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Multi-Index Drought Assessment in Europe

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Abstract: Any attempt for the application of integrated drought management, requires identifying and characterizing the event per se. The questions of scale, boundary, and of geographic areal extend are of central concern for any efforts of drought assessment, impacts identification, and thus of drought mitigation implementation mechanisms. The use of drought indices, such as Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI), has often lead to pragmatic realization of drought duration, magnitude and spatial extend. The current effort presents the implementation of SPI and SPEI on a Pan-European scale and it is evaluated using existing precipitation and temperature data. The E-OBS gridded dataset for precipitation, minimum temperature, and maximum temperature used covered the period 1969 – 2018. The two indices estimated for time steps of 6, and 12 months. The results for the application period of recurrent droughts indicate the potential that both indices offer for an improvement on drought critical areas identification, threshold definitions and comparability, towards contingency planning leading to better mitigation efforts.

Keywords: Drought; precipitation; SPI; SPEI; Europe

1. Introduction

Drought is a normal, periodic natural hazard, although often inaccurately pictured as an unexpected and exceptional phenomenon. It strikes practically all the planet, but its characteristics vary significantly from one region to another [1,2]. Drought is a temporary anomaly of the usual climatic events and it is considered a creepy slow evolving natural hazard, quite different from aridity, which is a long-term, permanent part of a climatic zone [3–9]. Droughts are generally caused by a combination of natural events that many times are boosted by anthropogenic pressures. The most common definition of drought is a rainfall deficiency, whose occurrence, distribution, and magnitude affect the existing water supply, demand, and consumption. Such deficiency may lead to in less than expected water quantities necessary for the natural and the societal systems.

Droughts can befall anywhere in both high and low rainfall areas, in any locale and in any season. Drought impacts are exacerbated, when drought strikes a region with already limited water resources, and/or misuse and mismanagement of water and with discrepancies between water demand and water supply.

Since there is no single definition of drought, its beginning and ending points are difficult to be accurately determined. Thus, it is difficult for decision makers and stakeholders to initiate measures to confront drought timely and accurately. In this quest, a drought indicator may be proved a valuable tool. Drought indicators are conveying objective information about a system's status that may aid decision makers to identify the onset, magnitude and duration of a drought. Nevertheless, the literature agrees that no single index alone can precisely describe the spatial extent, the duration and the magnitude of the phenomenon. Given such characteristics, appropriate and effective drought early-warning systems should be based on multiple indices and/or a synthesis of indicators to sufficiently demarcate the drought events [5,6,8,10–16].

Currently very few indicators may appropriately illuminate all the drought dimensions at a large scale. In addition, applying multiple and /or a combination of indicators provides crucial information to monitor and categorize droughts. There exists a plethora of climatic, water supply and demand indices to illustrate the drought dimensions and to portray them in a stochastic posture. Each index has strengths and weaknesses, with none being superior to the other in its specific application. In this regard, SPI and SPEI offer a very well tested and dependable combination of indicators, thus they were chosen for application to describe Drought conditions in Europe during the latest decades.

Drought events have regularly occurred all over Europe and particularly in the last fifty years. The spatial extent, the magnitude, the duration of such drought events, as well as the diversified impacts inflicted on societies and the environment varied all over this period. Existing information in the pertinent literature categorizes the most harsh events that distressed more than (30%) of the EU territory as the ones in 1972-74, 1990-94, 2000, 2003, 2007 and 2011 with the most recent in 2018 [4,17–20].

Drought information in the literature exposed that there are two distinct geographical regions in Europe reflecting mostly common meteorological, environmental and geomorphological conditions: the southern Mediterranean corridor from the Atlantic Ocean to Asia Minor including Portugal, Spain, southern France, Italy, Greece, and Cyprus); and the Northern one beyond the Alps mountain chain having Belgium, UK, Finland, Germany, Hungary, Lithuania, Netherlands, Norway, Slovakia [6,7,17–21]. It is within these two regions that drought dimensions namely spatial extent, duration (temporal extent), and magnitude are markedly pronounced.

Drought spatial extent is closely associated to a country's given geographical locale and total area with the smaller countries to be usually devoured by the event per se (Cyprus, Greece, Italy, Malta, Spain, Portugal, France, Ireland, Great Britain, Denmark, Latvia, Estonia, etc.). Drought magnitude diversifies all over the continent with the most prominent the 1990-94, 2000 and 2007 ones in Spain Italy, Greece, France and Hungary [4,17–19]. Drought duration is equally fluctuating from country to country. In the Mediterranean area Cyprus, Greece, Italy, Malta, Southern France, Portugal and Spain, are having an extended summer period annually with minimal rain. Thus, droughts may only manifest themselves during the rainy winter months. In other words, a drought may have a six-month duration which compounding to the arid summer period creates a full problematic year [4,6,7,22,23]. In the northern countries, droughts occur primarily during the rainy summer season having durations from one month (Germany, Hungary, and Lithuania) to two up to six months (Northern France, Austria, Belgium). It is noted that Finland was distressed by a nine-month drought from August 2002 to April 2003 [24,25]. The estimation of the foremost drought impacts usually involves economic costs resulting from the various droughts. Such estimations depict the overall economic impacts of droughts during the last fifty years to more than 100 billion € at EU level. They also present that the annual average impacts doubled from the 1976-1990 period to the 1991-2006 one. Overall, the impacts cost on the average 6.2 billion €/year up to 2003, with an escalation to 8.7 billion € during the 2003 drought [24]. In the 2018 summer as shown in Figure 1, the majority of northern Europe is under a drought spell, including Ireland, Great Britain, Netherlands, Belgium, Northern France, Germany, Czech Republic, Denmark, Norway, Sweden, Estonia Latvia and Finland [20].

In this regard, drought impacts are already influencing the agricultural production in the region. According to EC (2018) the decrease in crop yields will exceed 50% in the majority of these countries, reaching up to 70% in Estonia. Hence, on August the 30th 2018, the European Commission offers advanced payments to distressed farmers to receive up to 70% of their direct payment and 85% of payments under rural development by mid-October 2018. It is pointed out that such compensations refer to economic costs and do not incorporate social and environmental costs as relevant data are not available. All in all, the improvement of the economic cost estimation has to comprise social and environmental impact assessments in an EC level approach.

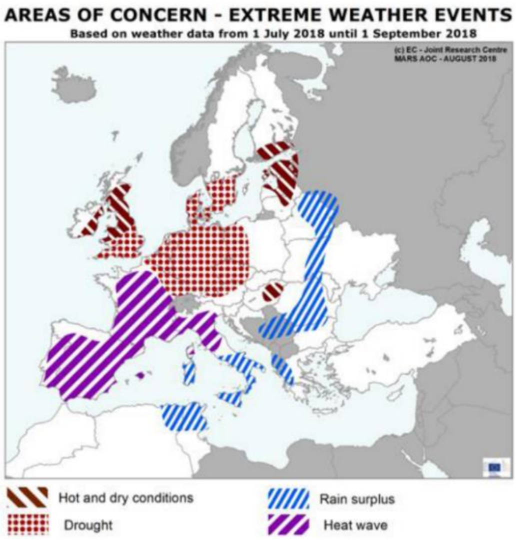


Figure 1. Weather Situation in EU Europe during July and August 2018 [26].

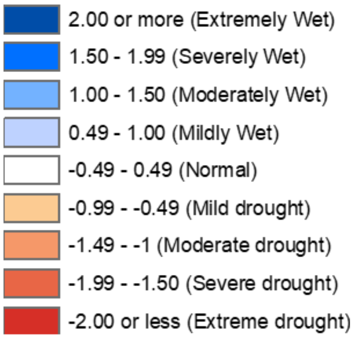
2. Materials and Methods

To produce SPI and SPEI, the ensemble version of the E-OBS dataset [27], which covers the area of 25N-71.5N x 25W-45E, in 0.25 degree regular latitude-longitude grid resolution, was used. The period on record of the E-OBS dataset starts on January 1950 and extends until September 2018. The information retrieved includes the following parameters: daily minimum temperature, daily maximum temperature, and daily precipitation sum. The data files are in NetCDF-4 format and their temporal resolution is daily following the regular calendar (including leap years). All data manipulation was performed in **R** [28] utilizing ncdf4 [29], raster [30], plyr [31], abind [32], and SPEI [33] R packages.

For the computation of the 6-month and 12-month SPI, daily precipitation for the study period (Jan. 1969 - Sep. 2018) was converted to a monthly step. Missing value criteria for each one of the grid cells' (93,264 in total) daily time series were set for quality control purposes. Such criteria are that the missing daily values within a month should not exceed 35% or they should not exceed 30% if the missing data are continuous. The minimum (maximum) daily temperature data were transformed to monthly mean. Daily minimum (maximum) temperature also based on the aforementioned criteria. Monthly evapotranspiration was computed for each grid cell based on the 1985 Hargreaves method [34] in order to be used as input for the SPEI index calculation.

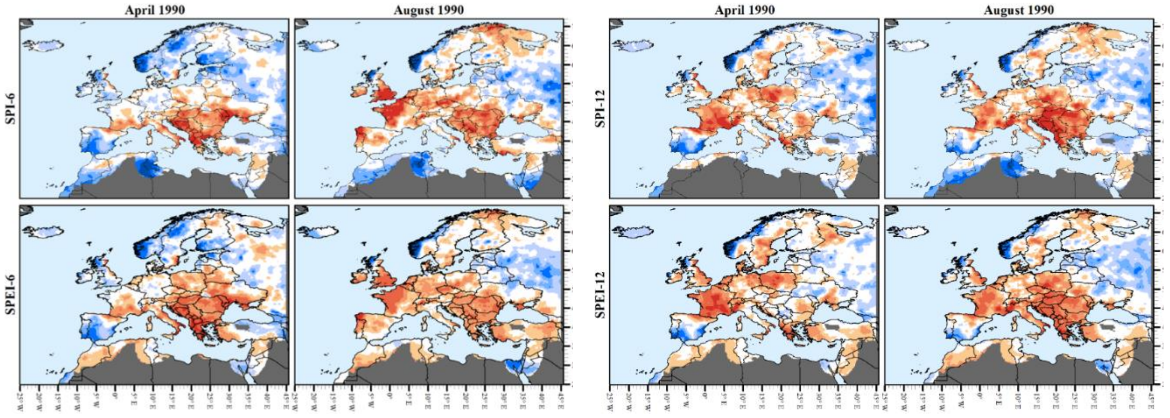
3. Results and Discussion

The resulting values were spatially visualized in a GIS environment. According to the classification presented in Figure 2. The 1990, 1993, 2003, 2007, 2015 and 2018, droughts were identified and spatially portrayed. From these droughts, the most intense drought periods were chosen to be included in the current effort namely the 1990, 2007 and 2018 ones. These events are presented in Figures 3, 4 and 5.



■	2.00 or more (Extremely Wet)
■	1.50 - 1.99 (Severely Wet)
■	1.00 - 1.50 (Moderately Wet)
■	0.49 - 1.00 (Mildly Wet)
□	-0.49 - 0.49 (Normal)
■	-0.99 - -0.49 (Mild drought)
■	-1.49 - -1 (Moderate drought)
■	-1.99 - -1.50 (Severe drought)
■	-2.00 or less (Extreme drought)

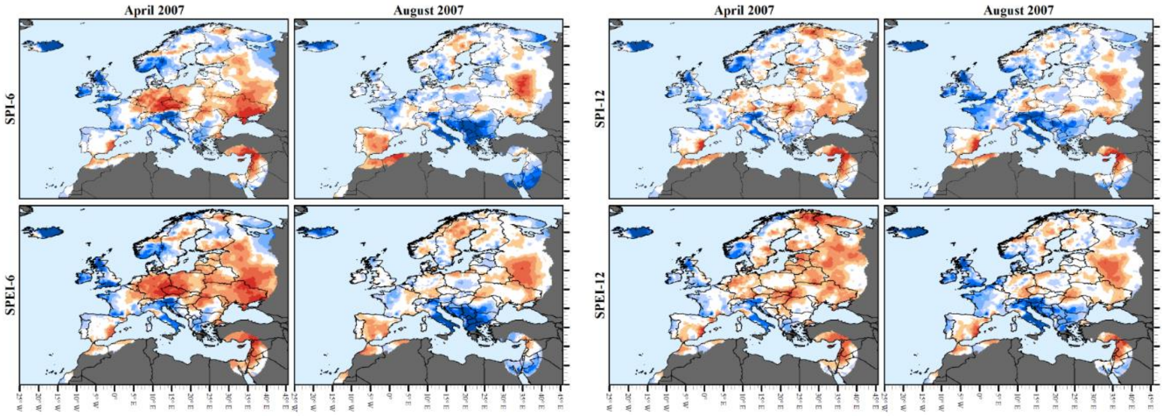
Figure 2. SPI Classification scale.



(**a**) (**b**)

Figure 3. SPI and SPEI for Europe on April and August 1990, a) 6-month step and b) 12-month step.

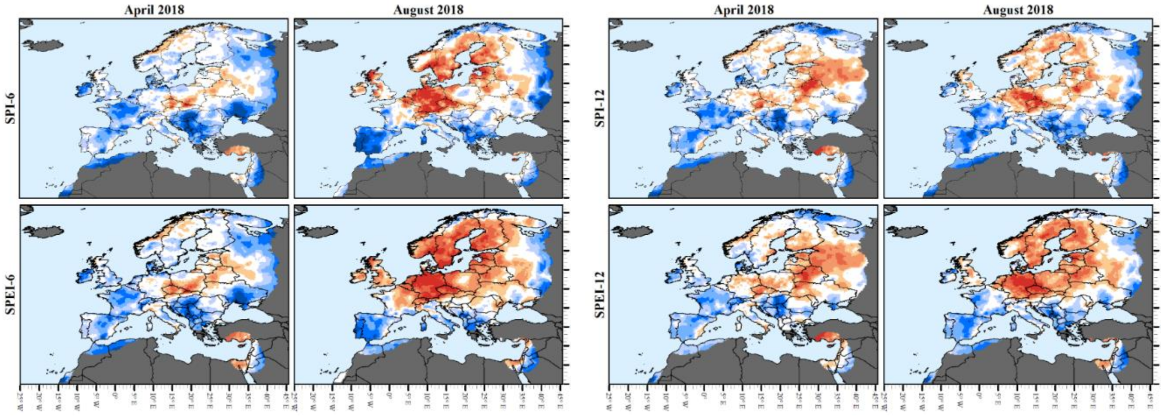
From Figure 3, it may be deduced that the drought was spread out all over Europe. The distinct behaviour of southern Europe points out that drought is intensified at the end of the usually rainy winter season. Such an event was recorded in the pertinent literature [4,5,7,19,22]. Particularly in Greece precipitation was only 43% of the annual average [4], a fact also portrayed in Figure 3. On north-western Europe drought reaches its peak at the end of the summer period, when the usual rains are crucial also for agriculture. The pertinent literature reported that during 1989, the weather all over Europe was unusually dry. This particular trend has continued in 1990, and drought alert was issued in many European countries [5,35].



(**a**) (**b**)

Figure 4. SPI and SPEI for Europe on April and August 2007, a) 6-month step and b) 12-month step.

From Figure 4 is more evident in North eastern Europe. Such an event was recorded by EEA [18] and Spinoni et al. [19]. Karavitis et al. [6] also report the manifestation of a rather minor drought in southern Europe.



(**a**) (**b**)

Figure 5. SPI and SPEI for Europe on April and August 2018, a) 6-month step and b) 12-month step.

The 2018 drought clearly manifests its spell on the Northern part of Europe as portrayed in Figure 5. These facts are also shown in Figure 1, as well as in the pertinent literature [20,26,36]. By comparing the various drought incidents as portrayed by SPI and SPEI, it may be derived that the most intense drought was the greatest on record for the given time period.

4. Conclusions

Effective decision-making is paramount for improving the assessment and responses to drought. In order that such Decision Making to take place the aid of indicators to pinpoint, the dimension of drought phenomena is more than critical. The application of SPI and SPEI has led to clearly depict drought events all over Europe with two distinct zones, the Mediterranean and the Northern one beyond the Alps. It would seem that the 1990 drought was the greatest on record. Policy makers and others must understand that drought is a normal climatic phenomenon, and its recurrence is inevitable and the delineation of its dimension are fundamental for any drought contingency and impact mitigation efforts.

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Conflicts of Interest: “The authors declare no conflict of interest."

Abbreviations

The following abbreviations are used in this manuscript:

SPI: Standardised Precipitation Index
SPEI: Standardised Precipitation Evapotranspiration Index

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