales each value has been associated with a drought category in Table 1. Then the spatial distribution of the categories of Normal (N), Moderately Dry (MD), Very Dry (VD), Extremely Dry (ED) and Wet (combination of all "Wet" categories) based on the percentage of occurrences have been examined by IDW technique using ArcGIS software. The spatial distributions of the dry and wet categories have been demonstrated with Figure 5. As it can be seen from the figure that no matter what index and times scale is the normal (0.99 to -0.99) and wet (≥2) conditions have been detected with the highest percentages. In SPI-1, with a spatial distribution range of 28.67-31.78 N has been seen as higher around 17300-Antalya Havalimanı station which has been lower in eastern side of the study area. MD (7.44-8.89) has been captured as higher around 17340 Mersin station. VD which has been observed with a low distribution range (2.33-2.89) has been detected higher around 17340 and 17351 stations. ED (2.11-2.89) that has been also detected with low frequencies has been higher around 17351 Adana Bölge station. Then the Wet (55.78-58.22) has higher occurrences around 17351 station. In SPI-3, N (33.67-38.11) has been noted with higher around 17300 while it has been lower around 17340 and 17351 stations. MD that has been observed with a distribution range of 9.11-9.56 has been higher in around 17300 station. Although N and MD have seemed similar, the distribution ranges of percentage of occurrences of both categories have been different and a small part around 17340 and 17351 has shifted to another color range. When it comes to VD (3.44-4) and ED (2.11-2.89), the distribution of these two categories has been quite similar except at small differences. In Wet (46.78-50.56), while lower percentages have been observed around 17300, the higher ones have been seen around 17340 and 17351.

In SPEI-1, N has distributed to study area with a distribution range of 33-34.89 and been higher around 17351. MD (10.44-11.11) and VD (3.89-4.89) have been higher around 17300 station and the lower percentages have been observed around other two stations. ED with a lower distribution range of percentage of occurrence it has been distributed to area as 1-1.44 and it has been higher around 17351 similar to ED of SPI-1 and SPI-3. Wet category (49.11-50) has been higher around 17300 which is different than Wet case of SPI-1 and SPI-3 but there is not much difference between percentages. In SPEI-3, N (31-35.11) has been detected as higher around 17300 which is similar to N of SPI-1 and SPI-3. MD with a distribution range of 10.44-11.89, the higher percentages have been observed around 17340. When it comes to VD (4.44-5.33) while it has been detected as higher around 17351 it is lower around 17300. ED (1.33-1.56) has become higher around 17300 and Wet (48.44-51.11) has been detected higher around 17340.

When the minimum and maximum ranges are considered, N has got the highest range in SPI-3, MD and VD have had the highest range in SPEI-3, ED has been detected with highest range in SPI-1,3 and Wet has got the highest range in SPI-1.

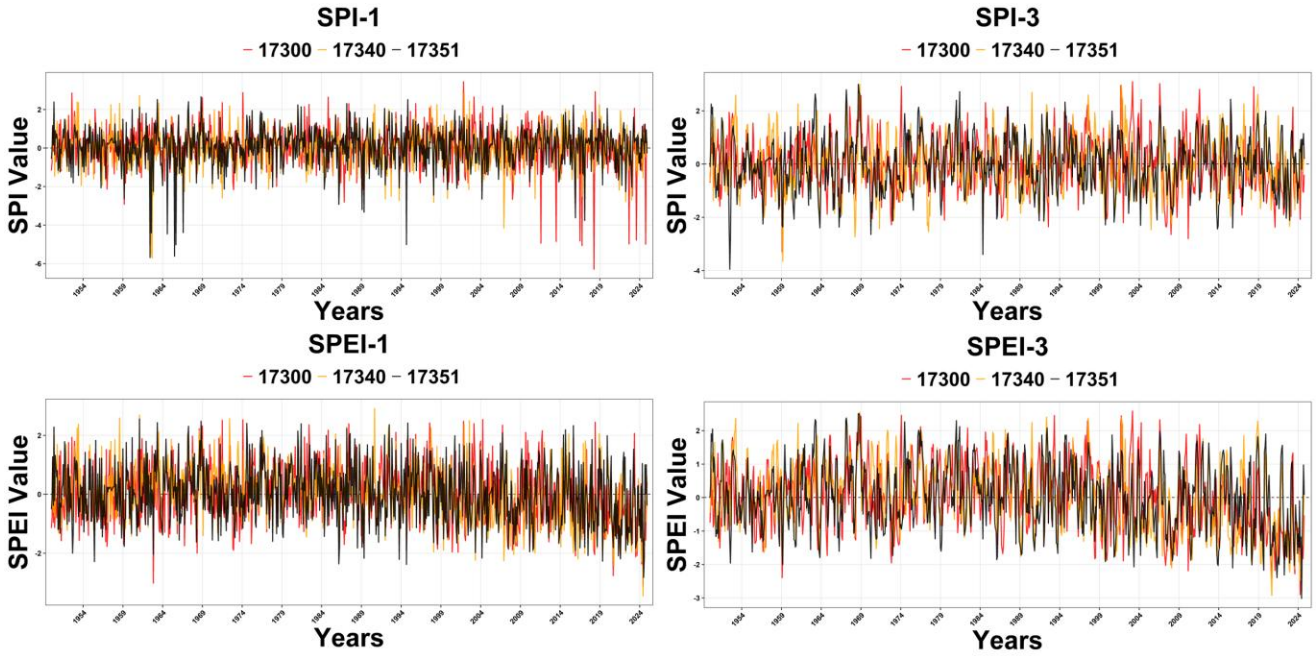

Figure 4. Presenting SPI (up) and SPEI (down) values at 1-month (left) and 3-month (right).

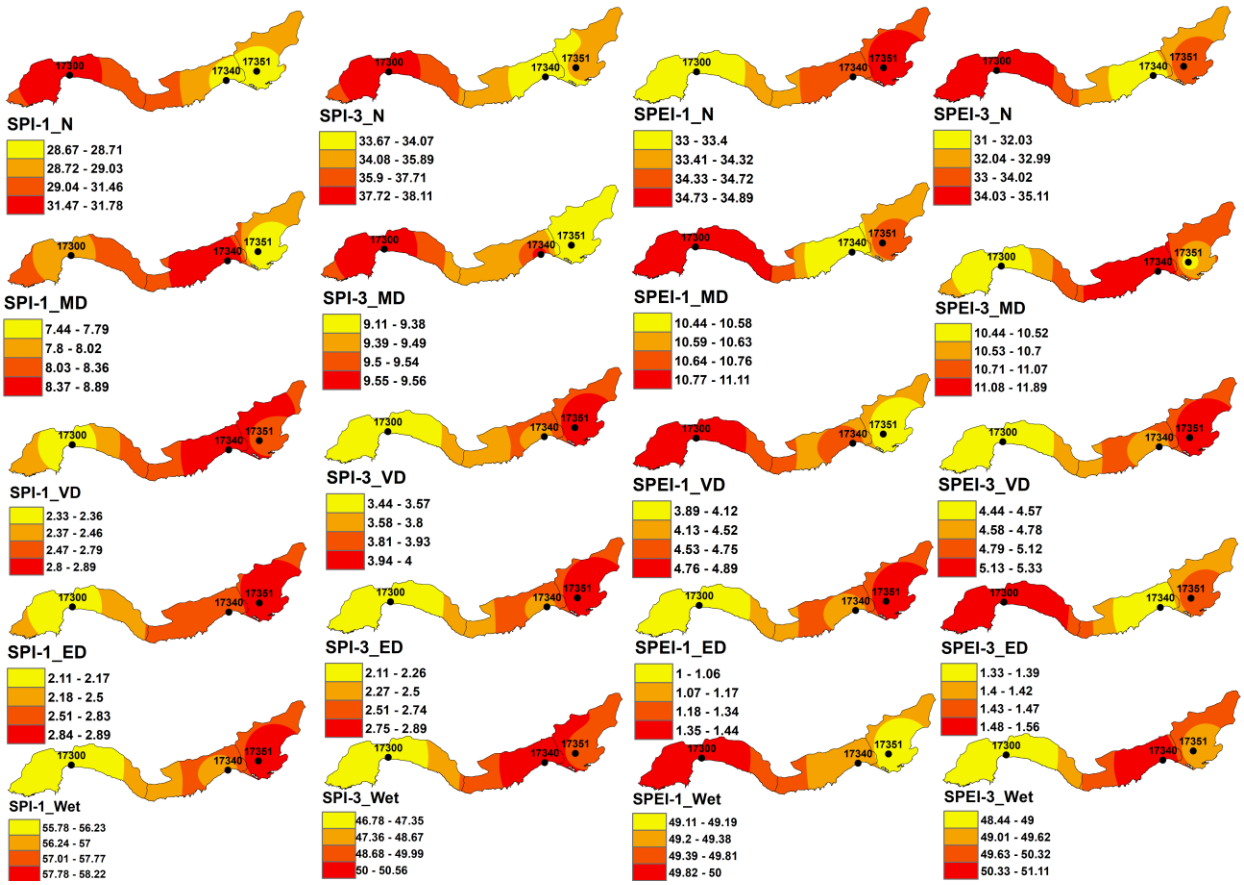

Figure 5. The spatial distribution of dry and wet categories in SPI and SPEI at 1 and 3- month time scales.

3.2. Analyzing Drought Characteristics and Trend Detection

In the study, by benefiting from Run Theory and determined SPI and SPEI values DS and DD series have been determined. Among all determined severity and duration values, maximum ones have been observed in SPEI-3 in all stations. In 17300 Antalya Havalimanı station the maximum drought severity and maximum duration has been observed as 58.044 and 49 months that have been happened in 2019(4)- 2023(4). In 17340 Mersin the highest drought severity and duration have been noted as 43.178 with 32 months that has been captured 2022(4)-2024(11). Unlike 17300 and 17340 stations, the highest severity and duration have not been detected in same event for 17351-Adana. The highest severity has been recorded as 23.493 with 16 months that has been occurred in 2020(8)-2021(11) and the highest duration is 19 months with a severity of 19.256 that has been noted in 2007(7)- 2009(1). Among 3 stations 17300 Antalya Station have experienced the most severe drought event during data record.

Trend detection tests of MKT, SRT, WT and SST has been applied to DS and DD series and the results have been tabulated in Table 3. In the results of MKT, SRT, WT tests, the results have been shown by different colors to determine the trend type either increasing or decreasing and the writing type has been made normal and bold to show the significant and no significant cases. Beginning with 17300 Antalya Station, as it can be seen that all DS and DD series of SPI and SPEI have been detected with increasing trends based on three tests. Only duration series of SPI-1, severity and duration series of SPE-1 have been noted with significant increasing trends. In 17340 Mersin station the results have been more variable as there has been mostly decreasing trends in SPI-3 series while increasing trends in SPI-1, SPEI-1 and SPEI-3. The DS and DD series of SPEI-1 and SPEI-3 have been recorded with significantly increasing trends. Addition to this, it is important to emphasize that in 17340 station the highest drought severity and duration in SPEI-1 and SPEI-3 have become 12.35 with 13 months (2022(3)-2023(3) and 43.178 with 32 months (2022(4)-2024(11)) respectively. In 17351-Adana Station while in SPI-1 and SPEI-1 and SPEI-3 DS and DD series have been recorded with increasing trends, SPI-3 series have been observed with decreasing trends. Significantly increasing trends have been observed only in SPEI-1 series. As common, DS and DD series of SPEI-1 have been noted with significantly increasing trends in three stations. In terms of trend types, the results of 17340 and 17351 have been similar. Among 3 stations, mostly significant cases have been observed in 17340 Mersin station. Usually, MKT, SRT and WT have given similar trend types and significance cases except at WT result of SPI-3 Severity series of 17340.

When it comes to SST, all of the duration series have been observed with no trend case except at SPEI-3 Duration series of 17340-Mersin. In 17300 all severity series have

been observed with increasing trend slopes. In 17340 Mersin except at SPI-3 Severity, there has been an increasing trend slope in all severity and SPEI-3 duration series. When it comes to 17351 Adana except at SPI-3 severity, all severity series have been obtained with increasing trend slopes. While duration series of 17300 and 17351 have been same, severity series of 17340 and 17351 are same in terms of trend type. In severity series there has been a good agreement between MKT, SRT, WT and SST except at SPI-3 severity series of 17340. Even in SPEI-3 duration which has been detected with increasing trend slope among all duration series there has been a good agreement between the tests.

In the study, beside of MKT, SRT, WT and SST, ITA and NO-ITA techniques have been used to examine trends in drought severity and duration series as graphically. To do so, graphical trend results have been given by Figure 6, 7, 8, 9 separately while trend types have been presented by Table 4. As it can be seen from the table that many times trends in the characteristics have been increasing trend. While all series have been detected with increasing trends in 17300 station, the results of 17340 and 17351 have been more variable. In 17340 and 17351 stations, in addition to increasing and decreasing trend types there has been no trend cases that are SPI-1 severity series of both stations and SPI-3 of 17340 station. Also, while there has been same behavior of drought characteristics in SPEI series, they have been more variable in SPI series. In all series ITA and NO-ITA have given same trend type. In comparison, when the trend type is being considered, MKT, SRT, WT, ITA and NO-ITA have given similar outcomes many times. Even ITA, NO-ITA and SST have had similar outcomes in most of severity series.

Table 3. MKT, SRT, WT and SST trend results of drought characteristics

Station	Drought Index-Time Scale	Drought Characteristics	MKT	SRT	WT		SST
17300-Antalya	SPI-1	Severity	3.0737	3.0673	2.8308	↑	0.0036
		Duration	1.7851	1.7930	1.1333	0	0
	SPI-3	Severity	1.7708	1.7644	1.5276	↑	0.0056
		Duration	0.9643	0.9873	1.0015	0	0
	SPEI-1	Severity	3.2463	3.2029	3.1646	↑	0.0053
		Duration	3.1710	3.1265	2.6750	0	0
	SPEI-3	Severity	2.2882	2.2262	1.5120	↑	0.0091
		Duration	1.8382	1.8261	1.4940	0	0
17340-Mersin	SPI-1	Severity	0.1997	0.2194	0.7755	↑	0.0002
		Duration	0.3033	0.3043	0.5155	0	0
	SPI-3	Severity	-0.3270	-0.3449	0.0437	↓	-0.0011
		Duration	-0.3869	-0.4208	-0.2467	0	0
	SPEI-1	Severity	4.8448	4.8648	4.7957	↑	0.0088
		Duration	3.6091	3.6058	3.6042	0	0
	SPEI-3	Severity	3.7568	3.7417	3.3970	↑	0.0345
		Duration	3.0823	2.9878	2.9096	↑	0.0282
17351-Adana	SPI-1	Severity	0.7461	0.6671	0.8620	↑	0.0007
		Duration	0.7609	0.7849	1.2469	0	0
	SPI-3	Severity	-1.0319	-1.1359	-0.4280	↓	-0.0033
		Duration	-1.2864	-1.3541	-0.5718	0	0
	SPEI-1	Severity	3.6513	3.6399	3.3263	↑	0.0049
		Duration	2.6115	2.7129	2.7285	0	0
	SPEI-3	Severity	1.1640	1.0859	1.4473	↑	0.0047
		Duration	0.6082	0.5719	0.7614	0	0

	Significant decreasing trend at α=0.01 significance level (Z = -2.576)
	Non-significant decreasing trend at α=0.01 significance level (Z = -2.576)
	Significant increasing trend at α=0.01 significance level (Z = 2.576)
	Non-significant increasing trend at α=0.01 significance level (Z = 2.576)
↓	Decreasing trend slope
↑	Increasing trend slope
0	No Trend

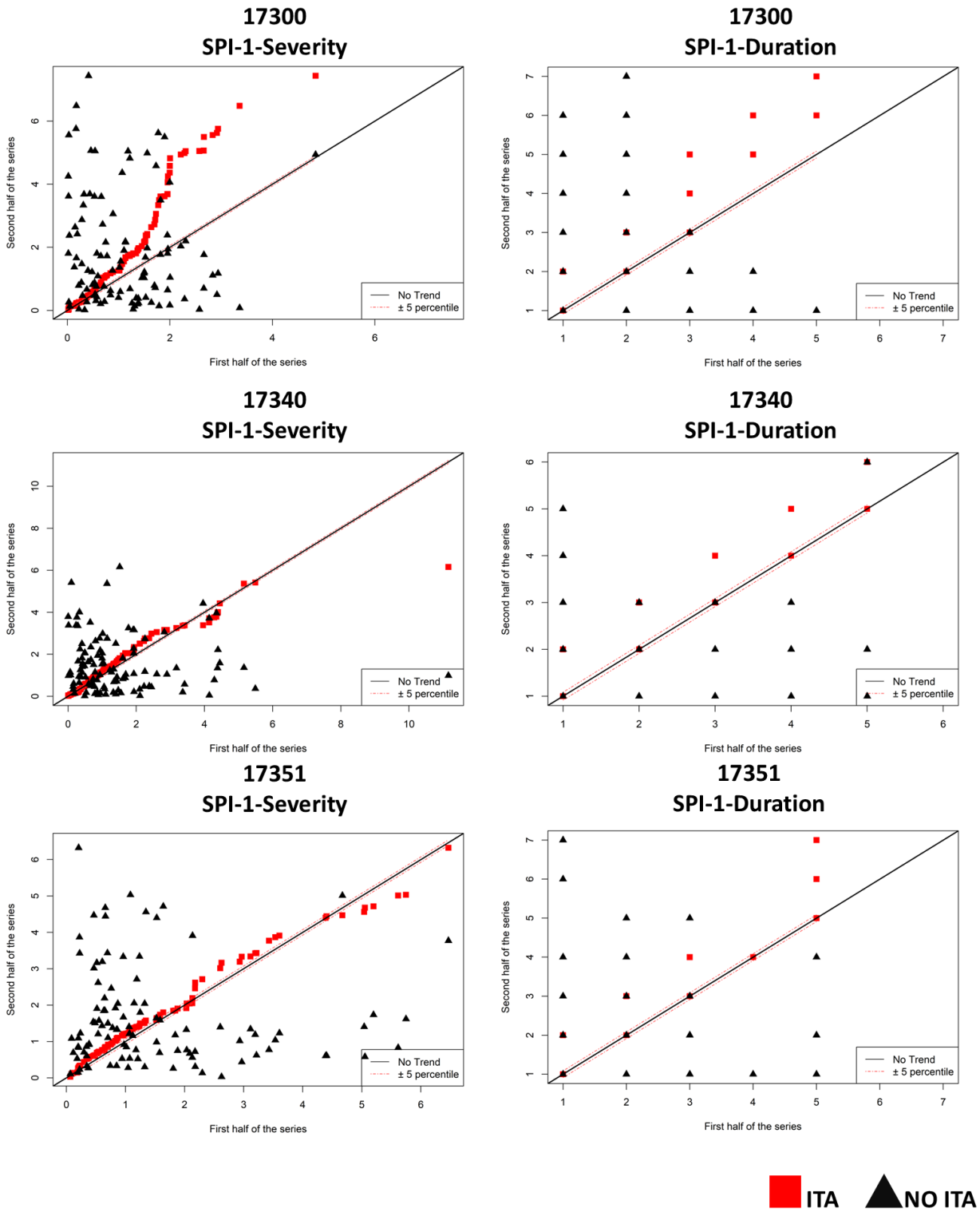

Figure 6. ITA and NO-ITA results of severity (left) and duration (right) in SPI-1.

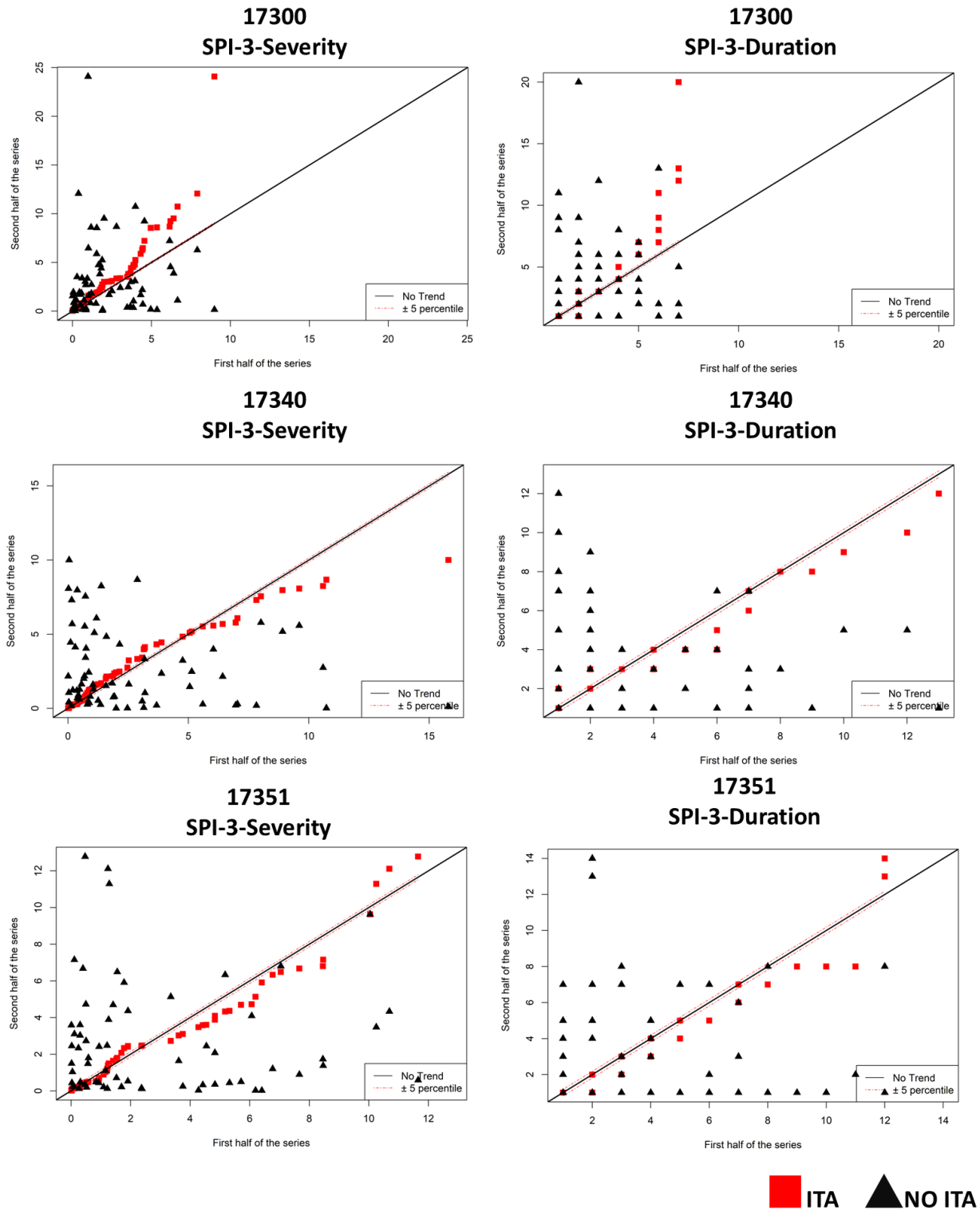

Figure 7. ITA and NO-ITA results of severity (left) and duration (right) in SPI-3.

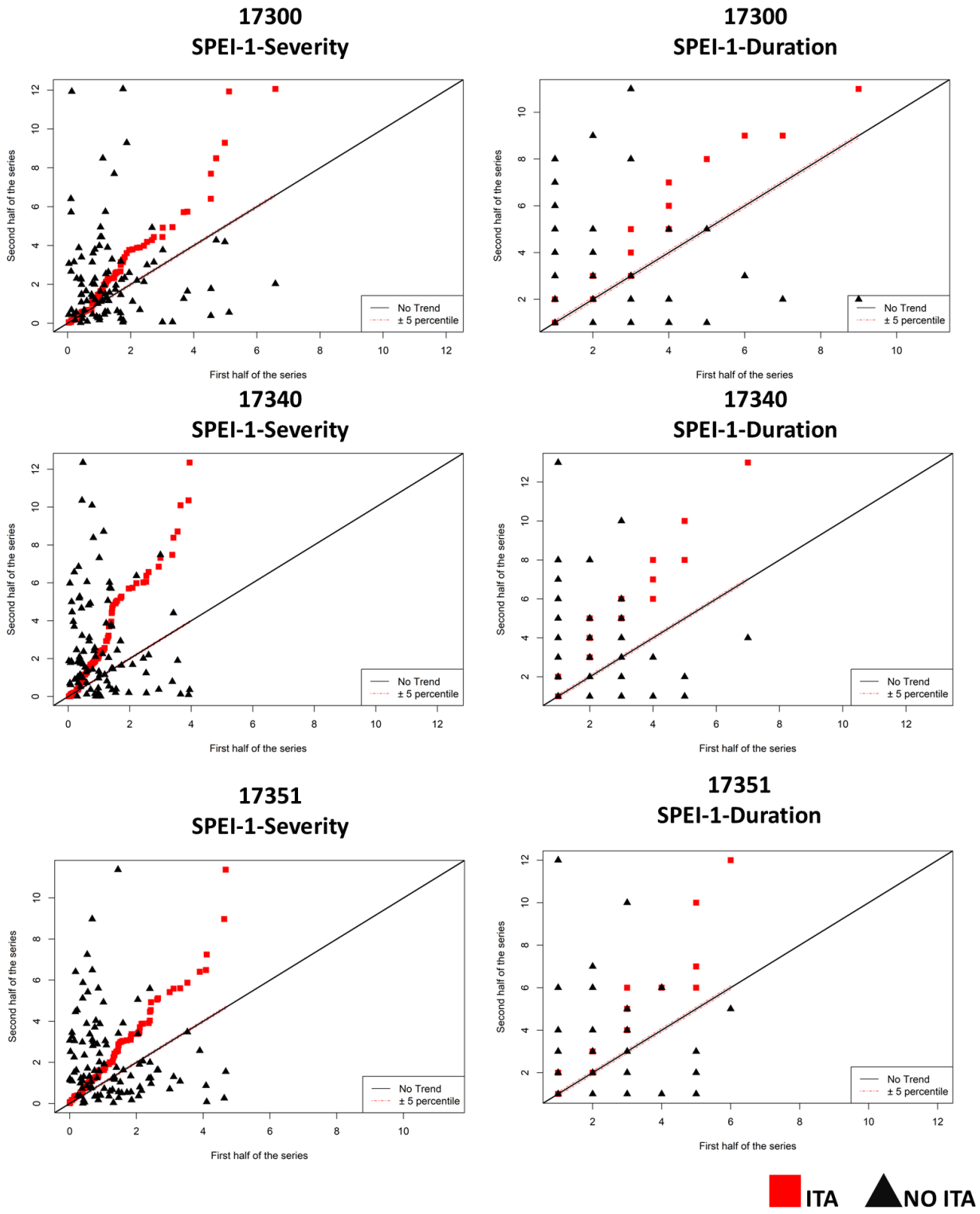

Figure 8. ITA and NO-ITA results of severity (left) and duration (right) in SPEI-1.

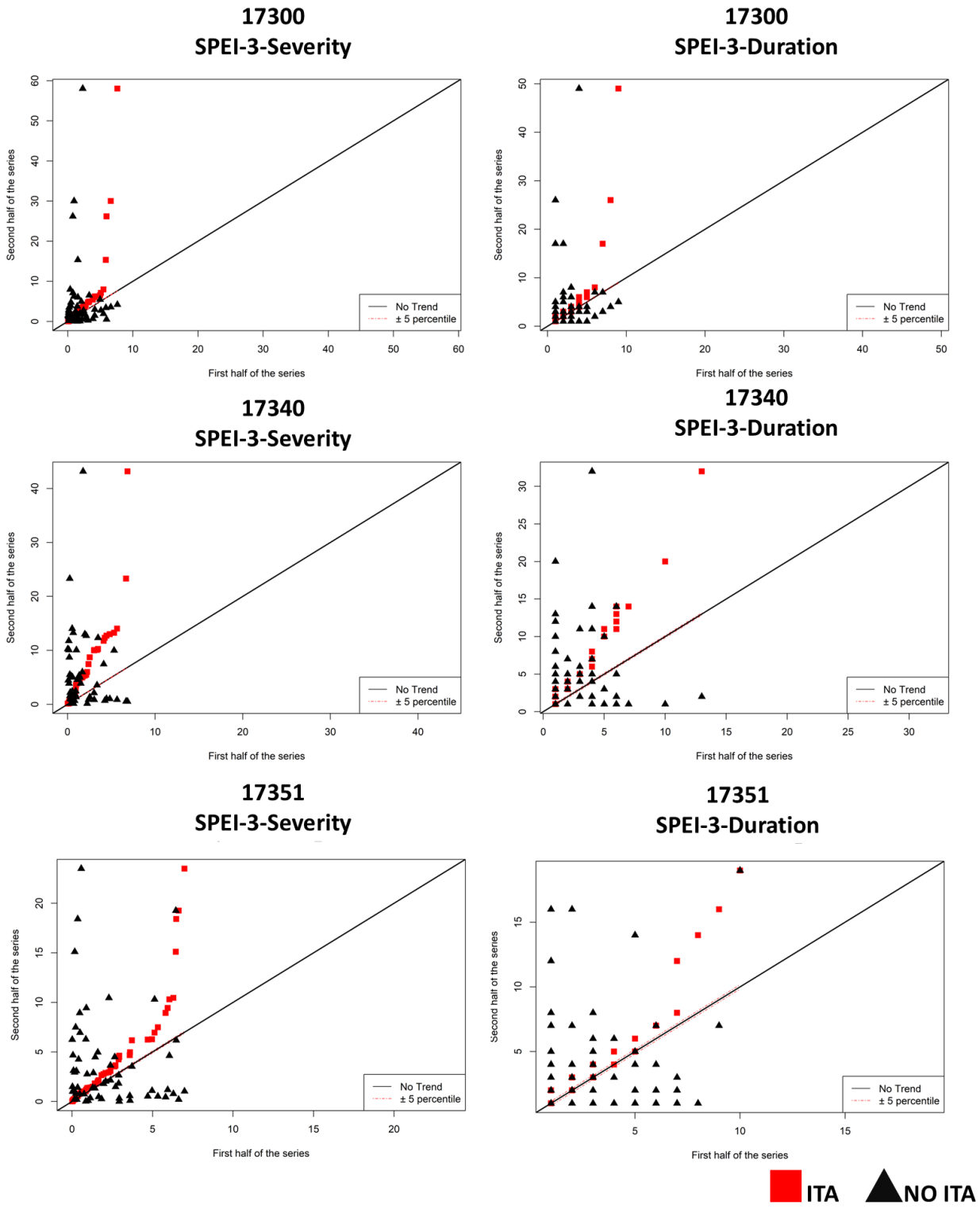

Figure 9. ITA and NO-ITA results of severity (left) and duration (right) in SPEI-3.

Table 4. ITA and NO-ITA trend type results of drought characteristics

Station	Drought Index-Time Scale	Drought Characteristics	ITA	NO ITA
17300-Antalya	SPI-1	Severity	+	+
		Duration	+	+
	SPI-3	Severity	+	+
		Duration	+	+
	SPEI-1	Severity	+	+
		Duration	+	+
	SPEI-3	Severity	+	+
		Duration	+	+
17340-Mersin	SPI-1	Severity	0	0
		Duration	+	+
	SPI-3	Severity	0	0
		Duration	-	-
	SPEI-1	Severity	+	+
		Duration	+	+
	SPEI-3	Severity	+	+
		Duration	+	+
17351-Adana	SPI-1	Severity	0	0
		Duration	+	+
	SPI-3	Severity	-	-
		Duration	-	-
	SPEI-1	Severity	+	+
		Duration	+	+
	SPEI-3	Severity	+	+
		Duration	+	+

-	Decreasing Trend
+	Increasing Trend
0	No Trend

4. Discussion

The aim of this study is to monitor the variability meteorological drought characteristics of severity and duration for selected stations in Mediterranean Region of Türkiye using SPI and SPEI indices at 1-month and 3-month scale. Beside of this aim, for an effective and beneficial drought monitoring spatial distribution of dry and wet categories have been analyzed. The findings of this study have put forth that the Normal (N) and Wet (combination of all wet groups) categories have been the most repetitive groups in both time scales of SPI and SPEI. Earlier in some studies such as (Akşan and Bacanlı, 2021; Yuce and Esit, 2021; Mersin et al., 2022; Yuce et al., 2022; Abu Arra and Şişman, 2024; Simsek et al., 2025; Akbas et al., 2026) the prevalence of normal, near normal and wet or one of those categories have been noted for different parts of Türkiye. In another study that has been done by (Gumus, 2023) mild droughts (-1<SPI/SPEI≤0) have been prevalent across Türkiye with SPI and SPEI at multiple time scales. In one another study that has been performed by (Kiliç, 2026) mild drought and wet categories have been most repetitive by SPI and SPEI at 12-month time scale for Southeastern Region of Türkiye. Similarly (Eris et al., 2020) have reported mild drought risk by SPI and SPEI at multiple time scales for Kucuk Menderes River Basin, Türkiye. As a limitation of the study, in the determination of SPEI, Thornthwaite method which is based only temperature have been used. However, earlier (Gumus, 2023) have stated that the PET is effected notably by wind speed, humidity, sunshine duration and solar duration.

The findings of the study have revealed that most severe droughts are obtained by SPEI series. Earlier these case has been emphasized by (Terzi and Üçüncü, 2025) because of the crucial influence of temperature in SPEI calculations while SPI only utilizes precipitation. In the findings of this study, the most severe drought events have been seen after 2000s. In the literature in the studies such as (Gümüş, 2017; Boustani and Asli, 2020; Aksoy et al., 2021; Akturk et al., 2022; Yuce et al., 2023; Simsek et al., 2025;) similar years have been reported for different types of drought in Türkiye. It has been reported in some research studies such as (Sönmez et al., 2005; Cavus and Aksoy, 2019) that climate projections indicate that by the end of the 21st century, the Mediterranean region will experience more extensive, intense, and prolonged droughts. The observed post-2000 increase in severe drought events in this study may represent an early manifestation of this projected drying trend. In the main aim of the study, trend detection tests have been applied to drought severity and duration series. The findings have shown that both series

generally have tended to increase while a small part of series have tended to decrease by MKT, SRT and WT. On other hand SST results have shown the similar behavior for severity series while all duration series have been seen with no trend case. ITA and NO-ITA have shown the same behavior but unlike the MKT, SRT and WT in some severity series no trend has been observed. Recently (Akbas et al., 2026) have found mainly decreasing trends in severity and magnitude and increasing trend in duration for The Lower Tigris-Euphrates Basin. Also, the researchers have found no trend slope many times for the characteristics by SST and mainly decreasing and no trends by ITA and NO-ITA. In another study (Yaşa and Partal, 2024b) have obtained mostly non-significant decreasing trends by MKT and a variety of trend types by ITA for Southeastern Region of Türkiye. Similar results with previous studies can be due to usage of same indices and implying same probability distributions. Different results can be due to different climatic conditions due to regional properties, data intervals, approximations to the problem and software used and so on.

These increasing trends in severity and duration characteristics which threatens water availability and the related sectors such as energy and agriculture must be monitored and necessary preventions must be applied. In addition to meteorological drought, via different techniques and suitable data other drought types must be addressed for a more comprehensive and applicable drought management plan.

5. Conclusion

In this study, a comprehensive meteorological drought monitoring of drought characteristics of drought severity and duration series have been done for selected 3 stations in Mediterranean Region of Türkiye considering the data record of 1950-2024. Drought events have been determined by SPI and SPEI indices at multiple time scales. For a comprehensive monitoring, drought categories have been spatially analyzed by IDW. Two important drought characteristics that are severity and duration have been computed by Theory of Runs. Trends in these characteristics have been determined by a set of classical (MKT, SRT, WT and SST) and innovative (ITA and NO-ITA) techniques. Overall, following conclusions have been made under the light of findings:

- In the analysis of SPI and SPEI series within the time at multiple time scales, the results have shown that many drought events have been occurred in the past and even near today.
- In both time scales of both indices Normal (N) and Wet (combination of all wet groups) categories have been most repetitive categories. After these two, the percentage of occurrences ordered from high to low as MD>VD>ED in the time scales of indices. By IDW, different parts of the study area have experienced with different drought categories. When interpreting the findings, it is important to check both color and distribution ranges together.
- Drought characteristics of the SPI and SPEI at multiple time scales have shown that the highest severity and duration series have been obtained by SPEI-3 series. It is also significant to emphasize that the highest ones have been occurred in 2000s.
- The trend detection results by MKT, SRT and WT test considering α=0.01 significance level have shown that a big part of the series of drought characteristics have been detected with increasing trends. Decreasing trends have been obtained with less amount. While 17300 station has been detected with totally increasing trends, 17340 and 17351 stations have been more variable as they have included decreasing trends. However, these trends have not been significant in all the times. Since there have been 2 indices, 2-time scales in each, two characteristics in each time scale for 3 stations, out of 24 analyses, in 9 series significantly increasing trends have been obtained. These significantly increasing trends have been detected mostly in 17340 Mersin by 4 times. There has been no significantly decreasing trends. In almost all series, 3 tests have had a good agreement in care of either trend type or significant cases.
- SST results have put forth that while there has been mostly increasing trends in severity, in all duration series no trend (0 slope) have been obtained.
- ITA and NO-ITA tests have provided the graphical assessment of the drought characteristics. In many times, trends of the characteristics have been increasing. In all the series ITA and NO-ITA have given same trend type. Unlike the MKT, SRT and WT, no trend cases have been observed in severity series.
- It is important to emphasize that in severity series (DS), classical (MKT, SRT, WT and SST) and innovative (ITA and NO-ITA) techniques have a good agreement except at small number of series.
- The findings of this study are expected to be beneficial for local authorities as the study presents significant findings using multiple indices at multiple time scales for prediction and monitoring drought severity and duration. As droughts are complex and serious natural hazards, effective and sustainable drought management plan is required and current plans must be updated by monitoring drought events via all possible techniques. Beside of this, the findings of this study offer updated findings in the context of spatial distribution of drought categories and trends in drought characteristics based on multiple drought indices. These findings can be beneficial for policy making for water and water related sectors and developing drought early warning systems of the region.

Although the study presents significant findings for the region based on selected stations, the study is limited with used drought indices, spatial interpolation technique and trend detection techniques for drought

severity and duration for 2-time scales. Further studies can use different indices and other innovative and reasonable techniques for drought monitoring that is quite significant subject for all living things.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	I.H.D
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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