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Analysis of the relationship between meteorological and agricultural drought of 2007 in Bartın province, Türkiye

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Keywords
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Agricultural Drought
SPI
VCI
NDVI

Abstract

Drought is a recurring climatic event that devastates agriculture and depletes surface and subsurface water resources. While it cannot be avoided, it can be monitored to mitigate its negative effects on economy. In recent decades, remote sensing has played a major role to track droughts from space. In this study, the 16-day composite Normalized Difference Vegetation Index (NDVI) images collected by the Moderate Resolution Imaging Spectroradiometer onboard the Terra satellite between 2000 and 2016 along with the Vegetation Condition Index (VCI) was used to monitor the drought event of 2007 in Bartın province, Türkiye. Later, the Standard Precipitation Index (SPI) was calculated using precipitation observations recorded at the meteorological station managed by the Turkish State Meteorological Service (MGM) to validate the drought findings of the VCI method. The results indicated that there was a 4-month lag of vegetation to precipitation and meteorological drought signaled by SPI led to agricultural drought indicated by VCI in 2007 in the study area.

1. Introduction

Drought is a direct result of a prolonged precipitation deficit which recurs frequently as a part of climate variability. Because the occurrence of drought can be seen with the human eye, drought indices have been developed to detect drought events.

So far, precipitation observations recorded at the meteorological stations have been heavily used to detect meteorological drought, a prolonged precipitation deficit in comparison to the historical precipitation average. The Standard Precipitation Index (SPI) is selected as a standard index to monitor meteorological drought worldwide by the World Meteorological Organization (WMO 2012). However, this method calculates a point-based estimate of meteorological drought that can not be used to estimate regional drought conditions since meteorological towers are very far away from each other.

Satellite remote sensing is a proven tool to monitor droughts from space (Deng et al. 2013). Because satellites collect spatially continuous observations over the Earth surface every day, they can be used to estimate regional drought conditions with spatially interpolating point-based drought estimates. Agricultural drought is a result of depleted soil moisture that cannot sustain healthy vegetation growth. Vegetation condition can be observed from satellites using proxy indicators such as Normalized Difference Vegetation Index (NDVI). When agricultural drought strikes, it affects vegetation health and growth relative to historical vegetation growth conditions over a region of interest. There have been many studies to track agricultural drought using remotely-sensed images (Yağcı 2018; Deng et al. 2013; Yagci 2021; Tucker and Choudhury 1987; Yagci et al. 2018; Kogan 1997). The vegetation condition index (VCI) calculated from the multi-year NDVI data has been found simple, effective and accurate to identify agricultural drought conditions over the globe (Yagci, Di, and Deng 2013; Kogan 2001; Deng et al. 2013).

In this study, the relationship between meteorological and agricultural drought is investigated by taking the drought event that took place in 2007 in Bartın Province, Türkiye as an example. The time series of SPI and VCI are compared in 2007 at the location of the meteorological tower to reveal the lagged relationship between vegetation condition and precipitation deficit.

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2. Data and Methods

2.1. The study area

The study area is selected as Bartın Province, Türkiye. There is a meteorological station (Station code = 17020) managed by MGM with a long record of precipitation observations spanning from 1961 to 2017. The location of the tower with respect to Bartın province are shown in Figure 1.

The study area features a temperate climate with no dry seasons and hot summer (e.g., Cfa) according to Köppen-Geiger (Beck et al., 2018). The landscape is dominated by the mixed forestland.

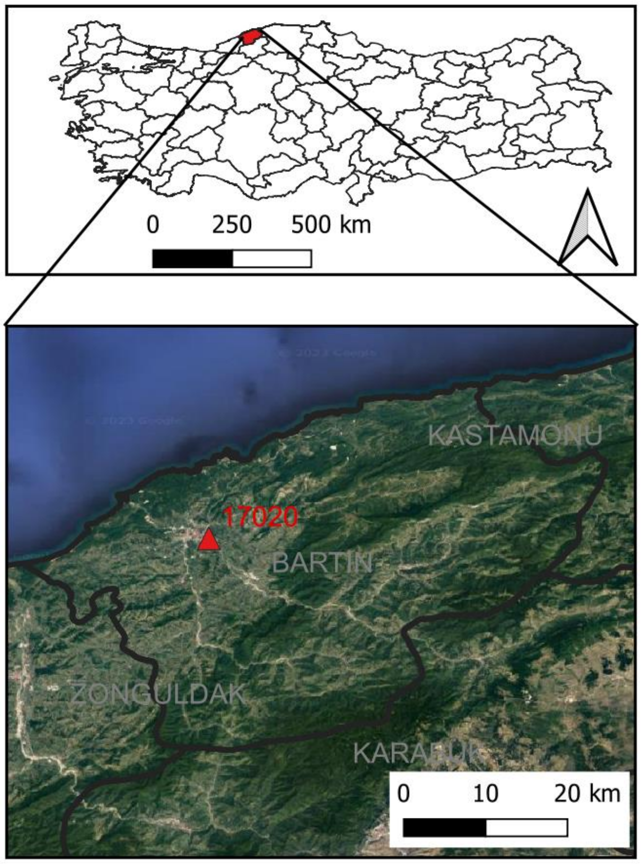

Figure 1. The location of the tower in the study area

2.2. Data

The version 6.1 Vegetation Index Products collected by the Moderate Resolution Imaging Spectroradiometer onboard the Terra satellite between 2000 and 2016 was retrieved from LP DAAC data pool website. The product name of the dataset is MOD13A2. Each granule has a NDVI and pixel reliability layer with 16-day temporal and 1-km spatial resolutions.

The pixel reliability layer holds critical quality information about each pixel in the NDVI layer (Table 1). NDVI pixels as indicated by fill/no data, snow/ice and cloudy in the pixel reliability layer were removed from the analysis. The resulting gaps were temporally interpolated from good quality observations. Later, the VCI was calculated by Equation (1) using only good quality NDVIs.

Table 1. Pixel values and their description in the pixel reliability layer of MODIS vegetation index products

Key	Summary	Description
-1	Fill/No data	Not processed
0	Good Data	Use with confidence
1	Marginal Data	Useful, check QA information
2	Snow/Ice	Target is snow or ice
3	Cloudy	Target is cloudy

Table 2. Drought classification scheme of the VCI

Range	Category
41 - 100	No drought
21 - 40	Abnormally dry
16 - 20	Moderate drought
11 - 15	Severe drought
6 - 10	Extreme drought
0 - 5	Exceptional drought

In addition to NDVI data, the monthly precipitation observations recorded at the station, 17020, were downloaded from the MGM website through the data distribution tool, MEVBIS, between 1961 and 2016.

Table 3. Drought classification scheme of the SPI (WMO 2012)

Range	Category
> 2.0	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
0.99 to -0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severe dry
< -2.0	Extremely dry

2.3. Methods

In this study, two drought indices were used to examine the relationship between meteorological and agricultural drought. The first index is the VCI, an agricultural drought index, whereas the other one is SPI, a meteorological drought index. The VCI highlights vegetation variation induced by annual prevailing conditions and can be calculated by the Equation 1.

$$VCI_i = 100\ x\ \frac{NDVI_i - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (1)$$

where $NDVI_{ij}$ is the NDVI value at i^{th} day of year, *j,* while $NDVI_{max}$ and $NDVI_{min}$ are the maximum and minimum NDVI values for a given pixel between 2000 and 2016, respectively. In the final step, the drought maps were constructed from the VCI using the classification scheme given in Table 2.

The SPI is a statistical indicator of precipitation deficit normalized by the sample standard deviation on multiple timescales (e.g., 1, 2, 3 ..., 12 months). Before transformation to a normal distribution, long-term precipitation records collected at the tower between 1961 and 2016 are fitted to a 3 parameter pearson probability distribution. Then, the SPI can be calculated by the Equation 2.

$$SPI_{ij} = 100\ x\ \frac{P_{ij} - \bar{P}_i}{s_i} \qquad (2)$$

where P_{ij} precipitation value at i^{th} month j year, while $\bar{P}_{ij}$ and s_{ij} mean and standard deviation of long-time precipitation records at i^{th} month, respectively. Later, SPI values were categorized by the classification scheme given in Table 3.

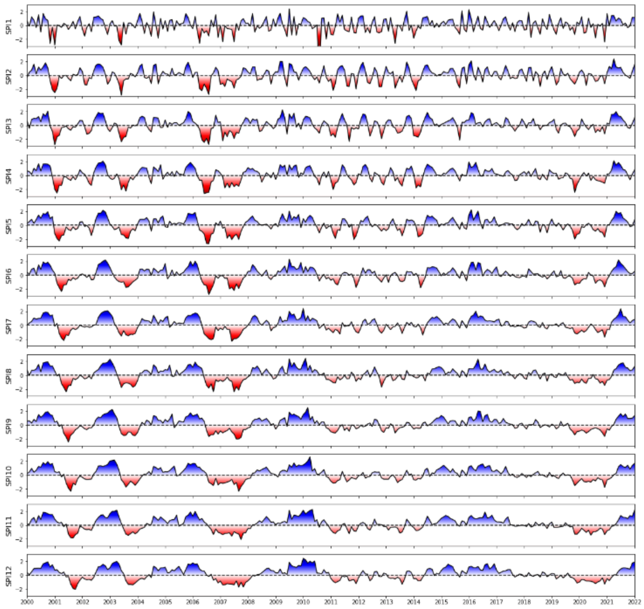

Figure 2. **Th**e time series of SPI on multiple timescales from 1-month to 12-month between 2000 and 2016.

3. Results

In the first step, the drought years at the station was found based on the SPI time series analysis given in Figure 2. The 12-month SPI (SPI-12) indicated that the most severe drought occurred from winter 2006 until the end of winter of 2008. In other words, the year 2007, was the month when the drought hit the study area hard. The second severe drought started in the winter of 2019 and continued until the spring season in 2021. Furthermore, the other notable drought events took place in the summer-fall season of 2001 and the fall-winter season 2013.

The frequency of changes in the 1-month SPI (SPI-1) was high and impacted by monthly rainfall. The time series of SPI-12 varied slowly in comparison to other SPI on time scales less than 12-month. It is more suitable to determine drought events using SPI with long-timescales (>4 months) .

The correlation analysis was conducted between VCI and all SPIs in the 2007 drought year (Figure 3). The VCI was highly correlated with 4-month SPI (SPI-4). This implies that there was a 4-month lag between vegetation and meteorological drought. The second highest correlation was observed between VCI and 6-month SPI (SPI-6). The lowest correlation coefficient values were seen between VCI and SPI-11, and VCI-SPI-1. This demonstrated that the short-term rainfall deficit does not impact the vegetation growth.

The time series of SPI-4, SPI-6 and VCI was plotted together for visual analysis of the 2007 drought event (Figure 4). SPI-4 showed that the drought started in April 2007 and ended in October 2007, while SPI-6 indicated the onset of drought was May 2007 and the drought event continued until October 2007. On the other hand, VCI was more in line with SPI-4, indicating that drought event occurred between April and October of 2007.

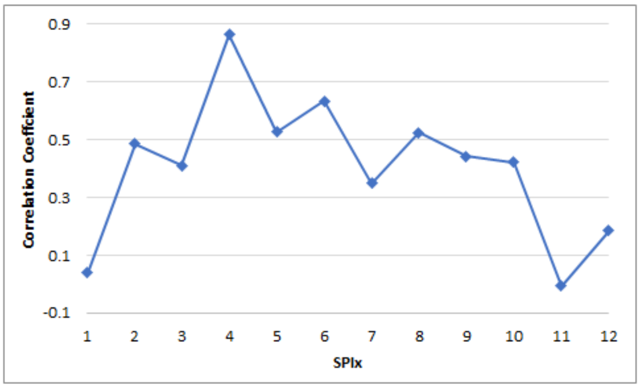

Figure 3. Correlation coefficient (r) values between VCI and SPI1-SPI12 in 2007

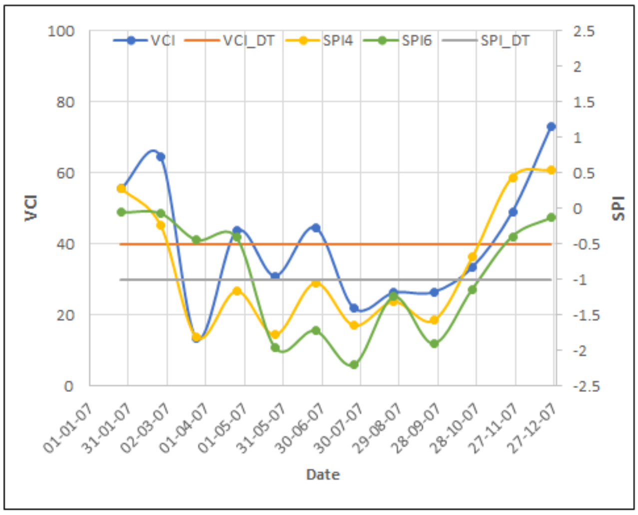

Figure 4. Comparison of VCI and SPI4-SPI-12 in 2007. VCI-DT and SPI-DT are the drought thresholds, respectively

4. Conclusion

In this study, a relationship between meteorological and agricultural drought was examined in the 2007 drought event. VCI is employed to track agricultural drought as whereas the SPI was the indicator of meteorological drought. During the study period (2000-2017), Bartın province experienced the most severe drought in 2007.

In the study area, 4 months lag was found between precipitation deficit and vegetation stress. In other words, vegetation in this area can sustain 4 months long rainfall deficit. Overall, agricultural drought can develop in this region after more than 4 months long meteorological droughts.

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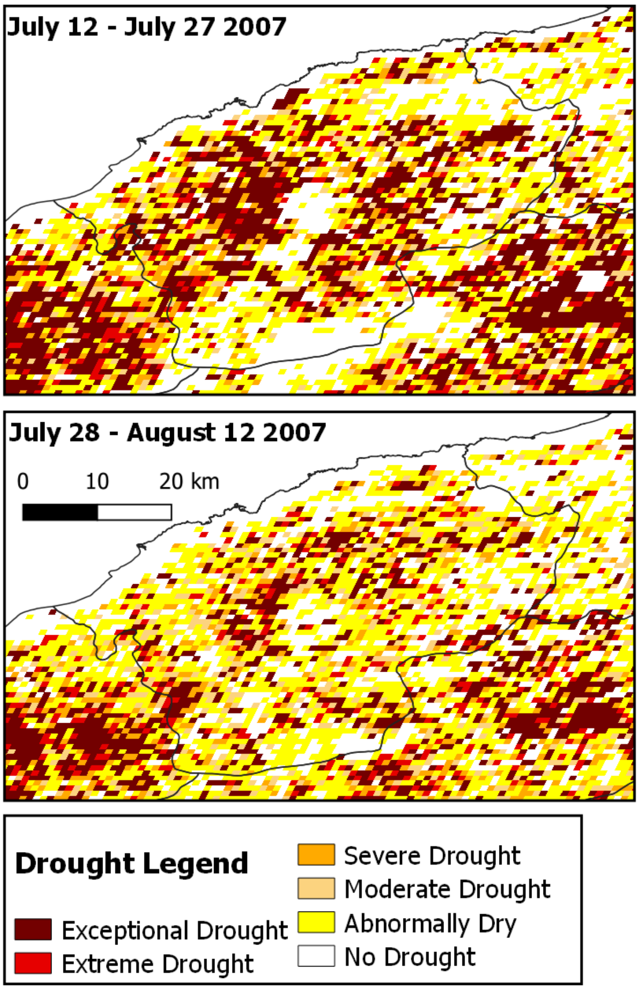

Figure 5. VCI-based drought maps between July 12 and July 27, 2007 (above) and July 28 and August 12, 2007 (below) for Bartın Province

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