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CHAPTER TWENTY TWO

DROUGHT ASSESSMENT OF THE KAZ MOUNTAINS AND THEIR SURROUNDING AREA (NOTHERN AEGEAN BASIN)

ERTAN TURGU AND ALI ÜMRAN KÖMÜŞÇÜ

Introduction

Drought is defined as deficiency in precipitation over an extended period of time, usually a season or more. In more comprehensive terms, drought can be defined as lack of precipitation over a certain period of time resulting in a water shortage causing adverse impacts on agricultural and water resources and adverse consequences on hydrologic balance (UNCCD, 1995). During drought events, water is insufficient to meet the demands of human activities and the environment. Therefore, not only quantity of the precipitation but also timing and effectiveness of the precipitation are important to define drought conditions over an area. Drought differs from other natural hazards in the sense that it has a slow-onset, and its impacts are non-structural and cumulative. Contrary to other hydrometeorological hazards, droughts can affect large areas which make assessment and response difficult. Droughts are not simply climate phenomena; in fact they have profound societal, economic and environmental consequences. Various drought types can be identified based on the environments they affect, including meteorological, agricultural, hydrological and socio-economic drought. Complexity of impacts and conflicts vary from meteorological drought to socio-economic drought.

Drought is a recurrent climate phenomenon for most parts of Turkey. As the climate of Turkey is characterized mainly by the Mediterranean macro-climate, it therefore has a highly seasonal precipitation regime in the western and southern parts (Türkeş, 2000). In this study, drought occurrences and trends of several locations in the Northern Aegean Basin (indicated by basin number 4 in Figure 22-1), which includes the Kaz

Mountains, are analysed based on SPI index for the last 3 decades. For this purpose, SPI index values to reflect intensity and occurrences of drought were computed using the precipitation data of Bozcaada, Edremit, Ayvalık, Dikili, Burhaniye and Bergama stations for the 1975-2009 period at 3, 6, 12 and 22-month time scales in the first part of the study. In the second part, SPI index series for the above mentioned stations were subjected to Mann-Kendall trend tests to determine temporal behaviour of the drought over the basin area.

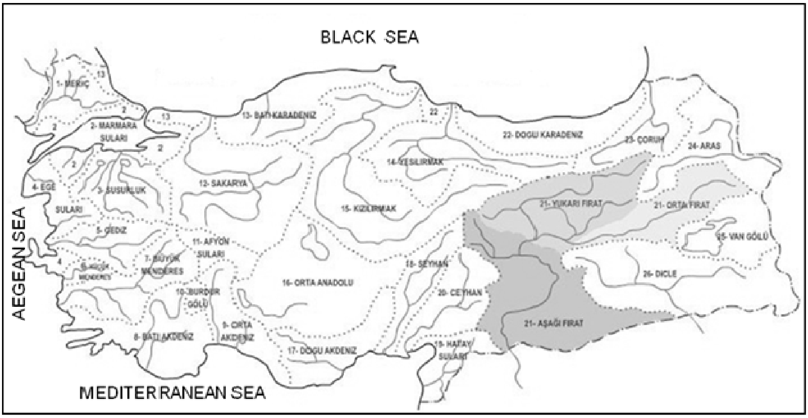


Fig. 22-1: Hydrological Basins of Turkey (source: www.eiei.gov.tr)

The Kaz Mountains have a unique geographical location. They have the second highest peak in the Marmara region. Geographically they are located in the border of Marmara and Aegean regions at North-western Anatolia. They form a natural border between the two regions (Fig. 22-2). The mountains are surrounded by Biga peninsula in the north and Edremit Bay in the south. Another uniqueness of the geographical position of the Kaz Mountains is that they are located at the cross section of European-Siberia and İran-Turan flora regions (Atalay, 1994). The area which includes the Kaz Mountains is in a transition zone between Mediterranean and Black Sea climates. Based on various climate classifications, the Kaz Mountains and the surrounding area are classified as semi-humid or humid with a lack of rain in summers (Türkeş, 2010). According to the Koppen-Geiger climate classification, the area is classified as mid-latitude temperate climate with hot summers. Mediterranean depressions and physical geographical factors determine the amount of precipitation over the region considerably (Kızılçaoğlu, 1995). The variation of the annual precipitation and its frequency and intensity are closely associated with frontal activities originating from the Mediterranean Sea. The climate of the coastal parts is less extreme than the inland, due to the fact that the effect of the sea-induced atmospheric humidity is always present there. Annual average rainfall varies from 466 to 641mm for the stations included in the analysis. Typically the driest period in the area is from May to October. The wintertime can bring snow occasionally, with temperatures dropping below zero especially at high altitudes of the area. Both the unique topographic and climate conditions allow growth of several endemic plants in the region as well. The Kaz Mountains are considered to be a part of the Northern Aegean basin from the hydrological standpoint. The Northern Aegean basin is very rich in surface and ground water resources.

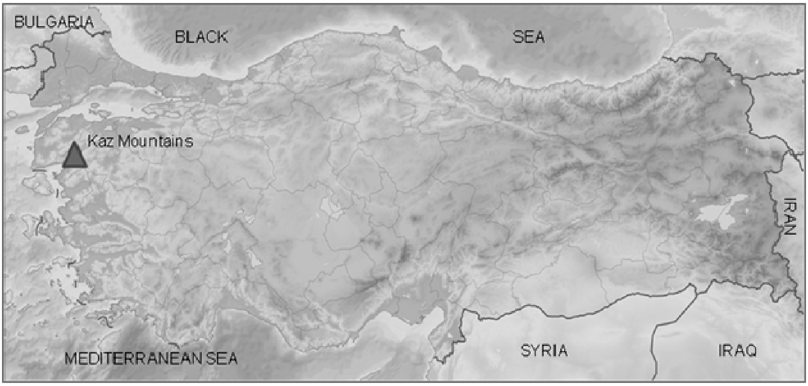


Fig. 22-2: Geographical location of the Kaz Mountains

Previous studies on drought in Turkey show that the country suffers from droughts at various intensity and durations, especially in the Central and South-eastern parts (Sönmez et al., 2005). Moreover, the same studies have also proven that even regions which receive high rainfall suffer from periodic droughts due to inadequate precipitation and varying precipitation regimes. Long-term rainfall trends indicate that annual and winter precipitation totals decrease at several locations, particularly in the Aegean and Mediterranean regions. As a result, severe and widespread dry conditions occurred periodically, especially in 1973, 1977, 1984, 1989, 1990, 1999 and 2007. Türkeş (1999) argues that variability of annual precipitation decreases from the southern part of the country, which is generally characterized by the Mediterranean rainfall regime, to the north where a uniform rainfall regime is dominant. Figure 22-3 shows long term temporal precipitation variations for the 6 stations located in the basin. Mainly four dry periods are identified in the series and the trends are upward during the last 3 years. Particularly 1989, 2000, 2006 and 2008 were the dominant dry years in the basin where almost all the stations experienced drought to some extent during those years.

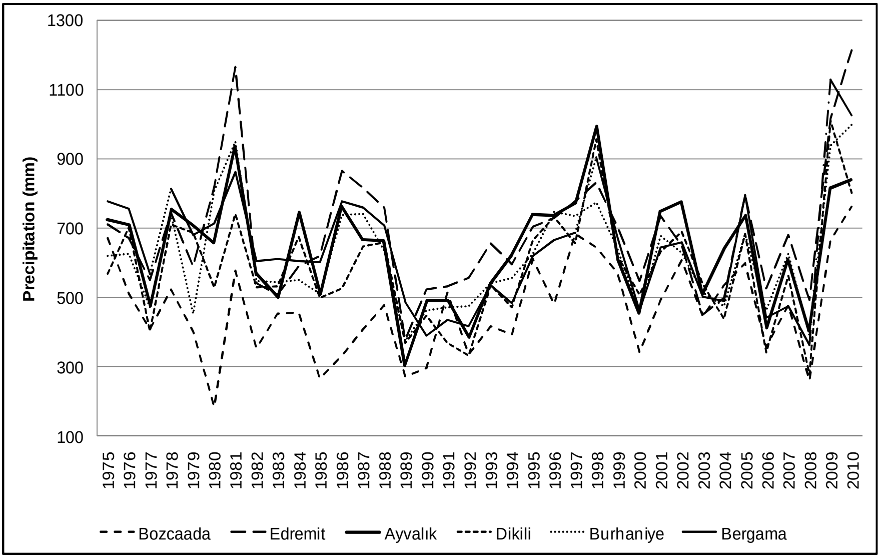


Fig. 22-3: Temporal variations of precipitation series for the selected stations.

Drought Analysis

Various approaches have been developed over the years to define and assess drought in an area. Typically using single or combined climate and hydrological parameters, drought indices based on climate and hydrologic parameters, and vegetation indices are the most common approaches to assess drought. Palmer Drought Severity Index (PDSI), Standardized Precipitation Index (SPI), Percent of Normal and Crop Moisture Index are typical drought indices that are commonly used in drought assessment. Usually, the complexity of the desired analysis and the data availability are the main factors in deciding which index to use.

The impact of precipitation deficiency on water resources varies on a temporal scale. While soil moisture responds to precipitation anomalies on a relatively short scale, most other water storages, such as groundwater, streamflow, and reservoir storage, reflect longer-term precipitation anomalies. McKee et al. (1993) developed SPI to quantify the precipitation deficit for multiple time scales to reflect impact of precipitation deficiency on different water suppliers. The different timescales (seasons) for which the index is computed (such as 3, 6, 12 and 22-month) are associated with different types of drought: the shorter seasons for agricultural and meteorological drought and the longer seasons for hydrological drought. Guttman (1998) argued that the SPI is better in comparison of drought for different regions. Analysis of extreme drought events showed that the SPI provided a better spatial standardization than the PDSI (Lloyd-Hughes and Saunders, 2002). Given the advantages of the index standardization, the SPI has been largely used operationally to monitor climate conditions worldwide.

SPI index values to reflect intensity and occurrences of past drought conditions were computed using the precipitation data of Bozcaada, Edremit, Ayvalık, Dikili, Burhaniye and Bergama stations located in the basin for the 1975-2009 period at 3, 6, 12 and 22-month time scales. Initially, more than 20 stations in the basin area were considered to be included in the drought analysis. However, quality check and minimum 30-year data series requirement for the SPI calculations limited the number of the stations used in the analysis to 6 (Fig. 22-4). Bozcaada station was treated as part of the Northern Aegean basin although it is located outside the actual basin boundaries.

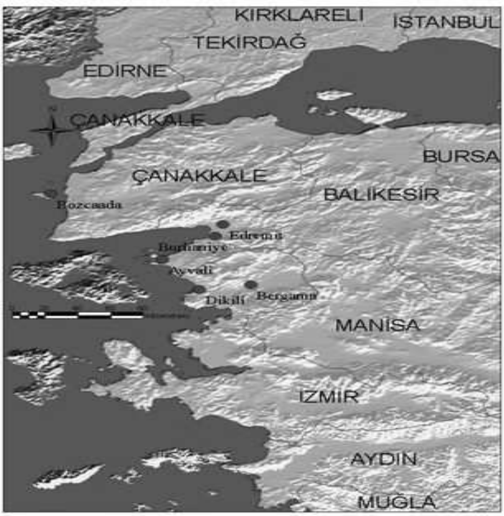


Fig. 22-4: Locations selected for the drought analysis

Methodology

In first part of the study, SPI index values were computed to reflect intensity and occurrences of drought using the precipitation data of Bozcaada, Edremit, Ayvalık, Dikili, Burhaniye and Bergama stations located in the basin for the 1975-2009 period at 3, 6, 12 and 22-month time scales. The computations are handled by software developed at the Turkish State Meteorological Service in Delphi based on the SPI methodology described by McKee and others (1993).

Calculation of the SPI

The SPI computation is based on the long-term precipitation data for the desired time scale. Simply, it is calculated by taking the difference of the precipitation from the mean for a particular time scale and then dividing it by the standard deviation.

$$SPI = \frac{x_i - \bar{x}_i}{\sigma} \qquad (1)$$

The SPI is a dimensionless index where negative values indicate drought and positive values wet conditions respectively. To compute the SPI index, first a long-term time series of precipitation is generated and then the long-term data are fitted to a gamma probability density function to a given frequency distribution of precipitation totals for a station. The gamma probability density function parameters are estimated for each station, for each time scale of interest (3 months, 12 months, 48 months, etc.) and for each month of the year. The resulting parameters are then used to determine the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. At the last stage of the computations, the cumulative probability is transformed to the standard normal random variable Z with zero mean, and variance of one. The more detailed computation of the SPI may be found in Guttmann (1998). McKee et al. (1994) defined the criteria for a "drought event" for any of the time scales and classified the SPI to define various drought intensities (Table 22-1).

The monthly precipitation time series are modelled using different statistical distributions. The probability distribution function is determined from the long-term record by fitting a gamma function to the data. The gamma distribution is defined as:

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

where α is a shape parameter, β is a scale parameter and x is the precipitation amount. Γ(α) defines the gamma function. Detailed procedures of the calculation of the above parameters can be found in Guttmann (1998) and Lloyd-Hughes and Saunders (2002).

Table 22-1: Drought Categories defined for SPI values

SPI Values	Drought Category
0 to -0.99	mild drought
-1.00 to -1.49	moderate drought
-1.50 to -1.99	severe drought
≤ - 2.0	extreme drought

Integrating the probability density function with respect to x and inserting the estimates of α and β yields an expression for the cumulative probability G(x) of an observed amount of precipitation occurring for a given month and time scale:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \qquad (3)$$

Since the gamma distribution is undefined for x = 0, and q = P(x = 0) > 0 where P(x = 0) is the probability of zero precipitation, the cumulative probability becomes

$$H(x) = q + (1-q)G(x) \qquad (4)$$

The cumulative probability distribution is then transformed into the standard normal distribution to obtain the SPI values at the desired time scale.

Mann-Kendall Trend Test

In second part of the study, the long-term SPI drought series for the selected stations were subjected to Mann-Kendall trend test to determine trends in the series. The Mann-Kendall test is a non-parametric test for identifying trends in a time series data. It is commonly used to identify trends in hydrological time series (Yue et al., 2002). The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). One advantage of the test is that the data do not need to have any particular distribution.

The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (i.e., no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The overall result of all such increments and decrements yields the final value of S.

Let 1 x , 2 x , … n x represent n data points where j x represents the data point at time j. Then the Mann-Kendall statistic (S) is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}\left(x_j - x_i\right) \qquad (5)$$

where

$$\mathrm{sgn}\,(x_j - x_\mathrm{i}) = \begin{cases} 1 & ;\ x_j > x_i \\ 0 & ;\ x_j = x_i \\ -1 & ;\ x_j < x_i \end{cases} \qquad (6)$$

A very high positive value of S indicates an increasing trend while a very low negative value is associated with a decreasing trend. A further step is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend detected.

Kendall (1975) describes a normal-approximation test that could be used for datasets with more than 10 values, provided there are not many tied values within the data set. At the first step, S is calculated as described in Equation 5. Then the variance of S, Var(S), is calculated by the following equation:

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{g} t_p (t_p - 1)(2t_p + 5)}{18} \qquad (7)$$

where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and tp is the number of data points in the pth group. In the sequence {2, 3, non-detect, 3, non-detect, 3}, we have n=6, g =2, t1 =2 for the non-detects, and t2 =3 for the tied value 3. Next step is to compute a normalized test statistic Z as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & ;\ S > 0 \\ 0 & ;\ S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(S)}} & ;\ S < 0 \end{cases} \tag{8}$$

Then the probability associated with this normalized test statistic is computed. The probability density function for a normal distribution with a mean of 0 and a standard deviation of 1 is given by the following equation:

$$f\,(Z) = \frac{1}{\sqrt{2\pi}} e^{\frac{z^2}{2}} \tag{9}$$

A negative Z refers to decreasing trend if the computed probability is greater than the level of significance. The trend is said to be increasing if the Z is positive and the computed probability is greater than the level of significance. If the computed probability is less than the level of significance, it is concluded that there is no trend.

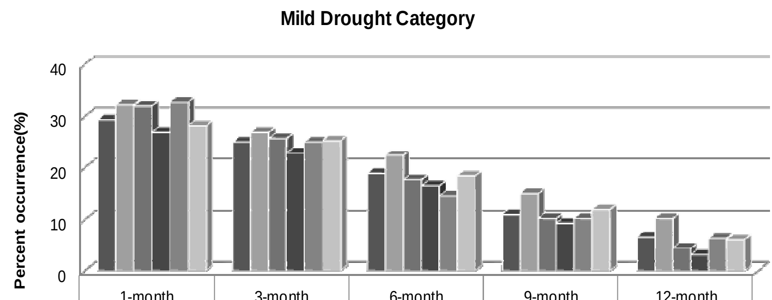
Partal and Kahya (2006) applied Mann-Kendall to the regional rainfall series and found significant decreasing trends in the months of January, February and September. They also concluded that the annual precipitation exhibited decreasing trends in coastal parts of the country on a regional basis.

Drought Occurrences

Drought occurrences at the selected 6 sites have been investigated based on the frequency of the events for each drought category at multiple-time scales for the 1975-2009 period. In this study, the 1-3 month SPI is associated with representation of short-term droughts, known as meteorological drought. On the other hand, 6-9 month SPI characterizes agricultural drought, and finally 12-month and longer time scale SPI represents hydrological drought (Serrano and Moreno, 2005).

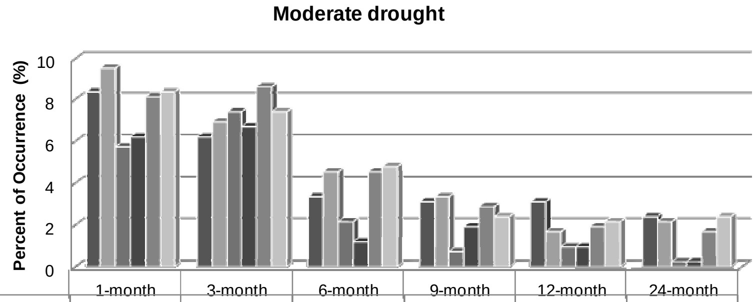
Analysis of Drought Occurrences for Mild Droughts

Drought occurrences over the Northern Aegean basin indicate that the mild droughts tend to occur in Edremit and Burhaniye at high frequencies at 1-month time scale while other coastal stations are characterized with the lowest frequencies at the same temporal scale. Figure 22-5 shows percentage of drought occurrences for short term droughts at 1-3 month time scale and indicates that the drought occurrences vary between 23% and 33%. As the time scale increases to 12 months, percentage of drought occurrence decreases down to 3%. The drought occurrence varies between 9.5% and 22.5% for medium term droughts (6-9 month time scale). On the other hand, they reach almost 10% for long term droughts (12-month and longer time scales). Overall Edremit and Burhaniye are the most effected settlements from meteorological droughts.



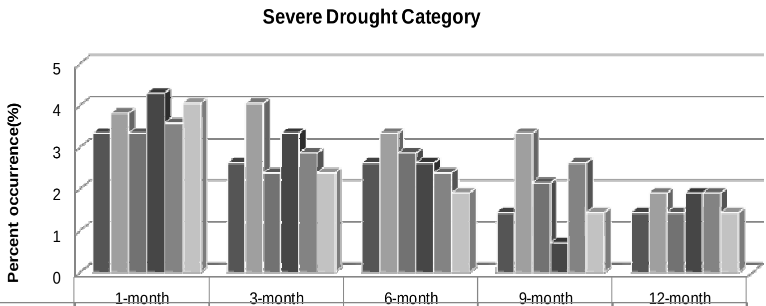
	1-month	3-month	6-month	9-month	12-month
Bozcaada	29	25	19	11	7
Edremit	32	27	22	15	10
Ayvalık	32	26	18	10	5
Dikili	27	23	16	9	3
Burhaniye	33	25	15	10	6
Bergama	28	25	18	12	6

Fig. 22-5: Percentages of mild drought occurrences at 1, 3, 6, 9, 12 and 22-month time scales (SPI values between 0.0 and -0.99)



	1-month	3-month	6-month	9-month	12-month	24-month
Bozcaada	8	6	3	3	3	2
Edremit	10	7	5	3	2	2
Ayvalık	6	7	2	1	1	0
Dikili	6	7	1	2	1	0
Burhaniye	8	9	5	3	2	2
Bergama	8	7	5	2	2	2

Fig. 22-6: Percentages of the moderate drought occurrences at 1, 3, 6, 9, 12 and 22-month time scales (SPI values between -1.0 and -1.49)



	1-month	3-month	6-month	9-month	12-month
Bozcaada	3	3	3	1	1
Edremit	4	4	3	3	2
Ayvalık	3	2	3	2	1
Dikili	4	3	3	1	2
Burhaniye	4	3	2	3	2
Bergama	4	2	2	1	1

Fig. 22-7: Percentages of the severe drought occurrences at 1, 3, 6, 9, 12 and 22-month time scales (SPI values between -1.5 and -2.0)

Analysis of Drought Occurrences for Moderate Droughts

Percentages of moderate drought occurrences for short term, medium term, and long term droughts are 6-9.5%, 1-5%, and 0-3% respectively at the selected stations (Fig. 22-6). At this category, Edremit is exposed to moderate drought compared to most of the other locations. Edremit, Burhaniye and Bergama are especially exposed to agricultural drought. Edremit particularly has maximum drought occurrences in all time scales. On the other hand, Dikili experiences the least drought occurrences in all time scales.Analysis of Drought Occurrences for Severe Droughts

Drought occurrences in this category indicate that severe drought occurrences at multiple-time scales have generally the lowest values (Fig. 22-7). There is usually 1 every 50 years and the results indicate that the severe drought is not likely effective in the region. Dikili and Bergama are characterized with higher severe drought occurrences than the others for 1-month time scale. Edremit suffers from both agricultural and hydrological droughts at medium time scale (Fig. 22-7).

Table 22-2: Stations identified with highest occurrences at moderate, mild and severe drought categories

Mild	**Bozcaada**	**Edremit**	**Ayvalık**	**Dikili**	**Burhaniye**	**Bergama**
1-month					✓	
3-month		✓				
6-month		✓				
9-month		✓				
12-month		✓				
24-month		✓				
Moderate						
1-month		✓				
3-month					✓	✓
6-month						✓
9-month		✓				
12-month	✓					
24-month	✓					
Severe						
1-month				✓		
3-month		✓				
6-month		✓				
9-month		✓				
12-month		✓		✓	✓	
24-month						

The overall results indicate that Edremit has the highest rate, especially at moderate and severe drought occurrences among all the stations (Table 22-2).

Trend Analysis

In the second part of the study, the Mann-Kendall test is used to analyse temporal and spatial trends in the SPI index values for the selected time scales (Table 22-3). Dikili, Burhaniye and Bergama are mostly characterized by a decreasing trend for long term droughts, whereas Bozcaada indicates increasing trends. Burhaniye and Bergama present decreasing trends for medium term droughts, while Bozcaada demonstrates increasing trends. There are no trends found at 1 month time scale. Interestingly, Edremit did not indicate any significant trends at any time scale. It is observed that in general the observed droughts tend to portray decreasing trends as the time scale increases.

Table 22-3: Mann-Kendall trend test results implemented at 1, 3, 6, 12 and 24-month time scales.

Station	**SPI-1**	**SPI-3**	**SPI-6**	**SPI-12**	**SPI-24**
Bozcaada	no trend	increasing	increasing	increasing	no trend
Edremit	no trend	no trend	no trend	no trend	no trend
Ayvalık	no trend	decreasing	no trend	no trend	no trend
Dikili	no trend	no trend	no trend	no trend	decreasing
Burhaniye	no trend	no trend	decreasing	no trend	decreasing
Bergama	no trend	no trend	decreasing	decreasing	no trend

Results

Overall, the results indicate that the Northern Aegean basin was under influence of mild droughts during the last three decades. Severe and very severe drought occurrences were relatively uncommon in the region. Nevertheless, coastal stations such as Burhaniye and Edremit are likely to be influenced by drought at higher frequencies as compared to the inner locations. Mann-Kendall trend analysis for the stations at different time scales indicated that Dikili, Burhaniye and Bergama stations experienced decreasing drought trends at longer time scales (12 and 22-month). Bozcaada station was noted to display increasing trends at short time scales. No significant trends were observed at 1-month time scale in any of the stations across the basin.

Both agricultural and hydrological droughts have been noted in the basin area since 1970s. The drought also portrayed varying trends in the region. Dikili, Burhaniye and Bergama are mostly characterized by decreasing trends for long term droughts, whereas Bozcaada is characterized by increasing trends. Edremit did not indicate any significant trends at any time scale. As the time scale increased, in general the drought conditions tended to portray decreasing trends.

Rainfall variations in western parts of Turkey are highly related to cyclonic activities originating from the Mediterranean Sea. Therefore, seasonal droughts observed over the basin area are closely connected to timing, intensity and frequency of such cyclonic activities. This matter requires further research.

Certainly the drought can have adverse impacts especially for the agricultural activities in the basin area. Therefore, it is important to take timing and degree of dryness into consideration in planning the agricultural activities at irrigated and non-irrigated fields of the basin. Lack of moisture conditions associated with the observed drought in the region can make the natural and socio-economic system of the Kaz Mountains and the surrounding area more vulnerable to projected changes in climate. Therefore drought variability in the area should be considered as part of land-use management, regional planning, forestry and agricultural activities in the area, especially in light of the expected climate change in the future.

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