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Drought analysis with SPI index and entropy

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Abstract: Drought is a natural disaster adversely affecting the survival and economy of the living organisms. Drought is related with many factors including climate and regional properties. Many different measures are used to determine drought. The goal of this study is the investigation of the Meteorological drought in Central Anatolian Region in Turkey. In the presented study, the Standard Precipitation Index and the Apportionment Entropy (AE) method are investigated and compared. For this purpose, observations of 13 meteorological stations located in Central Anatolia Region by The Turkish State Meteorological Service (DMİ) are evaluated. The results of the study contributed to the identification of drought parameters and consequently the missing information and data on this subject were completed. The entropy method provided similar results to the results obtained by other methods widely used in the literature regarding the data for the Central Anatolia Region. The entropy method was determined to yield similar results to that of the SPI method as indicated by the comparison of the relative frequencies of the severity of drought in the regional stations. Therefore, the method can be proposed as a method to be used in long-term drought calculations and regional drought calculations. The results of the present study showed that entropy method can be an alternative to be used in the analysis of drought.

Key words: Drought, Drought parameters, Entropy, SPI index

1. INTRODUCTION

Drought is a persistence period of water deficit and adversely affects the survival and economy of the living organisms. It is initiated by a significantly reduced precipitation at a local region within a definite time period and is intensified by the effect of other climatic factors such as high temperatures, high wind speed and low moisture content (Sırdaş and Şen, 2003; Chen et al., 2009; Fontaine and Steinemann, 2009). The severity and intensity of drought is expected to increase with deteriorating climate conditions, increasing population and water demand, destruction of the natural vegetation and desertification and reaches such a magnitude as to threaten human kind (Kallis, 2008). Drought adversely influences the ecosystem, agriculture and the environment.

Prevention of drought requires carrying out a detailed basin specific analysis and monitoring of the area closely. Different drought severity parameters based on single or multiple variables were proposed by researchers in order to define drought as well as to identify the interactions between drought and hydrological/meteorological events (e.g. Palmer, Erinc, Standard Precipitation Index or De Martonne, Thornthwaite methods). Methods such as trend analysis or statistical/stochastic evaluations and entropy were also used as alternative approaches for defining and investigating drought in addition to the previously mentioned indices.

Developing an accurate index for drought is difficult due to the complexity of the relationships between hydro climatic variables and drought. The indices that were proposed for the analysis of drought are mainly based on water budget calculations and they consider one type of drought, meteorological, hydrological or agricultural.

The Standard Precipitation Index (SPI) is a measure of precipitation deficit and it has found widespread use because it is based on the probability of precipitation at different time scales (Mckee et al., 1993; 1999). SPI is computationally simple to calculate and on-going research focuses on the improvement of the application of both SPI and PDSI (Keyantash and Dracup, 2002;

Wu et al., 2001, 2005). SPI has been widely used for monitoring drought in many regions (Vicente-Seriano et al., 2004; Cancelliere et al., 2007; Raziei et al., 2009; Liu et al., 2012; Zhang et al., 2012; Mallya et al., 2016).

Entropy (Shannon, 1949) is a measure of dispersion, uncertainty, disorder and diversification. Therefore, an entropy-based approach becomes useful for evaluating variability patterns of spatial and temporal precipitation (Mishra et al., 2009). This study investigates the applicability of entropy as a novel measure of drought based on long-term precipitation data collected from a number of stations in the Central Anatolian Region. For this purpose, the drought parameters determined based on the apportionment entropy values for Central Anatolia were compared with the Standard Precipitation Index.

2. THE STUDY AREA AND AVAILABLE DATA

Turkey has been separated into seven major geographic regions. The Central Anatolian Region occupies 19% of the total area of Turkey with its 151.000 square kilometers of land, it's the second largest region of Turkey after Eastern Anatolia. The Central Anatolian Region is divided into four sections, Upper Kızılırmak Basin, Middle Kızılırmak Basin Upper Sakarya Basin and Konya Basin. The climate of the Central Anatolian region is a steppe climate, with a great temperature difference between day and night. Rainfall is low and there is more snow in the winter. The average temperature is about 23°C in summer and -2°C in winter. Annual mean temperature is 10.8°C. Mean annual precipitation is 413.8 mm and most of the precipitation is in winter and spring seasons. Seasonal distribution of rainfall is as follows: Spring 36%, winter 28%, autumn 19%, summer 17% (DMI, 2009; Bacanlı et al., 2011).

In this study, the meteorological stations are evaluated to define meteorological drought. The meteorological stations which are managed by DMI (State Meteorological Service) and DSI (State Hydraulic Works) are pre-evaluated for available long term precipitation and temperature data. The drought analyses have been performed on Aksaray, Ankara, Çankırı, Eskişehir, Karaman, Kayseri, Konya, Kırıkkale, Kırşehir, Nevşehir, Niğde, Sivas and Yozgat meteorological stations. The evaluated records are observed in the 1965 - 2014 period.

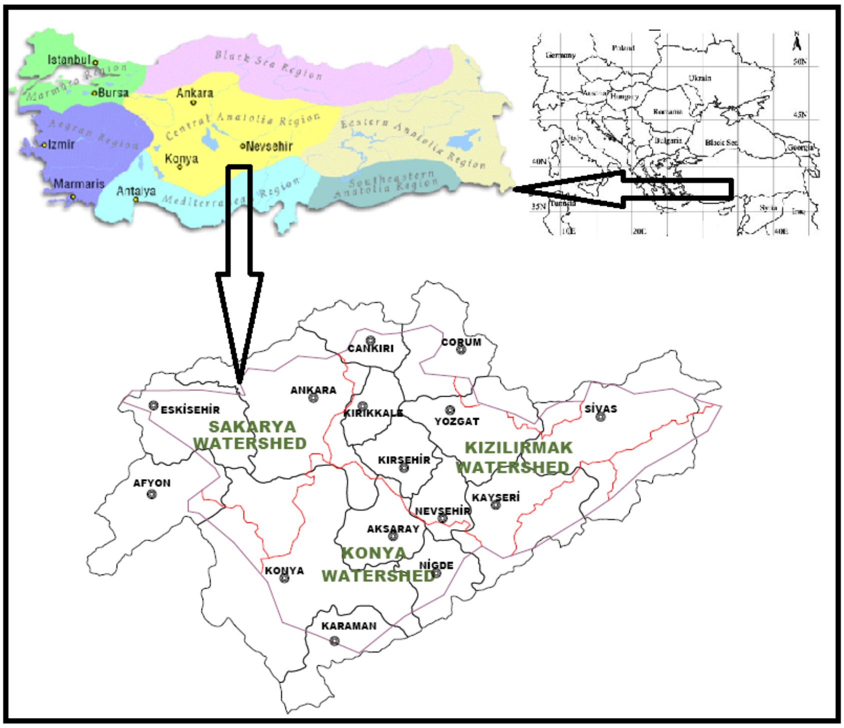

Figure 1. Central Anatolian Region

3. IDENTIFICATION OF THE SEVERITY OF DROUGHT

3.1 Entropy method

The concept of entropy is derived from classical thermodynamics and probability. The word "Entropy" was derived from "transinformation" by Classius. Boltzmann later characterized it as the "number of microscopic states of the particles making up a portion of the material" and stated that "all these portions appeared similar to the main macroscopic body" (Wehrl, 1978; Schrader, 2000).

Shannon showed that the concept of entropy could be used to describe the extent of disorder in a system following the notion established by Boltzmann (Shannon and Weaver, 1949).

Entropy finds itself an extensive area of application in water resources engineering and in many other subjects. Entropy is defined as the measure of the uncertainty that the hydrologic processes of random character embody and described as the information gained by observations = overcome uncertainty in water resources engineering applications. Owing to this attribute, the concept of entropy is used as an indirect measure of information content. The concept of entropy has application areas in many different aspects of hydrology and water resource studies including the identification of uncertainty in hydrological processes, information transfer between hydrological processes, planning of the measurement network, optimization and decision making theory. The concept of statistical entropy is used in these applications to overcome and account for the uncertainty in the systems or in the data content. The versatile application areas of entropy in hydrology and water resource problems were discussed extensively by Singh (1997, 2003).

Random variable entropy is a measure of the attained information or the overcome uncertainty. Information content, joint information, conditional information and transferred information concepts were described as marginal entropy H(X), joint entropy H(X,Y), conditional entropy H(X/Y) and transinformation T(X,Y), respectively (Karmeshu and Pal, 2003):

$$H(X) = -\sum_{i=1}^{n} p(x_i)\log p(x_i) \tag{1}$$

$$H(X,Y) = -\sum_{i=1}^{n}\sum_{J=1}^{m} p(x_i, y_j)\log p(x_i, y_j) \tag{2}$$

$$H(X|Y) = -\sum_{i=1}^{n}\sum_{J=1}^{m} p(x_i, y_j)\log p(x_i|y_j) \tag{3}$$

$$T(X,Y) = -\sum_{i=1}^{n}\sum_{J=1}^{m} p(x_i, y_j)\log\left(\frac{p(x_i, y_j)}{p(x_i)p(y_j)}\right) \tag{4}$$

where x and y in the statements are stated as two independent variables defined in the same probability space as that of x_i *(i*= 1, 2,…,*n* and y_j *j*= 1,2, …, *m)* while $p(x_i)$, $p(x_i,y_j)$ and $p(x_i|y_j)$ are defined as the discrete, point and conditional probabilities, respectively (Baran and Bacanlı, 2007).

3.2 Apportionment Entropy (AE)

Because the concept of entropy could be defined as the overcome uncertainty = attained information, this concept is thought to be a measure of determining how much information can be gained from a measured parameter. The apportionment entropy values for daily precipitation that were described by Kawachi et al. (2001) were also used by Maruyama et al. (2005) in a study regarding monthly precipitation.

The initial step in the calculation of apportionment entropy (AE) is the computation of the R value by consecutively adding the daily/monthly precipitation values (r_i):

$$R = \sum_{i=1}^{12} r_i \tag{5}$$

R value can only be determined through the use of annual monthly mean precipitation or temperature data and can be represented as the sum of r_i where I = 1 to i = 12. r_i is the sum of the monthly mean precipitation or temperature values on the i^{th} month of the year.

Finally, the apportionment entropy (AE) could be described as below by defining the probability of the occurrence of (r_i/R) as described in Equation 5:

$$AE = -\sum_{i=1}^{12} (r_i / R) \; \log_2 (r_i / R) \qquad \text{(bit)} \tag{6}$$

The entropy values are independent of the order of r in the series. Therefore, AE could be used to measure the change in precipitation and/or temperature. Unless a frequency is defined for precipitation, the entropy value (AE) could be zero. A uniform (equal) distribution of entropy across months would maximize the entropy value (AE).

Using the values from the same station for m years, a mean entropy ($\overline{AE}$) can be predicted using the annual total precipitation and monthly mean temperature data.

$$\overline{AE} = (1/m) \sum^{m} AE \quad \text{(bit)} \tag{7}$$

where $\overline{AE}$ is the mean entropy.

The previous works of Bacanlı et al. (2009, 2011, 2012) on AE produced similar results with other drought indices showing that AE can be used as a drought index. AE indicates the process of drought when it is used as a drought index. AE might perform cyclic behaviour at station scale when it is used on all existing observations. In the present study, the AE values are standardized and classified as shown in Table 1.

Table 1. Classification of the drought index of apportionment entropy

Apportionment Entropy - AE	Classification
≥ 1.1	Extremely Wet (W3)
1.1>Z ≥ 1.05	Wet (W2)
1.05>Z ≥ 1.03	Moderately Wet (W1)
1.03>Z ≥ 1.0	Normal (N)
1.0>Z ≥ 0.98	Moderate Drought (D1)
0.98>Z ≥ 0.95	Drought (D2)
0.95>Z ≥ 0.9	Extreme Drought (D3)
0.9>Z	Maximum Extreme Drought (D4)

3.3 Standard Precipitation Index (SPI)

SPI method is used commonly to monitor the drought. The SPI was developed by McKee et al. (1993). Seasonal (3, 6-month time scale) or long period (9, 12, 24, 48-month time scale) drought can be analyzed. Underground water, rivers and reservoirs do not respond rapidly to swift precipitation changes. Therefore, 12-month or long period time scale (24, 48, 72-month) monitoring is chosen. There are lots of studies about Standardized Precipitation Index for monitoring drought all around the world like McKee et al. (1993), Edwards and McKee (1997), Guttman (1999), Türkes (1999), Kömüscü (2001), Lloyd-Hughes and Saunders (2002), Tonkaz (2006), Li et al. (2008), Abolverdi and Khalili (2010) and Keskin and Sorman (2010).

The SPI is the non-dimensional drought index. This index is computed for long time precipitation series for the preferred time scales. The SPI calculated by Equation 8.

$$SPI = \frac{x_i - \mu}{\sigma} \tag{8}$$

where: SPI, standardized precipitation index; X_i, data point; μ , mean; σ , standard deviation of the data.

The gamma distribution is convenient for precipitation series and the distribution parameters can be calculated by maximum likelihood approximation of Thom (1958). If precipitation data has zero values, mixed distribution by Thom (1951) can be used for incorporation of zero probability and non-zero probabilities (Equation 9).

$$H(x) = q + (1-q)\,G(x) \tag{9}$$

where: q, the probability of zero precipitation; G(x), the gamma cumulative probability function. Probabilities calculated by Equation 2 are transformed into the standard normal distribution for calculation of the SPI values (Guttman, 1998; Abolverdi and Khalili, 2010).

SPI method shows the drought category corresponds to output values (Table 2). If the SPI gives negative values, it means there is drought and lack of precipitation; if the SPI gives positive values, it means there is no drought and enough precipitation. Yet, the negative values are getting lower, the degree of the drought shifts from no drought to extremely drought and then catastrophe bursts. And same for the positive values, if the positive values are getting higher.

Table 2. Standardized precipitation index categories (McKee et al.,1999).

SPI index values	Drought Category
≥ 2	Extreme Wet
1.50 ~ 1.99	Severe Wet
1.00 ~ 1.49	Moderate Wet
0.99 ~ 0	Normal
0 ~ -0.99	Mild Drought
-1.00 ~ -1.49	Moderate Drought
-1.50 ~ -1.99	Severe Drought
≤ - 2	Extreme Drought

4. APPLICATION

In the present study, the Standard Precipitation Index and the Entropy method were used on the data collected from all of the precipitation stations in the Central Anatolian Region. Monthly precipitation observations were used. A tendency of decrease in precipitation data was determined throughout the region for the months November, December, February, March and April.

Time periods of 1, 3, 6, 9, 12 and 24 months in the calculation of the Standard Precipitation Index (SPI) were taken into consideration. These time periods were selected subjectively. They would roughly represent the time until the effect of a decrease in precipitation could be observable on the usable water resources.

In this study, every station in the Central Anatolian Region was evaluated based on these SPI and Entropy classifications. Relative frequencies were also calculated. Results from selected stations are displayed in Tables 3 and 4. Evaluation of the SPI and Entropy classifications calculated for different time periods in the region did not indicate the presence of any significant change in terms of the stations with regards to the ratio of the dry and wet periods.

The results of the Standard Precipitation Index (SPI) analysis indicated that a significant change could not be observed in terms of the ratios of the dry, normal or wet periods of a single station. However, near-normal or mild droughts were more frequently encountered in short-term periods (3-6 months) whereas severe and very severe drought was observed during longer-term time periods (12-24 months). The drought ratios of the stations under investigation in the Central Anatolian Region were determined to vary drought ratios between 55% and 15%, the wetness ratios between 63% and 13% based on their SPI and Entropy indices.

Table 3. The drought (DR) ratios (%) of the SPI and Entropy values of several stations in the Central Anatolian Region for time periods of 3, 6, 9, 12 and 24 months

	Entropy	1 Month	3 Month	6 Month	9 Month	12 Month	24 Month
Eskişehir	35	43	47	44	44	41	44
Ankara	18	46	50	51	50	51	52
Çankırı	16	49	50	48	49	50	51
Konya	45	47	45	46	48	50	46
Aksaray	27	47	48	50	53	52	53
Karaman	51	48	49	46	46	48	54
Sivas	20	47	45	48	51	50	20
Kayseri	16	48	50	50	50	50	55
Nevşehir	29	48	46	50	47	46	51
Niğde	31	48	45	44	46	48	47
Kırşehir	31	48	46	48	49	52	47
Kırıkkale	31	48	49	49	54	55	52
Yozgat	20	49	48	46	48	48	20

Table 4. The wetness (WR) ratios (%) of the SPI and Entropy values of several stations in the Central Anatolian Region for time periods of 3, 6, 9, 12 and 24 months

	Entropy	1 Month	3 Month	6 Month	9 Month	12 Month	24 Month
Eskişehir	55	15	16	18	16	15	16
Ankara	63	16	17	16	16	16	15
Çankırı	59	16	18	16	16	14	16
Konya	31	16	15	14	16	14	13
Aksaray	45	16	16	17	18	17	16
Karaman	27	16	17	16	16	15	16
Sivas	61	15	16	16	18	17	18
Kayseri	53	16	16	17	16	16	18
Nevşehir	53	16	16	16	16	16	16
Niğde	47	16	17	15	16	15	14
Kırşehir	37	16	17	16	18	18	19
Kırıkkale	37	16	17	15	17	17	18
Yozgat	55	15	15	17	16	15	16

The relative frequency of SPI and Entropy in 3, 6, 9, 12 and 24 month time periods for Konya Station in the Central Anatolian Region are given in Figure 2.

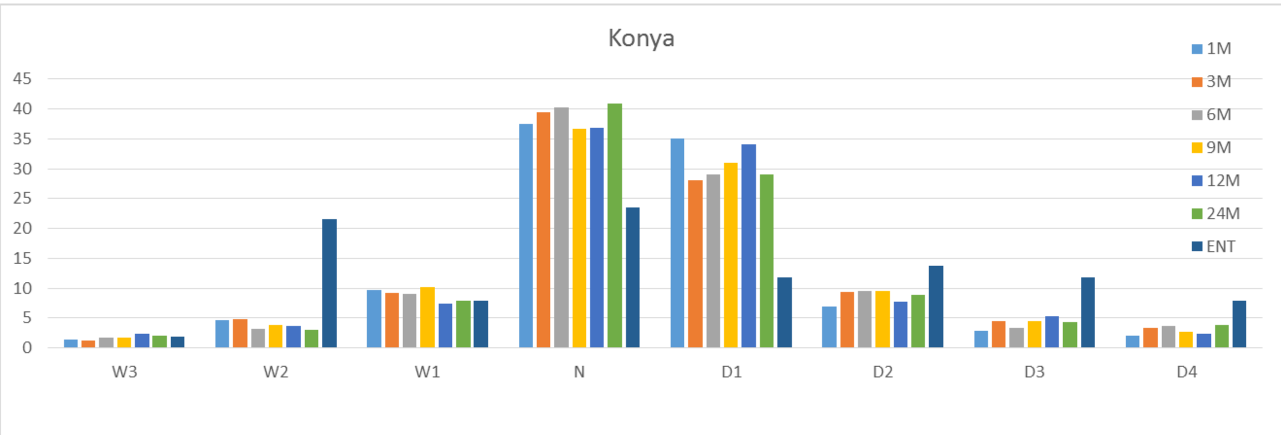

Figure 2. Relative frequency of SPI and Entropy for the Konya

Although the plots of precipitation and precipitation entropy displayed similar trends, the apportionment entropy values could specifically reflect the effect of the precipitation received especially during periods of drought. Similarly, the adverse distribution of precipitation, despite the sufficient total amount of precipitation, could be followed via the trends of the entropy values. The comparative precipitation and precipitation entropy values for the Konya station is given in Figure 3.

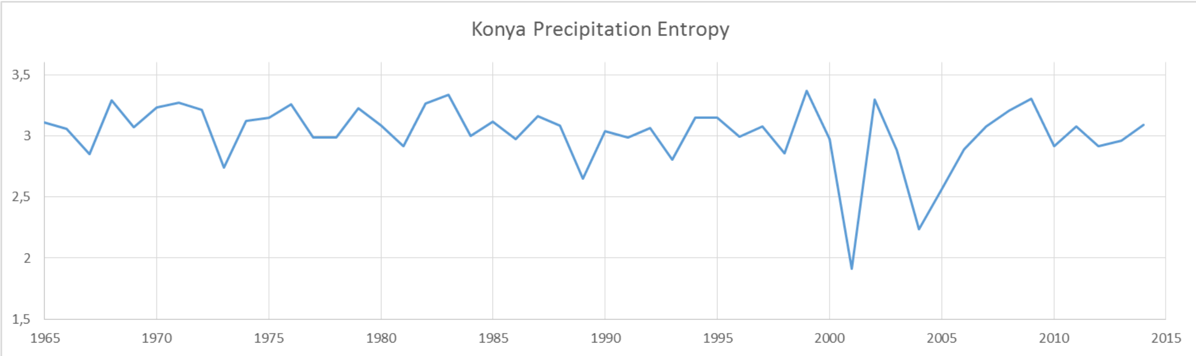

Figure 3. Drought Index Plot for the Konya Meteorology Station as calculated by the Entropy Method

5. RESULTS

Monitoring drought conditions with the use of reliable drought indices can help decision makers. In this study, SPI and AE was calculated from monthly precipitation values. Central Anatolian Region have shown a decreasing trend precipitation in winter, and spring seasons. The drought periods have shown a cyclic behavior in Central Anatolian Region as indicated by the long term observation data.

The AE method produced results similar to that of the SPI method as observed when the proportional frequencies of the drought severities in the stations of the region are compared. As shown in Figure 4, the SPI and the standardized entropy values are close to each other in Konya and Karaman stations, but, the ratio between SPI and the standardized entropy values are 1.4 in Eskisehir; 1.6 in Kırıkkale, Kırsehir, Nevsehir and Niğde stations; 1.9 in Aksaray; 2.5 in Yozgat and Sivas and it is 2.7 in Çankırı, Kayseri and Ankara.

The calculation of entropy by considering the monthly variation of precipitation provides a significant advantage to entropy in the determination of annual drought tendencies. It was observed from the series of precipitation and apportionment entropy that the relationship between the annual total precipitation values and entropy decreases. The apportionment entropy values are independent from the annual total precipitation values.

The assessment of drought plays an important role in the planning, design and determination of construction properties of water structures. Therefore, use of the entropy concept in drought assessment might be regarded as an alternative to the existing methods.

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