IDENTIFICATION OF DROUGHT PARAMETERS THROUGH THE USE OF ENTROPY

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ABSTRACT

The main purpose of the present study, investigate the availability of the informational entropy (IE) method as a drought parameters. For this purpose, the drought characteristics in the Northern Aegean Region in Turkey were investigated. Various drought indexes, which are widely used drought analysis methods, like the Erinc Index and the Standard Precipitation Index were performed for the region. In addition, the informational entropy (IE) method was also investigated and compared the common indexes in this study.

The evaluated data in 29 stations are gauged by The Turkish State Meteorological Service (DMİ). For determining the drought indexes both long term precipitation and temperature data were used.

The results of the study contributed to the identification of drought parameters for the Northern Aegean Region and consequently the missing information and data on this subject was completed. The entropy method provided similar results to the results obtained by other methods widely used in the literature regarding the data for the Northern Aegean Region. The results of the present study showed that entropy method can be an alternative to be used in the analysis of drought.

Keywords: Drought, Drought parameters, Entropy, Northern Aegean Region

1. INTRODUCTION

Drought is a natural disaster adversely affecting the survival and economy of the living organisms, which is initiated by 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 [1]. The drought issue grows by the day due to climate change, increase in population, destruction of the natural vegetation and desertification and reaches such a magnitude as to threaten human kind. Drought adversely affects many aspects of life ranging from agriculture to environment and from society to economics.

Prevention of drought requires carrying out a detailed basin specific analysis and monitoring of the area closely. Different drought severity parameters 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 analyses or statistical/stochastic evaluations were also used as alternative approaches for defining and investigating drought in addition to the previously mentioned indices.

The indices that were proposed for the analysis of drought are mainly based on water budget calculations. The main parameters used for this purpose, which are the amount of precipitation as the input and the extent of evaporation as the output, are attempted to be defined. A frequently encountered dilemma in proposing indices and reconstruction of hydrological models is the following:

i) Uncertainty which is caused by the prediction errors in calculating the weights of multiple parameters, appears in models, and the collection of extensive data records, which is usually difficult and expensive, is required if the reconstruction of a multi-parametric model is targeted.
ii) Defining simple models overlooks the effect of several physical phenomena including potential evaporation, transpiration or the current soil moisture, which would be omitted.

Palmer Drought Severity Index (PDSI), which finds itself a worldwide use [2], is suitable for relatively homogenous regions since its computation necessitates the use of classifications such as soil moisture algorithm. Although it is a multi-parametric method, which requires a number of inputs, it is suitable for agricultural applications and established itself an extensive area of application in North America [3].

The Standard Precipitation Index (SPI) has the advantage of being comparable across different time scales [4, 5], such an example being short-term drought against long-term drought, finding widespread use owing to this particular advantage. SPI has a relatively simple algorithm and on-going research focuses on the improvement of the application of both SPI and PDSI [6-8]. Thus, due to its advantages, the SPI appears to be the most powerful drought index. Many authors including, Vicente-Seriano et.al [9], Cancelliere et al. [10]; Raziei et al. [11], Liu et al. [12]; Zhang et al. [13]; Bacanli [14] used the SPI to monitor drought in many regions.

One of the indices that are frequently used to identify the drought in Turkey as well as highlighting the dry or humid areas and periods is the Erinc index. Erinc proposed a method based on maximum temperature, which is the main parameter affecting precipitation and water loss due to evaporation as the input [15]. This index, which is determined by the ratio of the total annual precipitation to the annual maximum mean temperature, was reported to provide realistic values for Turkey.

The present study investigated the applicability of entropy as a novel measure of drought based on long-term precipitation and temperature data collected from a number of stations in the Northern Aegean Region. For this purpose, the drought parameter determined based on the “Apportionment Entropy” values for Northern Aegean was compared with other methods including the Erinc Index, which is known to be suitable for the Turkish basins, and the Standard Precipitation Index, which has a widespread area of use.

2. DATA:

The border of the area under investigation in the Northern Aegean Region in the present study is displayed in Figure 1 along with the city centres and the locations of the stations evaluated in the present study.

![Figure 1: Area of study in the Northern Aegean Region](image)

A major portion of the Northern Aegean Region is affected by the Mediterranean climate characteristics. The inland areas comprised of the south of the Marmara Region and the Northern Aegean inlands are under the influence of Marmara (transitory) climatic characteristics. The Mediterranean climate regime is characterized by hot and dry summers and warm winters with precipitation whereas the Marmara (transitory) climate regime is characterized by as warm winters as that of the Mediterranean climate regime and summers with mild precipitation [16].

The annual precipitation in the western part of the Northern Aegean Region ranges between 624 and 691 mm and this range decreases in the eastern part of the region down to 541-623 mm. The average number of days with precipitation decreases from east to west as a natural consequence of this. The average number of days on which precipitation was observed varies between 52-60 days along the coastline and between 81-100 days in the inlands.

Stations with an extensive precipitation and temperature data available were selected for the purpose of the present study. The features of these stations in relation to the basin characteristic are displayed in Table 1.
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” [17, 18].

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 argued that every element comprising a series of signals or symbols took its value based on certain probabilities as implicated by the concept that message relay was a stochastic event and that each value was a function of one or more symbols preceding that value. Thus, the output of any information source or communication transmitter is a random variable at any particular time [19].

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 [20, 21].

Table 1: Characteristics of the Stations in the Northern Aegean Region

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 [22]:

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

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

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

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

x and y in the statements are stated as two independent variables defined in the same probability space as that of \( x_i (i = 1, 2, \ldots, n) \) and \( y_j (j = 1, 2, \ldots, m) \) 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 [23].

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. [24] were also used by Maruyama et al. [25] 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 (ri):

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

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 \( 12 \). \( r_i \) 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:
The entropy values are independent of the order of events 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 (AE) can be predicted using the annual total precipitation and monthly mean temperature data.

\[
\text{AE} = \frac{1}{m} \sum_{i=1}^{m} \left( \frac{1}{R} \log_2 \frac{1}{R} \right) \tag{6}
\]

(6)

\[
\text{AE} = (1/m) \sum_{1}^{m} \text{AE} \tag{7}
\]

(7)

where \( \overline{AE} \) is the mean entropy.

The oscillations around the long term mean entropy were considered further for the classification of the drought index of the apportionment entropy (Table 2). \( \bar{X} \) denotes the long term (throughout the observation period) mean value and \( \hat{S} \) denotes the independent standard deviation during the same period in the table [26, 27].

<table>
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<tr>
<th>Apportionment Entropy (AE)</th>
<th>Classification</th>
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</thead>
<tbody>
<tr>
<td>( \geq \bar{X} + 2\hat{S} )</td>
<td>Extremely Wet</td>
</tr>
<tr>
<td>( \bar{X} + 2\hat{S} - \bar{X} + \hat{S} )</td>
<td>Wet</td>
</tr>
<tr>
<td>( \bar{X} + \hat{S} - \bar{X} )</td>
<td>Moderately Wet</td>
</tr>
<tr>
<td>( \bar{X} - \bar{X} - \hat{S} )</td>
<td>Moderate Drought</td>
</tr>
<tr>
<td>( \bar{X} - \hat{S} - \bar{X} - 2\hat{S} )</td>
<td>Drought</td>
</tr>
<tr>
<td>( \leq \bar{X} - 2\hat{S} )</td>
<td>Extreme Drought</td>
</tr>
</tbody>
</table>

Table 2: Classification of the drought index of apportionment entropy

4. APPLICATION

The present study used the Turkish State Meteorological Service data (Table 1) on precipitation and temperature for the Northern Aegean Region. The Erinc Index, Standard Precipitation Index and the Entropy method were used on the data collected from all of the precipitation stations in the region within the scope of the project.

4.1 Results of the Standard Precipitation Index

Time periods of 3, 6, 9, 12 and 24 months were taken into consideration for observing the changes in the calculation of the Standard Precipitation Index (SPI). These time periods were selected subjectively such that 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, the SPI for short term or seasonal (3 and 6 months), mid-phase drought (9 and 12 months) and for long-term drought (24 months) were taken into consideration. Every station was evaluated based on these SPI classifications. Relative frequencies were also calculated in 3, 6, 9, 12 and 24 month time periods.

Results from selected stations are displayed in Table 3. Evaluation of the SPI 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, normal and wet periods.

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 long-term time periods (12-24 months).

The relative frequency of SPI in 3, 6, 9, 12 and 24 month time periods for the Little Maeander in the Northern Aegean Region are given in Figures 2a-2e.

Table 3: The drought (DR), normality (NR) and wetness (WR) ratios (%) of the SPI values of several stations in the Northern Aegean Region for time periods of 3, 6, 9, 12 and 24 months

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 Northern Aegean Region...
were determined to vary between 68% and 35%, the wetness ratios between 32% and 12%, and the normal precipitation ratios between 51% and 8% based on their SPI indices.

### 4.2 Results of the Erinc Index

The relative frequencies, which were calculated throughout the observation period for the stations situated at the Northern Aegean Region using the Erinc method are displayed in Figures 3a-3e. The highest drought frequency of 41% was observed in Alasehir. No period of drought was observed for Bigadic, Canakkale, Demirci, Dursunbey, Edremit, Gonen, Keles or Simav and the highest semi-drought period was observed in Turgutlu and Erdek (71%) [28, 29].

**Figure 3:** Relative Frequencies (P%) of the Investigated Basins as Calculated by the Erinc Method

Annual drought index values were used in the Erinc method as a different parameter than that of SPI. The drought ratios were observed to vary between 41% and 0% and the semi-drought ratios between 71% and 4% as determined by the Erinc index.

### 4.3 Results of the Entropy Index

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 Akhisar station is given in Figure 4.

**Figure 4:** Drought Index Plot for the Akhisar Meteorology Station as calculated by the Entropy Method

The repeated cyclic drought values might be determined by investigating the periodic components of Entropy Index (EI) drought values. For example, for the Akhisar station, a drought cycle with a nine year repeating range is seen (Figure 4).

The EI yields results parallel with other indices and this indicates that it can be used as a drought index. When EI is used as a drought index, it shows the process of drought. As the EI uses all existing observations, it can also show the cyclic behaviour (in station scale).

The entropy values that were calculated for the selected stations in the region and the frequency of dry and wet periods that were determined based on this parameter were presented in Figures 5a-5e.

**Figure 5:** Relative frequencies calculated based on the entropy method

### 5. CONCLUSION

Drought could be perceived as a decrease in the mean values for total precipitation in either summer or the wet winter seasons. The periods of drought displayed cyclic behaviour as indicated by the long term observation data provided from the stations in the Northern Aegean 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 safely be proposed as a method to be used in long-term drought calculations and regional drought calculations. The drought ratios calculated by the Erinc method were observed to be higher than those calculated by the other two methods.

Owing to the fact that the entropy values were calculated taking monthly distribution of precipitation into account, the method had a distinctive superiority in the determination of the drought trends. The relation between the entropy trends and the annual total precipitation values was reasonably low as it may be observed in the precipitation and apportionment entropy trends. In other words, the apportionment entropy values, which were calculated using the monthly total precipitation values, were independent from the total annual precipitation values. If the fact that other indices such as SPI, which were used in comparative evaluations, all provided results based on the total annual amount of precipitation were taken into consideration, the advantage of the entropy calculations over these methods become clearer. This advantage highlights the significance of using the apportionment entropy method in similar calculations.

### Acknowledgements

The present study is financially supported by the Scientific Research Council of Turkey (TUBITAK) through project no 107Y348. The authors...
gratefully acknowledge the support by TUBITAK. The data for the present study was provided by the DMI.

Symbols

H(X) : marginal entropy  
H(X,Y) : joint entropy  
H(X/Y) : conditional entropy  
T(X,Y) : transinformation  
p(x_i) : discrete probability  
p(x_i, y_j) : point probability  
p(x_i | y_j) : conditional probability  
X and Y : two independent variables defined in the same probability space as that of x  

R : Annual mean monthly precipitation  
r_i : Sum of all mean monthly precipitation values at the i-th month in a year  
AE : Apportionment entropy  
AVE : Mean apportionment entropy  
X : long term (throughout the duration of observation) mean value  
Σ : standard deviation value for unbiased long-term period

7. BIBLIOGRAPHY

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Table 1: Characteristics of the Stations in the Northern Aegean Region

<table>
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<th>Basin Name (Number)</th>
<th>Meteorological Stations</th>
<th>Latitude (°)</th>
<th>Longitude (°)</th>
<th>Basin Area (km²)</th>
<th>Average Elevation (m)</th>
<th>Annual Average Precipitation (mm)</th>
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Table 3: The drought (DR), normality (NR) and wetness (WR) ratios (%) of the SPI values of several stations in the Northern Aegean Region for time periods of 3, 6, 9, 12 and 24 months

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Figure 2: Relative Frequency of 3, 6, 9, 12 and 24 Month SPI for the Little Maeander
Figure 3: Relative Frequencies (P%) of the Investigated Basins as Calculated by the Erinc Method
Figure 4: Drought Index Plot for the Akhisar Meteorology Station as Calculated by the Entropy Method
Figure 5: Relative frequencies calculated based on the entropy method