Detection of drought events in Greece using daily precipitation

N. Kalamaras, H. Michalopoulou and H. R. Byun

ABSTRACT

In this study a method proposed by Byun & Wilhite, which estimates drought severity and duration using daily precipitation values, is applied to data from stations at different locations in Greece. Subsequently, a series of indices is calculated to facilitate the detection of drought events at these sites. The results provide insight into the trend of drought severity in the region. In addition, the seasonal distribution of days with moderate and severe drought is examined. Finally, the Hierarchical Cluster Analysis method is used to identify sites with similar drought features.

Key words | cluster analysis, drought duration, drought indices, effective precipitation

INTRODUCTION

Drought is characterized as an extreme hydrometeorological event. As a natural disaster, drought is considered to be one of the worst enemies of humanity.

Despite drought’s relationship to a deficit of water resources due to insufficient precipitation for an extended period of time, there is no universally acceptable definition of drought. The reason is that drought is not a distinct event and is often the result of many complex factors which interact with the environment. Furthermore, drought is the subject of study by experts from various scientific disciplines because it impacts so many aspects of human activities. Thus, drought can be classified as meteorological, agricultural, hydrological and socioeconomic.

Numerous studies dealing with drought have been carried out globally. A number of these studies have focused on the Mediterranean region, which consists of countries that are often affected by drought events (among others are Reiser & Kutiel (2008a,b) and Lana et al. (2008)). In Greece, the very serious drought of 1990 provided motivation for a more systematic study of drought by many investigators (Maheras 1992; Baloutsos et al. 1995; Theoharatos & Michalopoulou 1993; Spiliotopoulos & Michalopoulou 2000; Spiliotopoulos et al. 2002; Anagnostopoulos et al. 2003; Papaioannou et al. 2007 and others).

The quantification of the most important characteristics of drought, such as intensity, duration and areal extent, facilitates the study of this important phenomenon. Quantification addresses variables such as rainfall, soil moisture, evapotranspiration, waterway inflow and outflow, and others. Often, one or more of these variables are combined in a formula to create a drought index.

Due to the seriousness of the problems caused by drought, several drought indices have been proposed for widespread application, but unfortunately they do not give satisfactory results for all climatic zones (Palmer 1965; Rooy 1965; Bhalme & Mooley 1980; Oladipo 1985). Among the shortcomings of these indices is the fact that the time unit of assessment is often too long (a month or longer). But the daily time unit should be used because the water reserves of a region affected by drought can return to normal conditions relatively quickly.
conditions often with only a day's rainfall. Another problem is the storage component of water resources. Soil moisture is quickly influenced by a recent deficiency of precipitation but water resource deficiencies in reservoirs or other sources are affected by much longer-term precipitation totals. Furthermore, some drought indices take into account estimates of some parameters such as soil moisture and evapotranspiration. Moreover, the consideration of diminishing water resources over time may not be realistic. Thus, a simple summation of precipitation may not provide good results in detecting water deficiency.

More recently Byun & Wilhite (1999) proposed a new drought index based on daily precipitation; this study is based on their method. Since the introduction of Byun and Wilhite's method, only a few attempts to verify it have been carried out, namely in Korea (Min et al. 2003; Kang & Byun 2004; Kim & Byun 2006), India (Pandey et al. 2007) and Iran (Morid et al. 2006). This study represents a new approach for the detection of significant drought events in Greece during the period 1965–2001 using only daily precipitation values.

**METHOD AND DATA ANALYSIS**

In this study, the detection of drought in Greece is carried out using daily precipitation data from 14 stations of the Hellenic National Meteorological Service network. A series of indices is calculated using the method proposed by Byun & Wilhite (1999). The proposed set of drought indices attempts to overcome the aforementioned weaknesses of other indices in an effort to improve drought monitoring. The advantages of the Byun and Wilhite method include the use of daily precipitation values alone and the introduction of a new concept, Effective Precipitation (EP). EP is the summed value of daily precipitation with a time-dependant reduction function. Thus, the only data needed for calculation of the drought indices is daily precipitation values for a period of the order of 30 years or more. EP, which represents the daily depletion of water resources, is calculated using the equation

\[ EP_i = \sum_{n=1}^{i} \left[ \sum_{m=1}^{n} P_m \right] \frac{n}{n^i} \]  

where \( P_m \) is the precipitation \( m \) days before and the index \( i \) represents the duration of summation (DS) in days. Here \( i = 365 \) is used, that is, summation for a year, which is the most dominant precipitation cycle worldwide. \( EP_{365} \) is a representative value of the total water resources available. In cases where the focus of the study is on water resources stored for a short time, a smaller value of \( i \) can be used, for example \( i = 15 \). From this point onwards \( EP_{365} \) will simply be referred to as EP without any subscript. Various equations have been proposed for the calculation of EP, but Equation (1) is considered to be the most appropriate for representing the depletion of water resources (Lee 1998; Shim et al. 1998).

Once the daily EP of a station has been computed, a series of indices can then be calculated to highlight different characteristics of the water resources in the vicinity of the station. The first step is the calculation of Mean Effective Precipitation (MEP). This is equivalent to the 30 year mean of EP for each calendar day. MEP represents the climatological mean of stored water quantity.

The second step is to calculate the deviation of EP (DEP) from the MEP:

\[ DEP = EP - MEP. \]  

DEP shows the deficiency or surplus of water resources for a particular date and place.

The next step is the calculation of the standardized value of DEP (SEP):

\[ SEP = \frac{DEP}{ST(EP)} \]  

where \( ST(EP) \) denotes the standard deviation of each day's EP. SEP expresses the standardized deficit or surplus of stored water quantity. SEP enables the comparison of one location's drought severity with other locations, regardless of climatic differences.

A series of other indices can then be calculated. More details about them can be found in the paper of Byun & Wilhite (1999). For the purposes of this study, only the ANES and APD indices were required.

- **ANES** (accumulation of consecutive negative SEPs) is calculated by summing consecutive negative SEPs. All positive SEPs are translated into zeroes. The ANES index indicates the accumulated stress during drought
and emphasizes drought duration. The only disadvantage of ANES is that it may mistake a prolonged period of weak water deficit as severe drought.

- APD (accumulated precipitation deficit) shows the accumulated deficit of precipitation and is calculated by Equation (4):

$$APD_j = \sum_{m=1}^{j} P_m - AVG_j$$

where $P_m$ is daily precipitation $m$ days ago. The index $j$ is the duration of summation and is $j = i + CNS - 1 = 365 + CNS - 1$, as $i = 365$ is used; CNS is the number of consecutive days of negative SEP. $AVG_j$ is the sum for $j$ days of daily precipitation average for the corresponding calendar day. APD is simply the accumulated deficit of precipitation during $j$ days. For that reason, APD is useful because the general public is more accustomed to simple precipitation accumulation data than to the EP. Its main disadvantage, however, is that it can be used to compare drought damage only in regions with the same climatic conditions.

In the present study, the indices SEP, ANES and APD were calculated for 14 stations of the Hellenic National Meteorological Service (HNMS) for the period 1965–2001.

### RESULTS

#### Drought monitoring

Figures 1(a, b) show the daily variation of SEP, APD and ANES indices for the drought event of 1990 at two stations (Agrinion and Hellinikon). Daily precipitation values are also plotted in order to illustrate the relationship between rain events and the temporal evolution of the drought indices.

Some important aspects of these drought events must be noted. In the drought event depicted in Figure 1(a), the dry period ($SEP < 0$) lasted from 31 August 1989 until 29 October 1990, while the drought period ($SEP < -0.7$) lasted from 14 September 1989 until 28 October 1990.

#### Table 2 | Classification of SEP values

<table>
<thead>
<tr>
<th>SEP values</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 or more</td>
<td>Danger of flood</td>
</tr>
<tr>
<td>1.5 to 2.5</td>
<td>Probability of flood</td>
</tr>
<tr>
<td>0.7 to 1.5</td>
<td>Slight surplus of water</td>
</tr>
<tr>
<td>-0.7 to 0.7</td>
<td>Normal conditions</td>
</tr>
<tr>
<td>-0.7 to -1.5</td>
<td>Moderate drought</td>
</tr>
<tr>
<td>-1.5 to -2.5</td>
<td>Severe drought</td>
</tr>
<tr>
<td>-2.5 or less</td>
<td>Extreme drought</td>
</tr>
</tbody>
</table>

The coordinates and elevation of the stations are given in Table 1.

Drought severity can be estimated according to the classification of SEP values provided in Table 2. As this study is concerned with drought, the focus is on negative SEP values.

A “dry period” can be defined as a period of consecutive negative values of SEP. A “drought period” is defined as a period in which $SEP < -0.7$. Consecutive days with SEP values less than 0 but greater than $-0.7$ are included in the drought period unless followed by a positive value of SEP. A drought period ends when $SEP > -0.7$ and there are no subsequent values with $SEP < -0.7$ until SEP becomes positive. When SEP becomes positive, the dry period ends as well as the drought event (which started when SEP initially became negative) and all other indices become zero.

### Table 1 | Latitude, longitude and elevation of HNMS stations

<table>
<thead>
<tr>
<th>No.</th>
<th>Station</th>
<th>Latitude (North)</th>
<th>Longitude (East)</th>
<th>Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agrinion</td>
<td>38°37’</td>
<td>21°23’</td>
<td>46</td>
</tr>
<tr>
<td>2</td>
<td>Alexandroupolis</td>
<td>40°51’</td>
<td>25°56’</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Florina</td>
<td>40°48’</td>
<td>21°25’</td>
<td>650</td>
</tr>
<tr>
<td>4</td>
<td>Hellinikon (Athens)</td>
<td>37°54’</td>
<td>25°45’</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Ioannina</td>
<td>39°42’</td>
<td>20°49’</td>
<td>483</td>
</tr>
<tr>
<td>6</td>
<td>Iraklion</td>
<td>35°20’</td>
<td>25°11’</td>
<td>38</td>
</tr>
<tr>
<td>7</td>
<td>Kalamata</td>
<td>37°04’</td>
<td>22°00’</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>Kerkira</td>
<td>39°37’</td>
<td>19°55’</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Larisa</td>
<td>39°39’</td>
<td>22°27’</td>
<td>73</td>
</tr>
<tr>
<td>10</td>
<td>Mitilini</td>
<td>39°04’</td>
<td>26°36’</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Naxos</td>
<td>37°06’</td>
<td>25°23’</td>
<td>9</td>
</tr>
<tr>
<td>12</td>
<td>Souda (Hania)</td>
<td>35°33’</td>
<td>24°07’</td>
<td>62</td>
</tr>
<tr>
<td>13</td>
<td>Thessaloniki</td>
<td>40°31’</td>
<td>22°58’</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>Tripolis</td>
<td>37°32’</td>
<td>22°24’</td>
<td>661</td>
</tr>
</tbody>
</table>
Both the dry and drought periods ended with 44.9 mm of daily precipitation on 29 October 1990. It should be noted that the amount of daily precipitation (in mm) required for a Return to Normal (PRN) can be calculated by Equation (5):

\[ \text{PRN} = \frac{\text{DEP}}{\sum_{N=1}^{365} \left(1/N\right)} \]  

Correspondingly, in Figure 1(b) the dry period lasted from 28 October 1989 until 3 December 1990, while the drought period lasted from 16 November 1989 until 2 December 1990. The drought event ended with 21.9 mm of daily precipitation on 3 December 1990. In both Figures 1(a) and (b) it is remarkable to observe that a rain event causes SEP to become less negative, but the end of a drought event occurs only when daily precipitation exceeds the PRN.

**Regional spread of droughts**

In order to estimate the regional spread of the droughts that affected Greece during the period addressed by this study, the number of stations that were affected by at least one severe drought event (SEP < −1.5) is illustrated in Figure 2.

It is evident in Figure 2 that the drought event of 1990 dominated the period under study, affecting all 14 stations. This event was accompanied by important drought events before (1989) and after (1992) it. Other important drought events, but not so severe as the 1990 drought, include that of 1977 and more recently of 2000/01. The 1977 drought affected Western, Central and Northern Greece (initially the stations in Kalamata, Ioannina and Tripolis and subsequently the stations in Kerkira, Thessaloniki and Larisa), while the drought of 2000/01 affected mainly Central and Southern continental Greece (Larisa, Tripolis and Hellinikon) as well as parts of Western Greece (Agrinion). The drought events of 1970 and 1985 affected a significant number of stations, but were relatively short-lived and thus are not considered important. It is generally observed that the more severe a drought is, the larger its geographical extent (Yevjevich 1967).

These results are in good agreement with the findings of other similar studies. For instance, Loukas et al. (2002), who used the Palmer Z moisture anomaly index for several Greek stations for the period 1957–1983, identified the
The drought of 1977, while Livada & Assimakopoulo (2006), who used the SPI index for the period 1950–2000 for the entire region of Greece, found that the most important drought events were those of 1989 and 2000. Other studies addressing specific areas of Greece (Loukas & Vasilides (2004) for the region of Thessaly and Spiliotopoulos et al. (2006) for Crete) have also verified these drought events.

Drought trends

The trend in drought severity was subsequently analyzed at each station for the aforementioned period. Initially, the minimum yearly values of the SEP and ANES indices were identified. From the resulting time series a regression line \( y = bx + a \) was estimated, where \( y \) corresponds to the minimum yearly values of SEP and ANES and \( x \) is the relevant number of years. In order to test the significance of the trends, a statistical test (t test) was applied, specifically a two-tailed test at the 0.05 significance level. Interestingly, a decreasing trend in the minimum yearly values of SEP and ANES indices was detected at a number of stations. However, in most cases this trend was not statistically significant at the selected significance level.

Figure 3 presents graphs of the minimum yearly values of SEP and ANES indices and regression lines for two stations (Ioannina and Larisa). A statistically significant downward trend, an exception with respect to the aforementioned findings, is evident for Ioannina but not for Larisa. These results are generally in agreement with the findings of Loukas et al. (2002), who used the Student t test and the Mann–Whitney test (both at the 5% significance level) and found that there was not a statistically significant trend for the period 1957–1983. It could be argued that this trend may be related to the decrease in precipitation in the Mediterranean region predicted by several climatologists in relation to climate change. However, such a conclusion cannot be reached without first examining all the other factors involved in the complex science of climate change.

Seasonal distribution of drought severity

Another interesting aspect examined in this study is the relationship between season\(^1\) and drought severity. Specifically, the distribution of days with moderate and severe drought in the four seasons is examined. The resulting diagram for the Hellinikon (Athens) station, which shows the seasonal distribution of days with moderate (SEP < -0.7) and severe (SEP < -1.5) drought, is shown in Figure 4.

The results for the Hellinikon (Athens) station are representative of the other 13 stations with instances of moderate (or worse) drought severity being almost uniformly distributed throughout the four seasons. This confirms the premise that droughts may commence at any time of the year.

The seasonal distribution of days with severe (or worse) drought differs significantly. At almost all stations, the

\(^1\) Seasons: spring (March, April, May), summer (June, July, August), autumn (September, October, November), winter (December, January, February).
season in which the smallest number of days with SEP \(< -1.5\) is observed is autumn. In other seasons, the number of days with SEP \(< -1.5\) is almost uniformly distributed at nearly all stations. It should be noted that, for the period covered by the data, the end of most significant drought events occurs in autumn. This can be explained by the fact that the main rainy season in Greece starts in autumn. This finding was verified by testing the skewness of the EP values for each season separately. In particular, it was found that positive skewness was significantly greater in autumn than for all other seasons at almost all stations. This indicates the presence of larger rainfall events in autumn that were likely responsible for bringing about the end of drought episodes. The same result was found using SEP instead of EP. From the autumn, depressions follow a more southerly route, taking them over Greece where they result in significant rainfall. The fact that drought mitigation occurs mainly in autumn has also been noted by other investigators (Baloutsos et al. 1993).

### Cluster analysis

In the final part of this study, the stations were separated into clusters with similar drought characteristics. The clustering method applied was Hierarchical Cluster Analysis in version 9.0 of SPSS. The variable used for clustering was the daily value of the SEP index. This resulted in five clusters shown in Table 3 and illustrated in the relevant dendrogram in Figure 5.

The stations comprising the five different clusters in Table 3 are, in fact, located in neighboring areas. Cluster 1, containing the Hellinikon and Naxos stations, represents south coastal and insular areas. Cluster 2 includes western Greece stations (Agrinion, Ioannina, Kalamata and Kerkrira) as well as stations at a relatively higher elevation (Tripolis and Florina). Cluster 3 contains the low elevation stations of Thessaly and central Macedonia (Thessaloniki and Larisa). Cluster 4 includes stations located in northeastern Greece (Alexandroupolis and Mitilini) while the Cretan stations (Iraklion, Souda) make up cluster 5. The clusters are illustrated on the map in Figure 6.

This clustering is in good agreement with the classification of Loukas et al. (2001) in which the Greek territory

### Table 3 | Station clusters

<table>
<thead>
<tr>
<th>Cluster 1</th>
<th>Helinikon (Athens)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Naxos</td>
</tr>
<tr>
<td>Cluster 2</td>
<td>Agrinion</td>
</tr>
<tr>
<td></td>
<td>Ioannina</td>
</tr>
<tr>
<td></td>
<td>Kalamata</td>
</tr>
<tr>
<td></td>
<td>Kerkrira</td>
</tr>
<tr>
<td></td>
<td>Tripolis</td>
</tr>
<tr>
<td></td>
<td>Florina</td>
</tr>
<tr>
<td>Cluster 3</td>
<td>Thessaloniki</td>
</tr>
<tr>
<td></td>
<td>Larisa</td>
</tr>
<tr>
<td>Cluster 4</td>
<td>Alexandroupolis</td>
</tr>
<tr>
<td></td>
<td>Mitilini</td>
</tr>
<tr>
<td>Cluster 5</td>
<td>Iraklion</td>
</tr>
<tr>
<td></td>
<td>Souda (Hania)</td>
</tr>
</tbody>
</table>
was separated into five areas using factor analysis of precipitation amounts. Hence, the clustering shown in Table 3 is strongly related to the climate of Greece and its interannual variability, as mentioned in Livada & Assimakopoulos (2006).

CONCLUSIONS

In this study, a new method was used for the detection of drought events in Greece based on the work done by Byun & Wilhite (1999) using only daily precipitation values. For this purpose, data from 14 stations of the Hellenic National Meteorological Service network covering the period 1965–2001 were used. For the estimation of drought severity and duration, the SEP, ANES and APD indices were used. The SEP index provides insight into drought severity whereas the ANES index emphasizes drought duration. The APD index expresses the accumulated deficit of precipitation. Following a discussion of the main advantages and disadvantages of the indices, their daily values were calculated and presented.

From the resulting time series, the main drought events that affected Greece during the period covered by the data were identified. Analysis of the SEP, ANES and APD indices indicated that the main drought events were those of 1977, 1990 and 2000/01. The 1990 drought was the most severe and has been characterized as the worst drought to hit Greece during the 20th century. It was aggravated by other, relatively less important, drought events in 1989 and 1992. The SEP and ANES indices were used to successfully detect drought events that were verified against information provided by the Greek Ministry of Agriculture and the Hellenic National Meteorological Service.

The annual trend in SEP and ANES indices was examined and revealed a downward trend that could possibly confirm the reduction in precipitation due to climatic change forecast by a number of scientists. However, the application of a t test indicated that the trend was not statistically significant in most cases.

With respect to the seasonal distribution of drought severity, an almost uniform distribution of days with \( SEP < -0.7 \) (with at least moderate drought) was observed at all stations, proving that a drought may start at any time of the year. On the other hand, the seasonal distribution of days with \( SEP < -1.5 \) (with at least severe drought) showed that the least number of days with severe drought are observed in autumn. This can be explained by the onset of the rainy season in Greece, which occurs in autumn and offers mitigation from severe drought. This is also related to the fact that EP (and SEP) values in autumn appear to have significantly higher positive skewness than in the other seasons.

Finally, the stations were clustered according to the similarity of drought characteristics using Hierarchical Cluster Analysis. The resulting clustering, which grouped stations from adjacent geographical areas, can be attributed to the climate of Greece and its interannual variability.

In summation, the method developed by Byun & Wilhite (1999) provides a means for a more exact determination of the beginning and the end of a drought event. Moreover, it allows for the daily monitoring of the evolution of a drought event. This information could help the state authorities regarding the choice and implementation of measures to mitigate the effects of drought. However, further research is required prior to any operational use of this method.
ACKNOWLEDGEMENTS

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