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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Assessment of Meteorological and Agricultural Drought Analysis in Kırklareli province

Kırklareli İli Meteorolojik ve Tarımsal Kuraklık Analizlerinin Değerlendirilmesi

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Abstract

The Global warming in the world cause to the climate change in this century. Agriculture is one of the sectors that can be most affected by climate change. Agricultural production is affected by precipitation and temperature variables. Due to the changes in these two parameters, the increase in the temperatures and the changes in the amount of precipitation in parallel with this disrupt the ecological balance and bring along the problems of desertification and drought. Agricultural production is highly dependent on meteorological factors in Thrace region. For this reason, it is expected that changes in climatic factors will affect the agriculture of the region positively or negatively. The aim of this study is to determine the frequency and severity of meteorological and agricultural drought with two indexes between 1963-2019 years in Kırklareli province. Standardized Precipitation Evapotranspiration Index (SPEI) was used to determine monthly, seasonal, six monthly and annual agricultural drought. According to annual agricultural drought results, it was calculated ten years mild arid (1969, 1985, 1986, 1990, 1991, 1992, 1993, 2011, 2016, and 2019), five years moderate arid (1983, 1989, 1996, 2008, and 2015), one year severe arid (1994), and two years extreme arid (2000 and 2001). Another drought index which is Standardized Precipitation Index (SPI) was used to determine meteorological drought. According to annual meteorological drought results, Eight years mild arid (1964, 1969, 1982, 1985, 1986, 1990, 1991, and 2011), seven years moderate arid (1983, 1989, 1992, 1993, 1994, 1996, and 2008), and two years extreme arid (2000, 2001) was figured out. According to linear correlation analysis, a good correlation was obtained for SPI and SPEI values, between annual, six monthly (Spring-Summer), and three monthly only winter and spring periods (R^2=0.871, R^2=0.901, R^2=0.974, and R^2=0.919), respectively. In the 57-year observation period; 18 years were determined as the arid year with SPEI index and 67% of these total arid years (12 arid years) occurred and 17 years were determined as the arid year with SPI index and 76% of these total arid years (13 arid years) occurred, between 1982 and 2002 years. The SPEI drought index which use precipitation, temperature and evapotranspiration data could give much good results to policy makers in drought mitigation policies in terms of giving results that are more accurate in agricultural production and drought assessments.

Keywords: Climate change, Drought indexes, Evapotranspiration, Precipitation, Thrace region

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Öz

Dünyadaki küresel ısınma bu yüzyılda iklim değişikliğine neden olmaktadır. Tarım, iklim değişikliğinden en fazla etkilenebilecek sektörlerden biridir. Tarımsal üretim yağış ve sıcaklıktaki değişimlerden etkilenir. Bu iki parametre deki değişimler, sıcaklıkların artması ve buna paralel olarak yağış miktarındaki düzensizlikler ekolojik dengeyi bozmakta, çölleşme ve kuraklık sorunlarını beraberinde getirmektedir. Trakya bölgesinde tarımsal üretim büyük ölçüde meteorolojik faktörlere bağlıdır. Bu nedenle iklim faktörlerindeki değişikliklerin bölge tarımını olumlu veya olumsuz yönde etkilemesi beklenmektedir. Bu çalışmanın amacı, Kırklareli ilinde 1963-2019 yılları arasında meteorolojik ve tarımsal kuraklığın sıklığını ve şiddetini iki indeks ile belirlemektir. Aylık, mevsimsel, altı aylık ve yıllık tarımsal kuraklığı belirlemek için Standardize Yağış Evapotranspirasyon İndeksi (SPEI) kullanılmıştır. Yıllık tarımsal kuraklık sonuçlarına göre, on yıl hafif kurak (1969, 1985, 1986, 1990, 1991, 1992, 1993, 2011, 2016 ve 2019), beş yıl orta kurak (1983, 1989, 1996, 2008 ve 2015), bir yıl şiddetli kurak (1994) ve iki yıl aşırı kurak (2000 ve 2001) yıl olarak hesaplanmıştır. Meteorolojik kuraklığı belirlemek için bir diğer kuraklık indeksi olan Standardize Yağış İndeksi (SPI) kullanılmıştır. Yıllık meteorolojik kuraklık sonuçlarına göre, Sekiz yıl hafif kurak (1964, 1969, 1982, 1985, 1986, 1990, 1991 ve 2011), yedi yıl orta kurak (1983, 1989, 1992, 1993, 1994, 1996 ve 2008) ve iki yıl aşırı kurak (2000, 2001) yıl olarak hesaplanmıştır. Doğrusal korelasyon analizi sonuçlarına göre, SPI ve SPEI değerleri için yıllık, altı aylık (İlkbahar-Yaz) ve üç aylık sadece kış ve ilkbahar dönemleri arasında sırasıyla (R^2=0.871, R^2=0.901, R^2=0.974 ve R^2=0.919) iyi bir korelasyon elde edildi. 57 yıllık gözlem periyodunda SPEI yöntemi ile de 18, SPI yöntemi ile 17 yıl kurak yıl olarak belirlenmiştir. Bu toplam kurak yılların (SPEI 12 yıl) %67 (SPI 13 yıl) %76 gibi büyük bir bölümü 1982 ile 2002 yılları arası meydana gelmiştir. Tarımsal üretim açısından yağış, sıcaklık ve evapotranspirasyon verileri ile hesaplanan SPEI kuraklık indeksi tarımsal üretim ve kuraklık değerlendirmelerinde daha hassas sonuçlar verdiği için kuraklığın azaltılması politikalarında karar vericilere daha iyi değerlendirme imkânı verebilir.

Anahtar Kelimeler: İklim değişikliği, Kuraklık indeksleri, Evapotranspirasyon, Yağış, Trakya bölgesi

1. Introduction

Changes observed in the amount of precipitation and its distribution in the growing season from year to year cause significant changes in crop production and productivity in the Thrace Region. Even if the total precipitation is sufficient, the irregular distribution of precipitation may cause to decrease the performance of genotypes with high yield potential. Konukçu et al. (2020) stated that the yield during the development period of the modelled plant could be sensitive for the variation of meteorological factors. Calculations for the sensitivity analysis helped us understand how plants reacted to the meteorological changes in the research locations, and changes in temperature, precipitation and radiation were the most important variables that affected the plant's phenological stages. The insufficiency of available water resources and the observed and expected negative effects of global warming make it necessary to consider the resistance to drought of and effective water use ability as the main features in the selection of genotypes to be cultivated in the Thrace Region. The decrease and deterioration in quality and yield due to drought will adversely affect the economy of the region and the country. Decreasing the income to be obtained from the unit area in plant production will speed up the use of Thrace lands for non-agricultural purposes. Thus, the extent of the existing environmental problem will expand further. Drought is one of the most costly disasters in the world that affects a large number of people every year (Wilhite, 2000). At the same time, drought is cited as an environmental disaster. In some studies, it is mentioned that deficiencies in precipitation cause decreases in, the convenient water usage capacity (Wilhite, 2000; Koustroulis et al., 2011; Rossi, 2000). There are different definitions of drought based on precipitation, soil moisture or potential evapotranspiration (Türkeş, 2019; Heim, 2002; Svoboda et al., 2002; Wilhite, 1985).

In general, drought is defined as the periods when precipitation, groundwater or surface waters in a region are less than the expected amount (average). Drought is directly proportion with temperature increase and inversely proportion with precipitation increase (Çaldağ et al., 2004). Drought is the main abiotic stress factor and low moisture during grain filling period affected bread wheat yield and yield component (Öztürk and Korkut, 2017). Drought is classified as meteorological, agricultural, hydrological and socioeconomic. Standardized Precipitation Index (SPI) is commonly used to determine the severity of meteorological drought. SPI is based on converting and applying long term precipitation records to normal distribution and this index calculates dry and wet periods in different time periods (Dai, 2011). The Standardized Precipitation Evapotranspiration Index (SPEI) has been developed to evaluate the severity of agricultural drought by taking into account the evapotranspiration and meteorological drought in the environment where the crop is located (Vicente-Serrano, 2010a). In the determination of meteorological and agricultural drought, SPI and SPEI indexes have been conducted by different researchers on issues such as analysis, monitoring and comparison of the drought's spatial and temporal distribution (Alkan and Tombul, 2022; Şener, 2021; Bakanoğulları, 2020; Falzoi et al., 2019; Keskiner et al., 2019; Tefera et al., 2019; Bae et al., 2018; Çetin et al., 2018; Chen et al., 2018; Çamalan et al., 2017; Tong et al., 2017; Nedealcov et al., 2015; Stagge et al., 2015; Bakanoğulları and Yeşilköy, 2014; Kwak et al., 2013; Türkeş and Tatlı, 2009; Wilhite et al., 2007).

The first objective of this study is to determine meteorological and agricultural droughts were analyzed using SPI and SPEI indices from 1963 to 2019. For these purpose, monthly mean total precipitation and monthly mean air temperature data recorded at the Meteorological service in the Kırklareli city were used in different time periods (monthly, seasonal, 6 months and yearly). The second objective is to examine the drought results were evaluated.

2. Materials and Methods

2.1. Study area and meteorological data

Kırklareli province locates in the northwest part of Turkey. It is also in the northern part of Marmara Region. It neighbors with the provinces of Tekirdağ in the south and Edirne in the west. The north of the province is entirely the Bulgarian border and the east is entirely the Black Sea. In addition, Kırklareli province locates between the longitudes of 26° 52' and 28° 07' with latitudes of 41° 13' and 42° 06' (*Figure 1*).

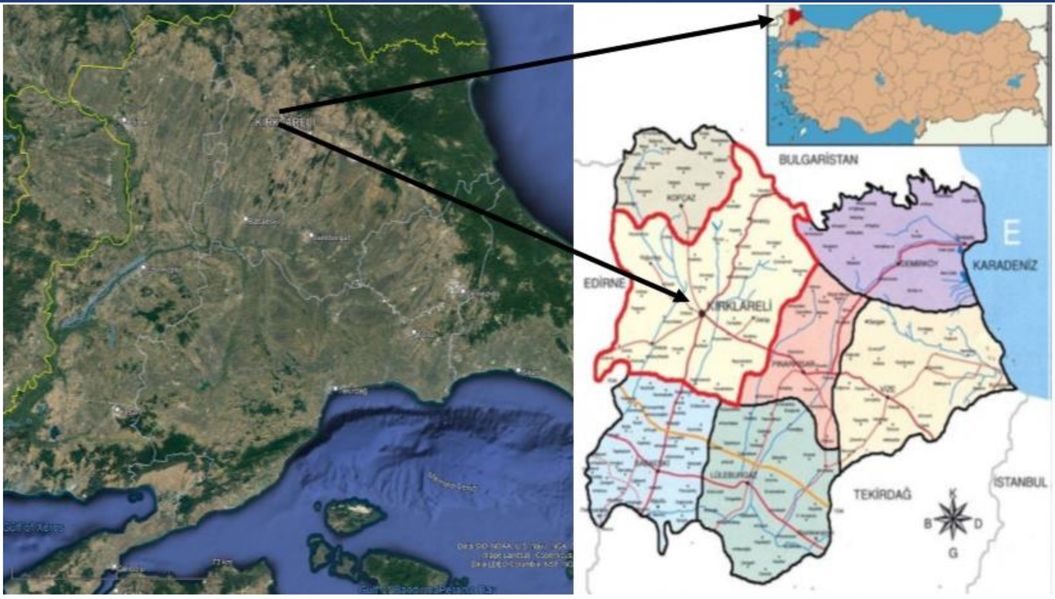

***Figure 1*. Kırklareli map and location of country (The map is rearranged from the Google Earth).**

Climate of Kırklareli province differs according to the regions with the effect of Strandzha Mountains and the Black Sea. The Black Sea climate is observed in the north-facing parts of the Strandzha Mountains. Summers are cool, winters are cold and the air temperature difference between the seasons is low. Terrestrial climate is observed in the inner parts. Summers are hot, winters are cold and sometimes snowy. The temperature difference is high between summer and winter seasons. Terrestrial climate is dominant in the centre of Kırklareli, which is located on the southern part of Strandzha Mountains. In the study, 57-year (1963-2019) monthly precipitation data and monthly average air temperature data obtained from the Kırklareli Meteorological Service were used. Monthly average values of these data are given in *Figure 2*.

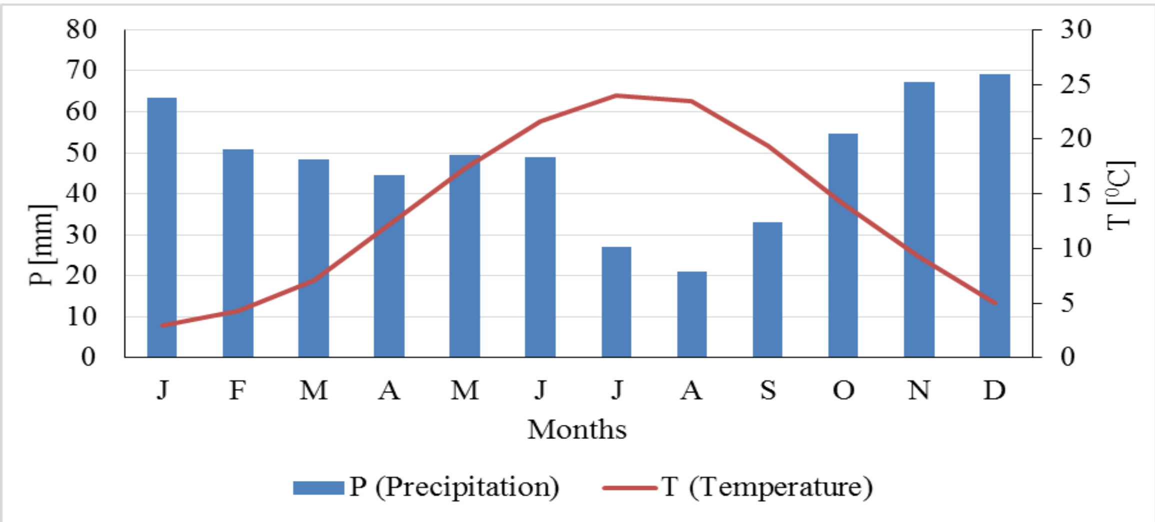

Figure 2. Long term monthly precipitation and mean air temperature data in Kırklareli

2.2. Standardized Precipitation Index (SPI)

SPI was developed by McKee et al. (1993) to define primarily a meteorological drought. With the help of the index, which is calculated based only on the precipitation values, dry periods can be monitored as well as the wet period. SPI is obtained by dividing the difference of precipitation from the mean by the standard deviation within a specified time frame.

$$SPI_{i,j} = \frac{X_{i,j} - X_j^{ort}}{\sigma_j} \qquad \text{(Eq.1).}$$

In Equation 1, Xi,j shows the precipitation (mm) in the month j, the average precipitation in the month Jj (mm), and σj shows the standard deviation of the month in j. SPI values can be calculated for different periods (such as 1, 3, 6, 9, 12, 24, 48 months). However, precipitation data may not conform to the normal distribution for 12 months or less. For this reason, each data set is adapted to the Gamma function. The Gamma distribution is then transformed to a Gaussian distribution (standard normal distribution with mean zero and variance of one), which gives the value of the SPI for the time scale used (Bakanoğulları and Yeşilköy, 2014, Türkeş and Tatlı, 2009). The classification of drought indices is given in *Table 1*.

Table 1. Drought categories of SPEI and SPI

Drought Category	Symbols	SPEI & SPI Values
Extreme wet	EW	≥ - 2.00
Severe wet	SW	1.50 - 1.99
Moderate wet	MoW	1.00 - 1.49
Mild wet	MiW	0.50 - 0.99
Near normal	NN	-0.49 - 0.49
Mild drought	MiD	-0.99 - -0.50
Moderate drought	MoD	-1.49 - -1.00
Severe drought	SD	-1.99 - 1.50
Extreme drought	ED	≤ - -2.00

2.2. Standardized Precipitation Evapotranspiration Index (SPEI)

SPEI was developed by Vicento Serrano et al. (2010a) to evaluate the severity of agricultural drought, taking into account plant evapotranspiration and meteorological drought. It is easy to calculate and based on the standard precipitation index (SPI) calculation basis.

SPEI is expressed as the difference (D) between the monthly or weekly potential evapotranspiration (PET) and precipitation (P). This difference (D) is the excess or lack of water for the month (i) analysed and is calculated using Equation 2.

Di=Pi-PETi (Eq.2).

The following steps should be followed to calculate the potential and actual evapotranspiration according to the Thornthwaite (1948) method.

a) Monthly mean temperature indices are determined according to the average temperature of each month.

$$i = (\frac{t}{5})^{1.514} \qquad \text{(Eq.3).}$$

In Equation 3, Where; i, monthly mean temperature index, t is the average monthly temperature (°C).

b) By adding the temperature indexes for each month, annual temperature index is found.

$$I = \sum_{k=1}^{12} i \qquad k = 1\text{-}12 \qquad \text{(Eq.4).}$$

In Eq.4, Where; I is annual temperature index; i is monthly mean temperature index; k is the month of operation

c) Potential Evapotranspiration,

$PET=16*(10*t)/I)^{a}$ (Eq.5).

$a = (0.000000675 * I3) - (0.000077 * I2) + (0.01792 * I) + 0.49239$ (Eq.6).

In Equation 5; PET, potential evapotranspiration (mm / month); t, monthly mean air temperature (°C); I, annual temperature index; a is the coefficient that is also given the calculation method in Equation 6.

d) In Equation 7, To find the corrected Potential Evapotranspiration (DPET, mm / month), it is sufficient to multiply the evapotranspiration and latitude correction coefficient of each month. The latitude correction coefficient (G) is a value that varies according to average sunshine times and is prepared in a tabular format by Thornthwaite (1948).

DPET= (PET*G) (Eq.7).

The results found by both methods (SPEI and SPI) in the research basin were classified according to the drought categories given in *Table 1*.

The SPI and SPEI analyses were conducted by Rstudio software programme with the SPEI package. Potential evapotranspiration (PET) and climatic water balance (BAL) data were calculated by Rstudio to complete the SPI and the SPEI.

SPEI is calculated similar to SPI. However, a three-parameter distribution is needed to standardize D-series as D-values can have negative values. Globally, the three-parameter log logistic distribution has been found to be a better fit for SPEI at all-time scales using Kolmogorov–Smirnov test (Vicente-Serrano et al. 2010b). The drought severity classification based on SPEI values is similar to the SPI classification and it can be defined at multiple scales.

3. Results and Discussion

In this study; meteorological and agricultural droughts were analyzed using SPI and SPEI indices from 1963 to 2019. Annual drought analyses were given in Figure 3. Three and six monthly drought analysis results with both index were given in *Figures 5* and *6*. Monthly drought analyses by both indexes were given by details in *Figure 9*.

The annual drought analysis by *Figure 3 (top)* SPI showed that 17 years were arid, 16 years were wet and 24 years were normal by the drought classification (*Table 1*) in the Kırklareli province. It indicates that approx. 30 % of the last 57 years were under arid conditions. The content of the arid years is categorized as follows; 8 years mild arid (1964, 1969, 1982, 1985, 1986, 1990, 1991, and 2011), 7 years moderate arid (1983, 1989, 1992, 1993, 1994, 1996, and 2008), 2 years extreme arid (2000, 2001). In *Figure 3(below),* The SPEI showed that 18 years were arid, 19 years were wet and 20 years were normal by the drought classification from 1963 to 2019 in the Kırklareli province. Evaluation of annual agricultural drought with SPEI index categorized as 10 years mild arid (1969, 1985, 1986, 1990, 1991, 1992, 1993, 2011, 2016, and 2019), 5 years moderate arid (1983, 1989, 1996, 2008, and 2015), 1 years severe arid (1994), 2 year extreme arid (2000 and 2001). It indicates that approx. 32 % of the last 57 years were under arid conditions. Depending on global warming and climate change, it was determined as a moderate and severe arid year in 1983, 1989 and 1994, and severe arid year in 2000 and 2001 in Kırklareli province. This situation may indicate that droughts will gradually increase in frequency and severity in the coming years (*Figure 3*).

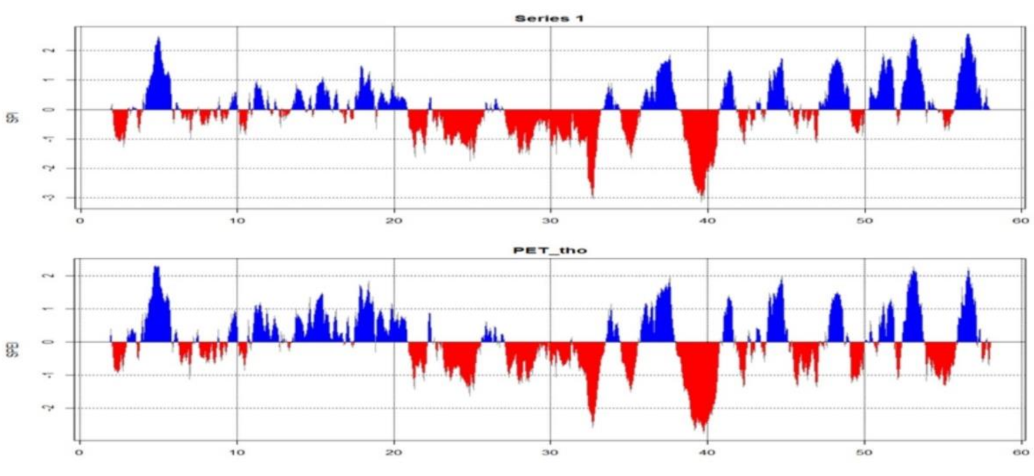

Figure 3. Comparison of long-term drought indices SPI (top) and SPEI (below) annual for Kırklareli

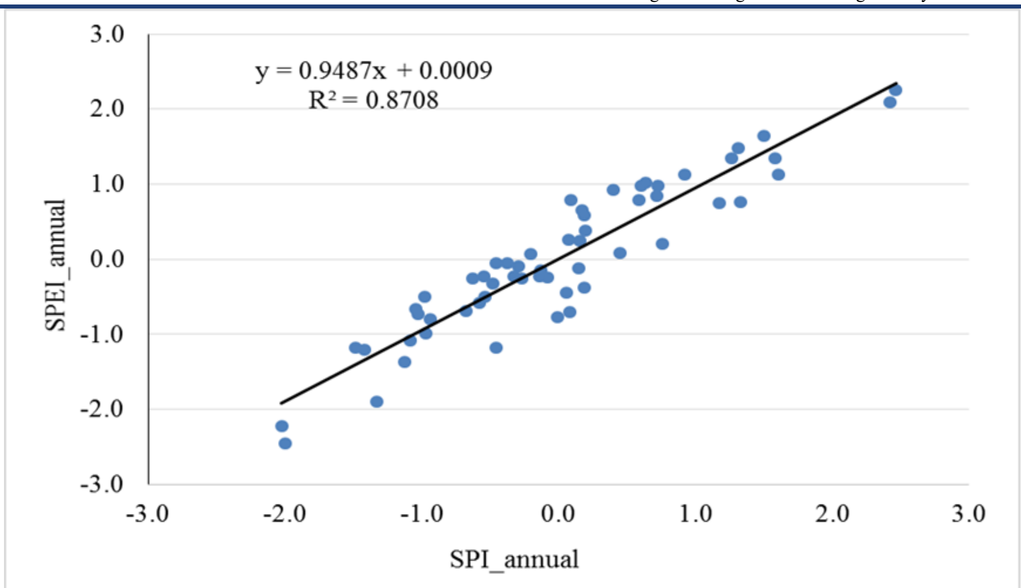

Figure 4. The relationship between annual SPI and SPEI index for Kırklareli

The followings Scatter diagram between SPI and SPEI are given in *Figure 4* in order to compare the results of both indices calculated using 57 years climatological data at Kırklareli. According to analysis, the determination coefficient (R^2) between the annual SPI and SPEI drought indexes was determined as 0.871 and was found statistically significant. Tong et al. (2017) conducted a drought analyses study at Xilingol pastures in Northern China with SPEI and NDVI indexes between 1961 and 2015 period for monthly, seasonal, biannually and annually. The results showed a 98% positive correlation between the annual SPEI and NDVI. They stated that the meteorological drought had a negative impact on plant vegetation development in arid and semi-arid regions. Alkan and Tombul (2022) conducted, a drought analyses were performed using data from 14 meteorological stations gathered between January 1989 and July 2020 in SPI and SPEI, based on 3-4-6-12 monthly scales. SPI and SPEI are common indices used for drought tracking. The coefficient of determination (R^2) was found to be 0.954 and used to analyze the regression between the annual SPI and SPEI.

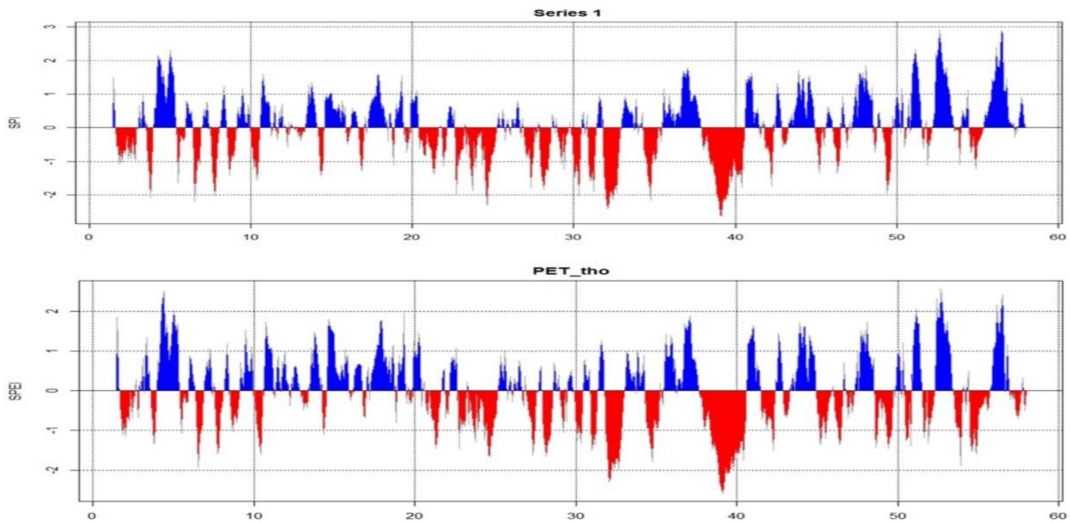

Figure 5. Comparison of long-term drought indices SPI-6 (top) and SPEI-6 (below) for Kırklareli

Figure 5 presents the time series of SPI index *(top)* and the SPEI index *(below)* calculated by considering 6 months data from autumn to winter and from spring to summer meteorological and agricultural drought for Kırklareli. Considering for two season, According to SPI, it was determined in autumn-winter season 14 years arid which of were 1 years severe, 5 years moderate, 8 years mild arid, in spring-summer season 18 years arid which of were 1 years extreme and severe, 3 years moderate, 13 years mild arid. According to SPEI, it was determined in autumn-winter season 11 years arid which of were 3 years severe, in spring-summer season 12 years arid which of were 1 years extreme and severe. In both methods, the number of arid years in spring-summer periods were more than autumn-winter periods. In this figure, it could be given an idea for conventional production which were cereal and oils plant rotations for agricultural drought in Kırklareli. Considering the additional data requirements of SPEI, it is more likely that SPI can be used to identify, analyze and monitor droughts in any climatic zone of the world (Vicente-Serrano et al., 2010a)

According to the SPI index in 3-monthly (seasonal) drought assessments *(Figure 6 (top));* while no drought observed in any of the four seasons for a total of 21 (1966, 1971, 1973, 1974, 1975, 1977, 1979, 1997, 1998, 1999, 2003, 2005, 2006, 2007, 2009, 2010, 2012, 2014, 2015, 2017 and 2018) years, at least one season was arid in all the other years. In arid years, drought was determined in 13 years winter, 17 years spring, 17 years summer and 18 years autumn seasons. According to the SPEI index *(Figure 6 (below));* in 1966, 1971, 1973, 1974, 1975, 1977, 1979, 1981, 1987, 1995, 1997, 1998, 2005, 2006, 2009, 2014, and 2017 there was no drought in any of the four seasons for a total of 17 years. However, at least one arid season observed in all the other years. In drought years, drought has been determined in 16 years winter, 15 years spring, 17 years summer and 20 years autumn season. Nedealcov et al. (2015) compared the temporal and spatial distributions of drought for 3 and 6 monthly periods with SPEI and SPI indexes in Moldova between the 1980-2014 periods. In temporal distribution both index showed similar results. However, differences observed in SPEI values in terms of drought length and intensities. Because SPEI values uses not only precipitation but also evapotranspiration. Keskiner et al. (2019) have produced meteorological drought maps at 5 and 10 repetition times in Seyhan Basin by use of 63 meteorological station long-term annual time scale data for SPI and PNI (Percent of Normal Index) indexes. They stated that PNI method is more sensitive than SPI method. Addition of the SPEI index to such basin-based drought analysis studies, contribute to monitoring agricultural drought as well as meteorological drought.

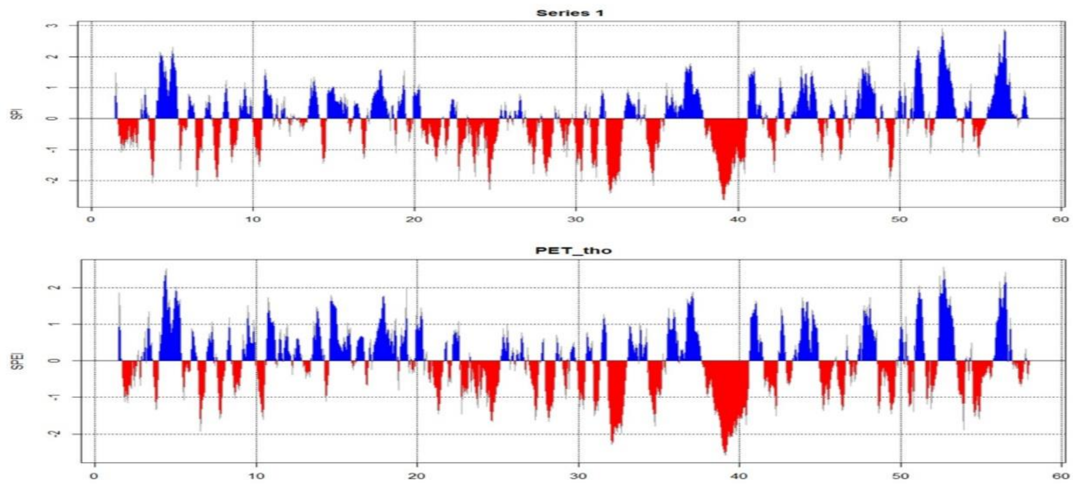

Figure 6. Comparison of long-term drought indices SPI-3 (top) and SPEI-3 (below) for Kırklareli

The evaluation between seasonal (three monthly) and six-monthy SPI and SPEI drought data which is estimated with 57 years meteorological data for Kırklareli province, linear correlation analysis results are given in *Figure 7* and *8*. According to the determination coefficient (R^2) between the three monthly (seasonal) and six-monthly between SPI and SPEI drought indexes was changed from 0.833 to 0.988. And it they were found statistically significant, respectively. Tefera et al. (2019) indicated that SPI and SPEI showed strong and significant relationship at 1-month (r = 0.69) and 3-month (r = 0.7) timescales. The linear relationship at 12-month and 24-month timescales(r = 0.83 and r = 0.79, respectively). Falzoi et al. (2019) the trends of the (SPI) and (SPEI) have been also evaluated. The similarities and differences between the indices of the two regions were then considered. In most stations of both zones, there is a statistically significant trend of increase in the SPI and decrease in the SPEI. Nevertheless, the trend of indices averaged over stations of the two indices is not significant in either of the two climatic zones considered.

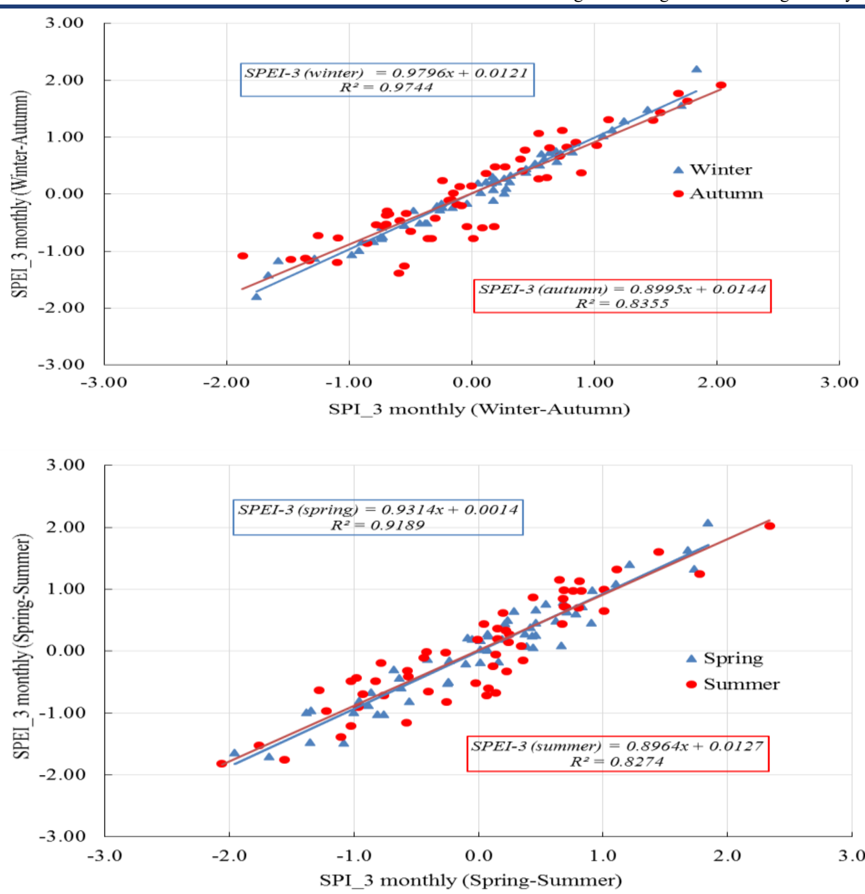

Figure 7. The relationship between seasonal SPI and SPEI index for Kırklareli

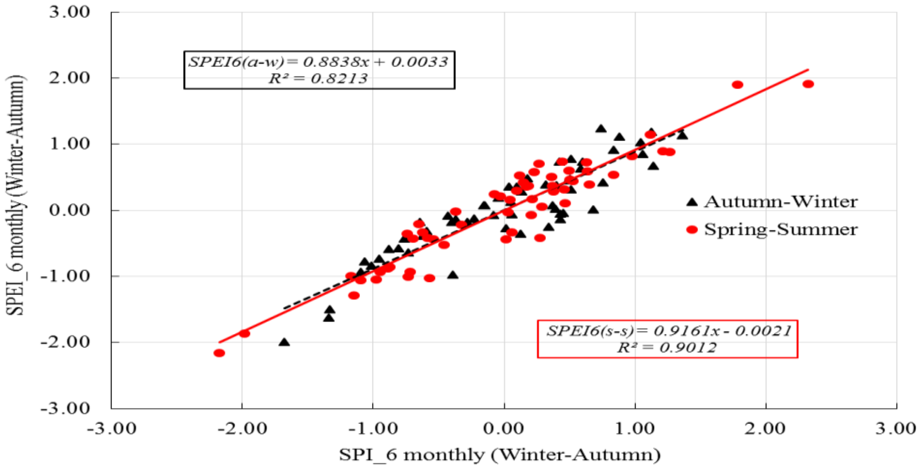

Figure 8. The relationship between SPI-6 and SPEI-6 index for Kırklareli

According to Kırklareli monthly bases SPI index drought assessment *(Figure 9(top));* April of 2018 observed as the most severe arid month (-3.69). 2008 of February (-3.49) followed this month. During the observation period, June observed as the most arid month, with 21 years. April was the least drought-determined month with the 14 times, during the period. According to the monthly drought assessment with the SPEI index *(Figure 9 (below))*; the most severe arid month determined as 1994 of April (-2.85) and 2010 of August (-2.46) followed this month. November observed most arid month with the 23 times repetition of drought, during the observation period. This month was followed by December with 22 times drought. The number of agriculturally drought months, monitored with SPEI index, determined more than the number of meteorologically drought months monitored with SPI index.

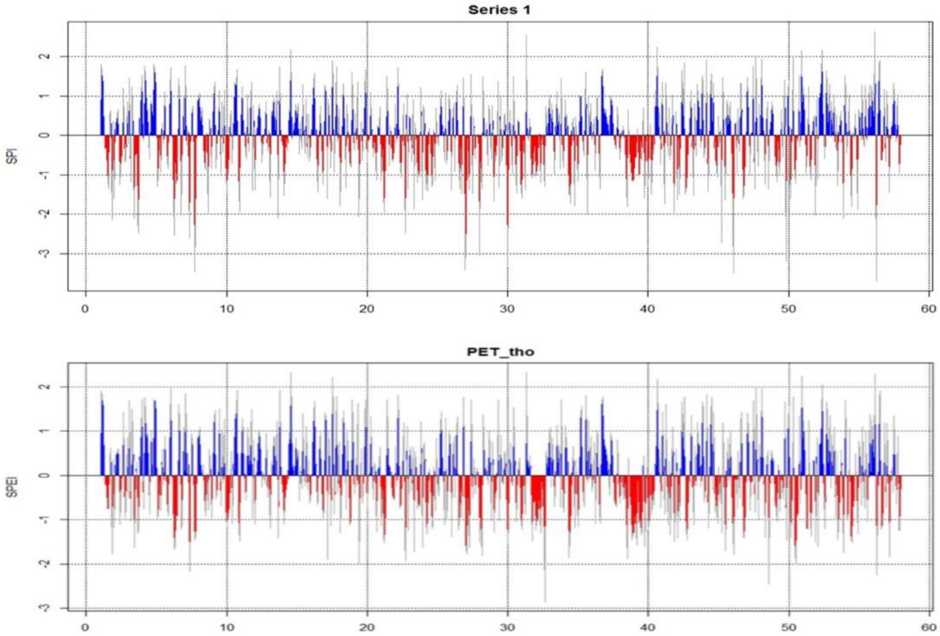

Figure 9. Comparison of long-term drought indices SPI-1 (top) and SPEI-1 (below) for Kırklareli

4. Conclusions

In this study, monthly, seasonal, 6-monthly and annual drought analyzed by SPI (meteorological) and SPEI (agricultural) drought indexes for the period of 1963-2019 in Kırklareli province. The linear relationship between both index values were estimated and compared. A strong relationship was found between SPI and SPEI. Furthermore, an important relationship (R^2 = 0.974, R^2=0.919 R^2=0.901) was figured out between seasonal winter and spring, six monthly (Spring-Summer) periods.

According to annual evaluation results; ten years mild arid (1969, 1985, 1986, 1990, 1991, 1992, 1993, 2011, 2016, and 2019), five years moderate arid (1983, 1989, 1996, 2008, and 2015), one year severe arid (1994), and two years extreme arid (2000 and 2001) observed with the SPEI index. SPI index analyses showed that, eight years mild arid (1964, 1969, 1982, 1985, 1986, 1990, 1991, and 2011), seven years moderate arid (1983, 1989, 1992, 1993, 1994, 1996, and 2008), and two years extreme arid (2000, 2001) Considering the annual periods according to the SPEI and SPI index, drought is severe and very frequent from 1982 until 2002 (SPEI 12 years, SPI 13 years). This process corresponds to 67% of the drought for SPEI and 76% of the drought for SPI observed during the 57-year observation period. This is an important indicator of change in climatic cycles.

In the monthly, 3-monthly and 6-monthly analyses of the SPEI index, there was a decrease in drought category intensity compared to the SPI index severity data. However, more sensitive results were obtained in this index by using temperature and evapotranspiration data. In order to examine and reduce drought in terms of agriculture, monthly, seasonal and semi-annual drought analysis of SPEI index should be done. Moreover, drought analysis of the cultivated plants based on vegetation periods, could contribute to more realistic and healthy results in the region.

The weaknesses of the SPI compared to the SPEI is that SPI relies on precipitation as input data. However, SPEI takes into account evapotranspiration, temperature, including precipitation. So while SPI analyzes meteorological drought, SPEI estimates agricultural drought. Thus, it would be appropriate to use this method for the determination of agricultural droughts on the basin and for future drought projections and making more accurate policies for regional decision makers.

Generally, there are various stages of crop development, and each stage lasts around 1 or 3 months. Therefore, it is better to focus on short-term drought conditions, such as 1- and 3-month time scales of SPEI, which are related to crop development.

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