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Meteorological and hydrological drought analysis of Sinop, Kastamonu, Bartın provinces in the Western Black Sea

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Abstract: In recent years, a significant change has been observed in the climate characteristics of Turkey. These changes, which are compatible with the general trend of global climate change, are also felt in the Western Black Sea Basin. This paper reported on the calculation of drought indices, with emphasis on two recently developed indices, the Reconnaissance Drought Index (RDI) and the Stream flow Drought Index (SDI) using specialized software package, named Drin C (Drought Indices Calculator). Additionally, Drin C includes a module for the estimation of potential evapo transpiration (PET) through temperature-based methods (Hargreaves, Blaney - Criddle, and Thornthwaite) that can be used for the calculation of RDI. Therefore, in this study carried out in the Western Black Sea region, meteorological drought analyzes for1-, 3-, 6- ve 12 months were made for 3 precipitation observation stations in the provinces of Sinop, Kastamonu, Bartın, and monthly total precipitation and monthly average temperature data were used to determine the meteorological drought.

Keywords: Drought analysis, Standard Precipitation Index (SPI), Reconnaissance Drought Index (RDI), Stream flow Drought Index (SDI), Sinop, Kastamonu, Bartın ,West Black Sea Region**.**

1. Introduction

Drought is defined as a phenomenon that may be related to the area under investigation and should be addressed using a specific application. The region can faces environmental, economic, and social challenges and so, many definitions of the dangerous drought have been developed [1]. During a drought, a lack of moisture usually results in a severe hydrological imbalance. The areas can had also experienced dry weather and long-term water scarcity due to water scarcity. According to Hagman (1984), drought is the most common natural disaster [2]. The event are the most complex of all-natural disasters that have affected man, but the nature of drought has been described as the event observed in a specific period and circumstances. Every year, various regions of the world are affected by the drought [3,4]. Considering the severity, duration, and effects of the drought, there are certaindroughttypes;meteorologicaldrought,agriculturaldrought,hydrologicaldrought,andsocioeconomic drought[5]. Meteorological drought is defined by the severity and duration of the drought. Depending on rainfall data, it is the first type of drought we encounter. Because its effect is dependent on rainfall, the period of rainfall corresponds to an average level in that drought type. Because the climate regime of the regions is an important factor, meteorological droughts vary in different locations. Taking two regions with different precipitation amounts as an example, the average annual rainfall in the first region is estimated to be 500 mm/year for longer years. In contrast, the annual rainfall in the second region is estimated to be around 1500 mm/year. If the amount of rainfall in the region in the same year is 750 mm/year, then the first region is experiencing a humid year, while the second region is experiencing a dry year. The main reason for this is due to atmospheric conditions that caused a lack of precipitation based on the climatic regime. Furthermore, meteorological drought had recorded monthly rainfall data. It is assessed on a seasonal, water-year, and annual time scale [6]. As a result, the researcher observed the significant socioeconomic impact of such frequent changes.

Agricultural drought is investigated due to a lack of rainfall due to meteorological drought and soil water deterioration. The water demand of a plant is determined by its biological properties, as well as the growth or stages of the soil's physical and biological properties [7].

A lack of water in the hydrological system was referred to as a hydrological drought. It was a type of drought in which water levels in rivers, lakes, reservoirs, and groundwater were unusually low [8].

The hydrological drought indicated that the total flow of the dry year was lower than the previous year's average flow. Furthermore, the frequency and severity of hydrological drought are typically defined at the river basin scale. Hydrological drought is considered to be ongoing if the actual flow in a river during a specified time period falls below a certain threshold. As a result, the effects of hydrological drought upstream of a river basin may reduce downstream flow and vice versa [9].

For example, after years of severe drought in a river basin, many years of normal rainfall were required to replenish the reservoirs. Therefore, the socioeconomic drought occurred due to meteorological, hydrological, and agricultural drought factors being linked to the supply and demand for certain economic goods or services. Water, food, and hydroelectric energy supply, for example, are all affected by weather conditions. In most cases, demand for these goods is increasing due to rising per capita consumption. As a result, droughts are typically caused by an increase in demand for supply goods and a decrease in climate factors [10].

Gümüş (2017) used the Stream Arid Index approach to conduct drought studies in the Asi Basin. Data from four flow monitoring sites between 1954 and 2005 were analyzed in the research. In the basin, the flow drought index calculations for the 3, 6, and 12-month time series indicated the dry, humid, and wet times of year. There were many more broken years between 1980 and 2005 than in prior years, according to the statistics. In addition, 2000 and 2001 were shown to be very dry years.[11].

Gümüş ve diğ., (2019),by the Ceyhan-Ceyhan area of Turkey conducted a study aimed to investigate the meteorological and hydrological drought, Standardized Precipitation Index, the method (SPI) and Current Drought Index (SDI) method in the region that was favored and methods gave similar results It is stated that they help to understand the drought better [12].

Bakanoğulları (2020) used SPEI (Standardized Precipitation Evapo transpiration Index) and SPI Indices to analyze the Istanbul-Damlca Stream Basin droughts. When determining drought frequency and severity in the study, researchers used the (SPEI) and (SPI). The Thornthwaite technique was used to determine the SPEI drought index evapotranspiration in the basin between 1982 and 2006, using meteorological data. It is statistically noteworthy that the coefficient of determination (R2) between the yearly SPEI and SPI indices (0.977) is substantial. Drought patterns differed across the one, three, and six-month time frames, however. Study findings show a more accurate SPEI Drought Index regarding agricultural productivity and its usage is healthier [13].

In research by Coşkun (2020), a long-term precipitation trend analysis in the Van Lake basin was performed. The long-term recorded precipitation data from Van-Bölge, Muradiye, Erçiş, Gevaş, zalp, Tatvan, and Ahlat meteorological stations were used to evaluate both yearly and seasonal patterns in precipitation. Gevaş and Ahlat stations have declined yearly precipitation since the MannKendall Test, Spearman's Rho, and en Tests were used to analyze the data. Van-District station had an increase in annual precipitation. However, this time the rise was negligible. Erciş and Ahlat stations have had a considerable fall in precipitation, whereas Van-Region has seen a slight rise [14].

2. 2. Material and Method

This study presented the methodology used to collect and analyze the data of the study. The scope of the study is to determine drought sensitivity and calculate drought years to show the driest year in the western Black Sea region with the help of data from 8 precipitation and 4 flow observation stations data. In order to track changes in drought index values through time, drought analysis was used. The Standard Precipitation Index (SPI), the Reconnaissance Drought Index (RDI) and the Stream flow Drought Index (SDI) used for this aim. Sinop, Kastamonu and Bartın provinces in the Western Black Sea region was selected for research due to sometimes the scarcity of precipitation. Analyzes for meteorological and hydrological drought analysis were performed with the help of data between 1969-2019, and 1965-2915, respectively. Missing precipitation, temperature and flow data were completed with regression analysis.

Station Number	Station Name	Connected Province	Height (m)	Coordinate	Observation Period
17020	Bartın	Bartın	33	41°K 32°D	1965-2015
17074	Kastamonu	Kastamonu	800	41°K 33°D	1965-2015
17026	Sinop	Sinop	32	42°K 35°D	1965-2015

2.1. Methodology

A meteorological and hydrological drought analysis will be conducted for 8 precipitation and 4 flow observation stations data in the study area. Missing data were completed with regression analysis. The Standard Precipitation Index (SPI) method is used to determine meteorological drought using monthly total rainfall data. The Reconnaissance Drought Index (RDI) method used to determine meteorological drought using average monthly temperature data and total monthly precipitation data. Also The Stream flow Drought Index (SDI)method is used to determine hydrological drought using monthly mean flow data A drought analysis were performed using Drin C software at the study areas for 1, 3, 6, and 12 months.

2.2. Data

Monthly total precipitation and mean temperature data for stations 8 in the Sinop, Kastamonu and Bartın provinces were obtained from the General Directorate of Meteorology and monthly mean flow data for stations 4 in the study area were obtained from the General Directorate of State Hydraulic Works. The average annual temperatures, the total annual averages of precipitation, and the average flow data obtained from these stations are shown in Table 1.

Table 1. Precipitation and flow monitoring stations and its geographic locations.

2.3. Standardized Precipitation Index

The Standard Precipitation Index (SPI) was developed by (McKee et al. 1993). to determine the effects of the reduction in precipitation on groundwater, reservoir storage, soil moisture, snow drifts, and streams. It is obtained by dividing the precipitation difference from the mean, which is converted to normal distribution within the specified time period by the standard deviation. In fact, SPI provides a standardized conversion of the observed precipitation probability and could be calculated for desired time periods such as 1, 3, 6, 9, 12, 24, and 48 months. The formula and classification of the method are given below [15]

$$SPI = (X_i - X_i) / \sigma \quad (1)$$

Where:

- SPI: Standard Precipitation Index
- Xi: amount of precipitation
- Xi: average of precipitation
- σ:standarddeviation

Table 2. Index values and classification of SPI method [15]

SPI	SPI
≤ 2.0	Extremly wet
1.50-1.99	Severely wet
1.00-1.49	Modetraly wet
0-0.99	Mildly wet
-0.99-0	Mild drought
-1.49- -1.00	Modarate drought
-1.99- -1.50	Severe drought
≤ - 2.00	Extreme drought

2.4. Reconnaissance Drought Index

ThereconnaissanceDroughtIndex(RDI)isdevelopedtoapproachthewaterdeficitinamoreaccurateway,asaso rtofbalancebetweeninputandoutputinawatersystem[16]. The initial value (α k) of RDI was calculated for the year on a time basis of k (months) as follows:

$$\alpha_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}}, i = 1(1)N \text{ and } j = 1(1)k \quad (2)$$

Where:

- Pij and PETij are the precipitation and potential e-vapo transpiration of the j-thmonthofthei-thyear
- Nis the total number of years of the available data
- The values of αk satisfactorily follow both the lognormal and the gamma distributions in a wide range of locations and different time scales, in which they were tested.

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \bar{y}}{\hat{\sigma}_y} \quad (3)$$

Where:

- $y^{(i)}$ is the $\ln(ak)^{(i)}$
- y is its arithmetic mean
- σ y is the standarddeviation of y

Table 3. Corresponding boundary values of RDIst[29].

Mild	Moderate	Severe	Extremeclasses
-0.5 to -1.0	- 1.0 to -1.5	-1.5 to -2.0	< -2.0

3. 2.5. The Stream flow Drought Index

The index is a hydrological drought analysis. According to Nalbantis and Tsakiris (2009), if a time series of monthly stream flow volumes Qi,j is available, in which i denotes the hydrological year and j the month within that hydrological year (j = 1 for October and j = 12 for September), Vi,k can be obtained based on the equation [17].

$$V_{i,k} = \sum_{j=1}^{3k} Q_i \quad i = 1,2,\ldots.12 \quad k = 1,2,3,4 \tag{4}$$

in which Vi,k is the cumulative stream flow volume for the i-th hydrological year and the k-th reference period, k = 1 for October-December, k = 2 for October-March, k = 3 for October-June, and k = 4 for October-September. Based on the cumulative stream flow volumes Vi,k, the Stream flow Drought Index (SDI) is defined for each reference period k of the i-th hydrological year as follows[18]

$$SDI_{i,k} = \frac{y_{i,k} - \bar{y}_k}{s_{y,k}} \quad i = 1, 2, \ldots, \quad k = 1, 2, 3, 4$$

Table 3 .Definition of states of hydrological drought with the aid of SDI [34]

State	Description	Criterion
0	Non-drought	SDI ≥ 0.0
1	Mild drought	-1.0 ≤ SDI < 0.0
2	Modarate drought	-1.5 ≤ SDI < -1.0
3	Severe drought	-2.0 ≤ SDI < -1.5
4	Extreme drought	SDI < -2.0

3.Result Discussion

Within the scope of this research, SPI, RDI and SDI values for 1, 3, 6, and 12 months were calculated and evaluated using the Precipitation, Reconnaissance and Stream flow Drought Index method respectively. The process used the values of the total monthly precipitation, the average monthly temperature and mean monthly discharge for total 12 monitoring stations of the Sinop, Kastamonu and Bartın provinces.

3.1 Bartin Precipitation Monitoring station (17020) meteorological drought analysis (SPI)

SPI values were examined during periods 1, 3, 6, and 12 months using monthly total precipitation data measured continuously between 1965 -2019 of the Bartın station. Figure 1 and Figure 2 show the rates of dryness and humidity of monthly, 3-, 6-, and 12-months, respectively. Figure 1 show that the monthly dryness ranged between 45% and 59% according to SPI values. The highest dry period is 59% in Nov and Feb, with the lowest dry 45% period in Mar. When analyzed, the wet periods were the period with a high moist of 41% in Nov, Feb. The periods of drought and moisture for each of 3-, 6-, and 12- months for the SPI values are shown in Figure 3.2.The most. Dry periods with the highest SPI -3 values are SPI3-3 in Oct of 59%, and the lowest dry period is SPI3-3 Jan with 48%. For the periods SPI3- in JAN and SPI6- in April, the droughts were 52% and 55%, respectively. SPI-12 calculated according to 12-month values dryness is 50%, and moisture is 50%.

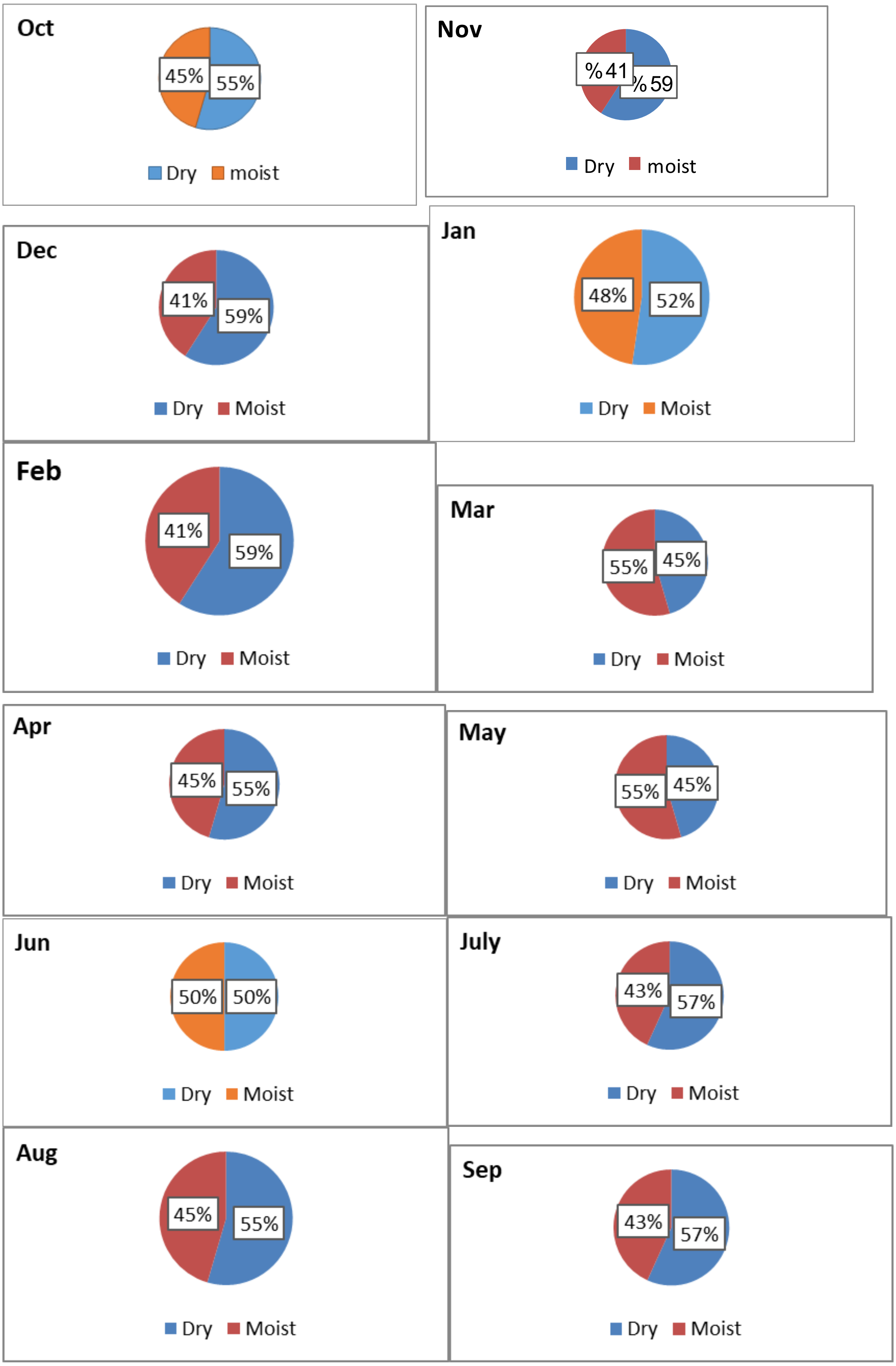

Figure 1. Dry - moist period distributions according to the monthly SPI values for the BARTINstation (No. 17020)Form 1965 to 2019.

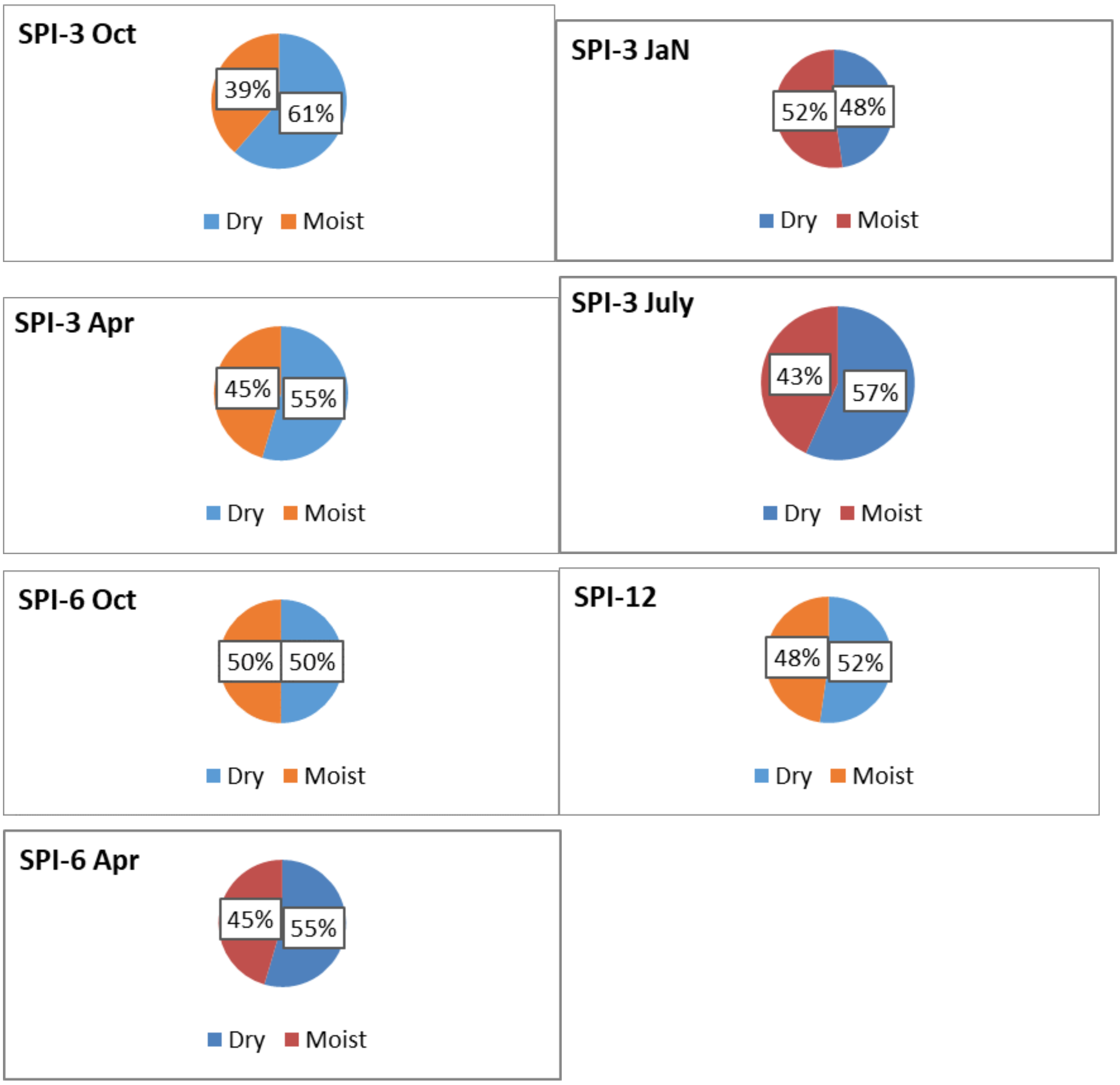

Figure 2. Dry - moist period distributions according to the 3,6,12month SPI values for the BARTINstation (No. 17020)Form 1965 to 2019

3.2.Kastamonu Precipitation Monitoring (17074)meteorological drought analysis (SPI)

SPI values were examined during periods 1, 3, 6, and 12 months using monthly total precipitation data measured continuously between 1965 -2019 of the Kastamonu station. Figure 3. and Figure 4 are shown the rates of monthly dryness and humidity 3-, 6-, and 12-months. In Figure 3.3, monthly dryness ranged between 52% and 73% according to SPI values. The highest dry period was 73% in Nov and 70% in Oct, with the lowest 52% dry period in Mar. The wet periods when analyzed were the period with a high moist of 69% in Dec, and the lows wet period was 5% in May. The periods of drought and moisture for each of 3-, 6-, and 12 months for the SPI values are shown in Figure 3.4. The driest periods with the highest SPI -3 values are SPI3-2 in Oct of 58%, and the lowest dry period is SPI3-3 Apr with 50%. For the two periods of SPI of every six months SPI-6, the dry period was SPI6-1 October and SPI6-2 April with 52%. SPI-12 calculated according to 12-month values dryness is 56%, and moisture is 44%.

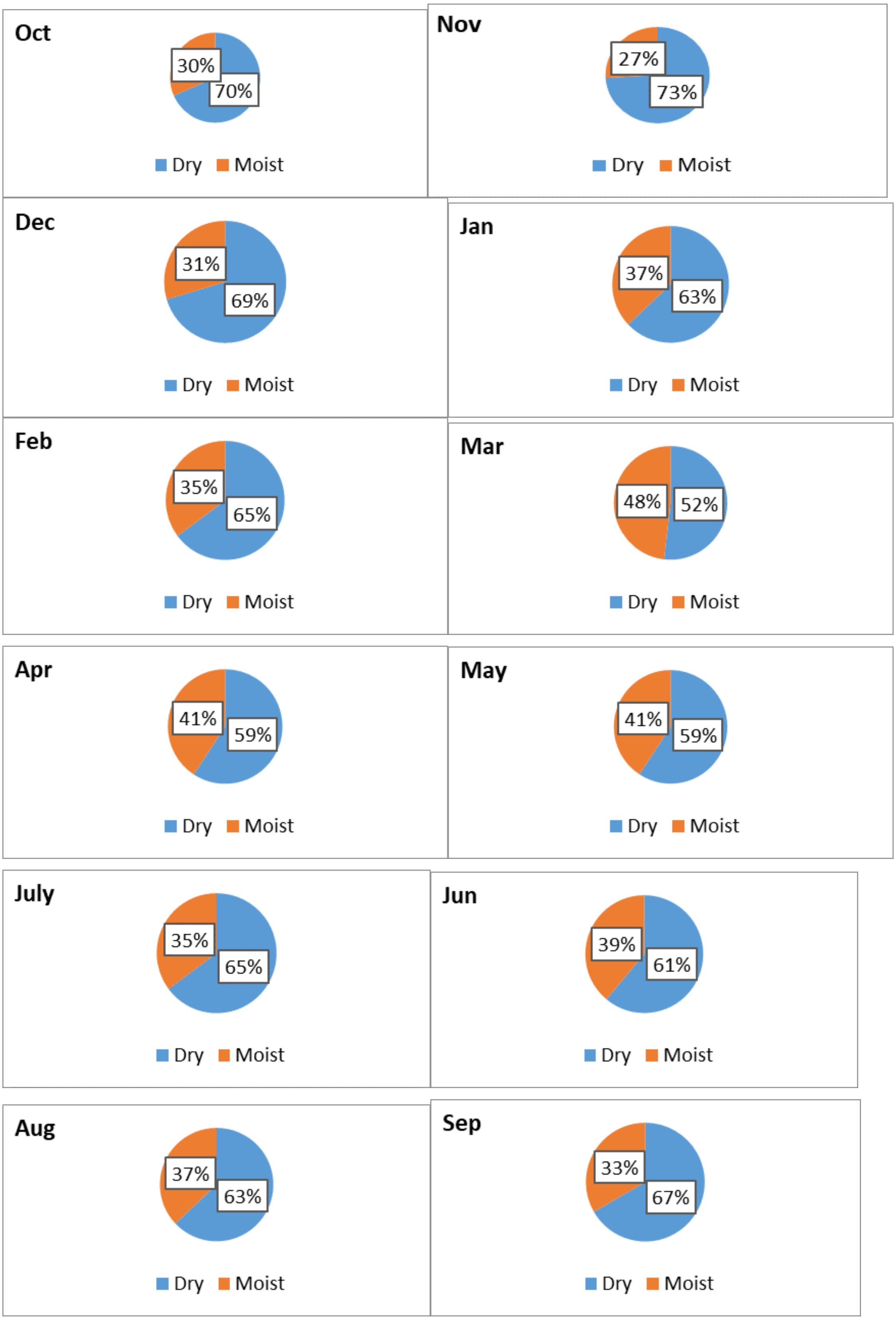

Figure.3. Dry - moist period distributions according to the monthly SPI values for the KASTAMONU station (No. 17074)Form 1965 to 2019.

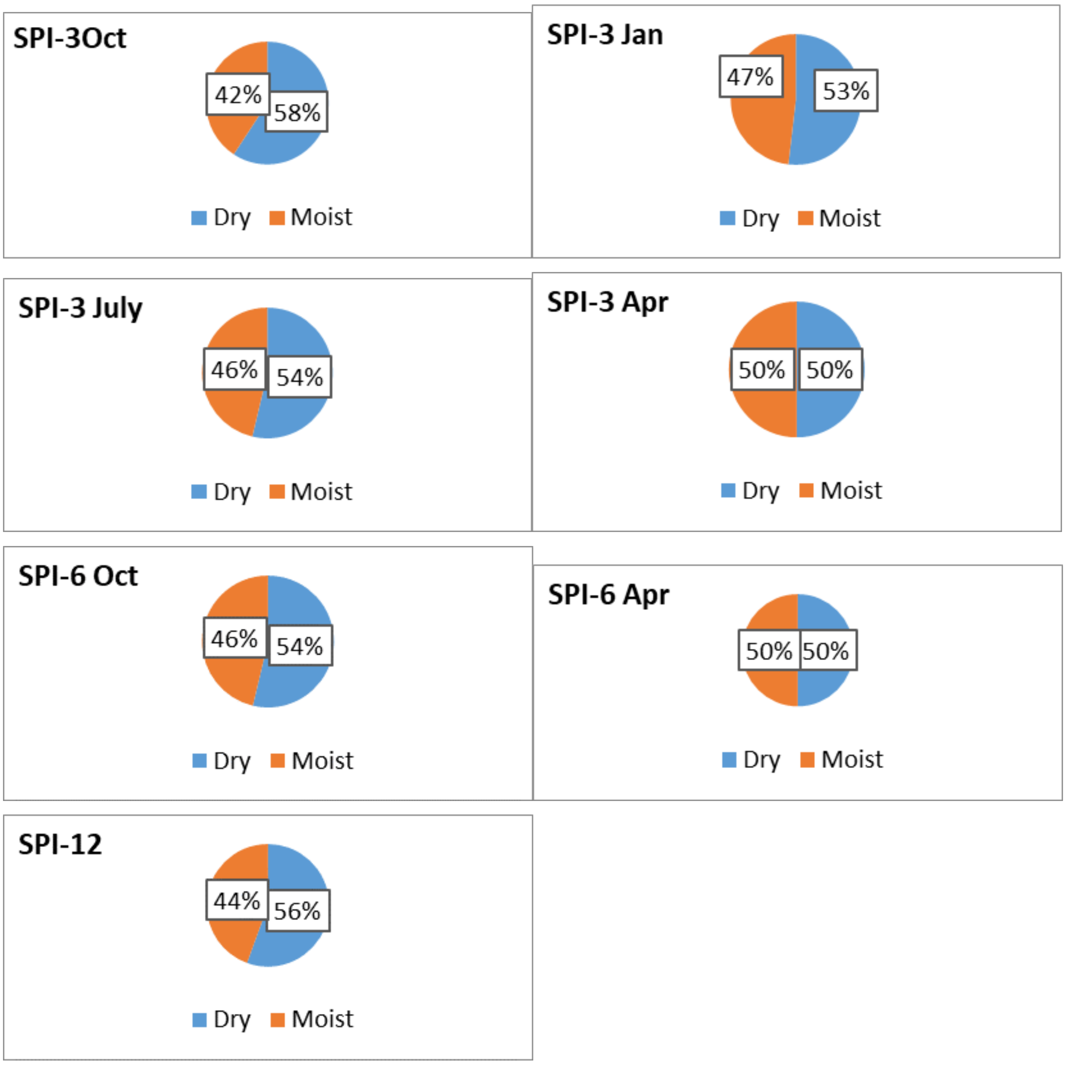

Figure 4. Dry - moist period distributions according to the 3,6,12month SPI values for the KASTAMONUstation (No. 17074)Form 1965 to 2019.

3.3.Sinop Precipitation Monitoring Station (17026)Meteorological Drought Analysis (SPI)

SPI values were examined during periods 1, 3, 6, and 12 months using monthly total precipitation data measured continuously between 1965 -2019 of the Sinop station. Figure 5 and Figure 6 are shown the rates of monthly dryness and humidity 3-, 6-, and 12-months. In Figure 3.5, monthly dryness ranged between 52% and 74% according to SPI values. The highest dry period was 74% in Nov and 70% in Dec, with the lowest 52% dry period in Mar. The wet periods when analyzed were the period with a high moist of 69% in Dec, and the lows wet period was 7% in May. The periods of drought and moisture for each of 3-, 6-, and 12 months for the SPI values are shown in Figure 3.6. The driest periods with the highest SPI -3 values are SPI3-1 in Oct of 59%, and the lowest dry period is SPI3-3 Apr with 50%. For the two periods of SPI of every six months SPI-6, the dry period was SPI6-1 October 54% and SPI6-2 April with 50%. SPI-12 calculated according to 12-month values dryness is 56%, and moisture is 44%.

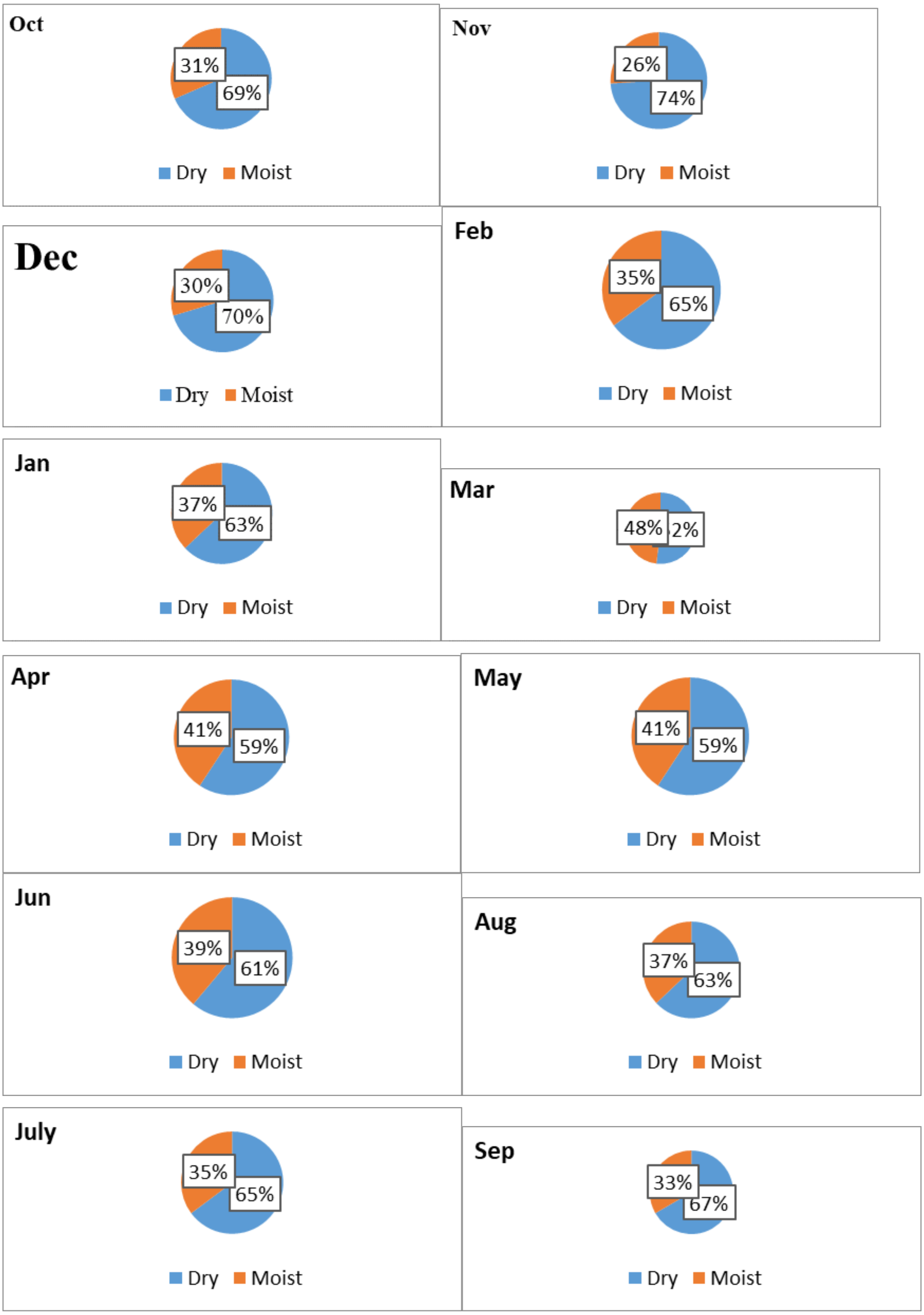

Figure 5. Dry - moist period distributions according to the monthly SPI values for the SINOP station No. 17026Form 1965 to 2019.

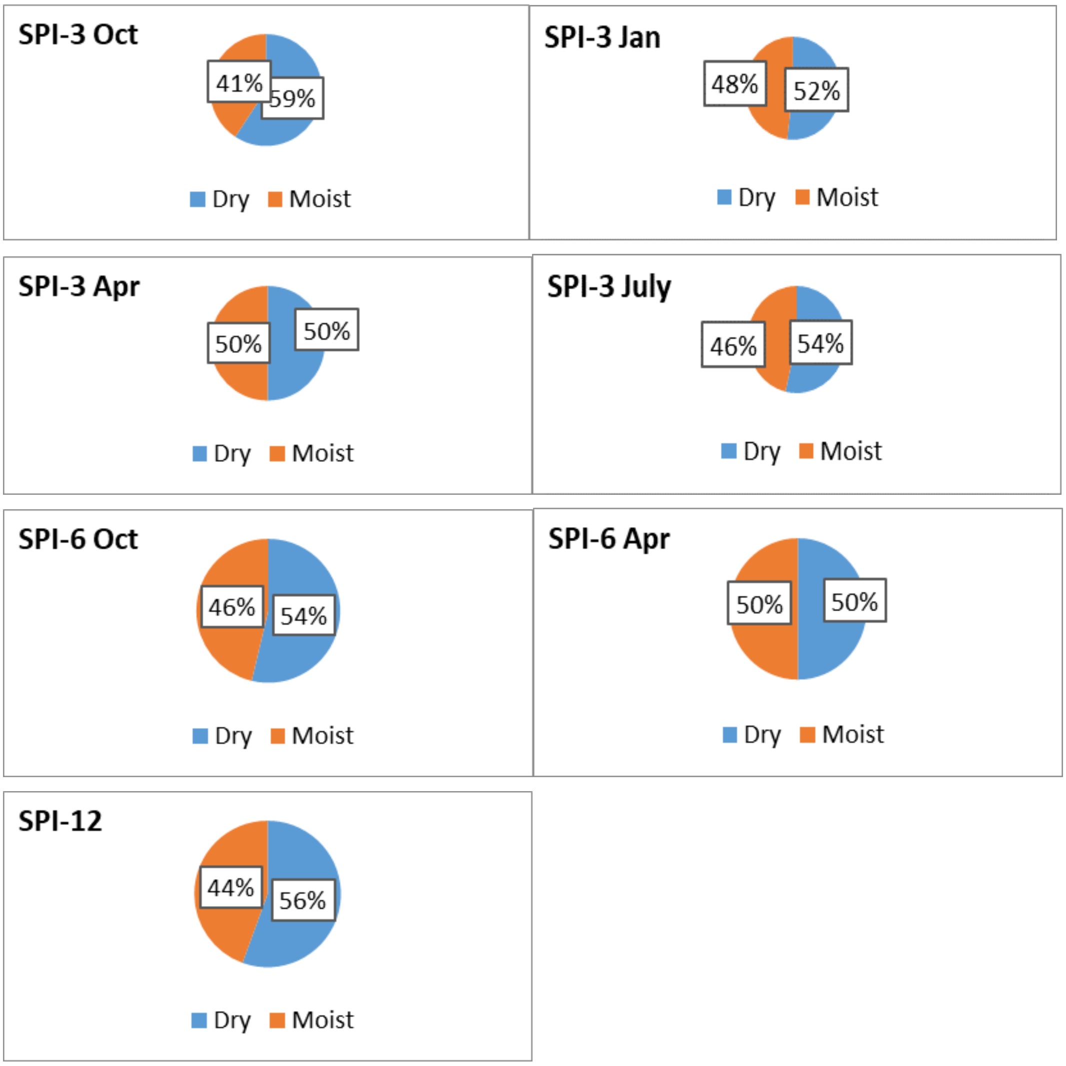

Figure 6. Dry - moist period distributions according to the 3,6,12month SPI values for the SINOP station (No. 17026)Form 1965 to 2019.

4. Conclusion

According to the precipitation efficiency index, the climate types in BARTIN are in the humid climate class, and there is no change. Work according to the evaluation of the temperature index on the basis of annual evaporation In the 54-year period between 1965 and 2019, the average-temperature climate type is observed quite consistently. Offers. The classification of drought index designed for rainy climates is generally in the summer period in BARTIN. One of the biggest impacts of global climate change occurs on precipitation, This is the case in some areas. While causing drought due to lack of precipitation; Some floods and overflow as a result of extreme rains in regions manifest itself. In this study, the climate The effect of the change in the West Black Sea Basin is innovative. It was investigated by the SPI method. This method is based on the precipitation of the basin, applied to the data. This precipitation data Obtained from the General Directorate of Meteorology Affairs. In the SPI analysis of all stations on a monthly basis, in Bartin station it is found that Dec, Nov, Feb is drier with 59% ratio and for Kastamonu station it was recorded that Nov was drier with 73%, at Sinop station it is discovered that Nov was drier than other months with 74%. In calculating SPI-3 for all stations based on the monthly rainfall data in SINOP station the highest value for drought in SPI3-1 Oct in 59% extremely dry, , and the highest value for BARTIN in SPI3-1 October In 59% exceptionally moist. Was in SPI3-4 July in 1985-1986 exceptionally moist. In calculating SPI-6 for all stations in

BARTIN station, the highest value of dryness and humidity is observed in SPI6-2 in Apr, the highest value of drought in 52% extremely dry and the highest value of humidity in 55 exceptionally moist; and the highest value of humidity is in the54% in Oct, exceptionally moist; in SINOP station, the highest value of drought was in SPI6-2 in April in the year 1983-1984 exceptionally dry. SPI-12 values range between 50-57% in all the mentioned stations.

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