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Proceeding Paper

Top European Droughts since 1991 †

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Abstract: Severe and repeated droughts in Europe have significant impacts on agriculture, transport, energy and healthcare. During the summer of 2003, more than the two-thirds of Europe was under drought. The drought events of 2010 and 2018 were of a similar extent to 2003. An unprecedented stress on water levels throughout the entire EU was created by the combination of severe drought and heat waves during August 2022—the worst drought event in 500 years according to according to the Commission's Joint Research Centre. A raised awareness of drought characteristics is essential for better drought forecasting and monitoring in order to provide reliable adaptation strategies for drought hazard. In this study, the drought over six European stations for the last three decades using the standardized precipitation index (SPI) and the standardized precipitation evapotranspiration index (SPEI) was analyzed. SPI reveals that there are no significant changes in dry and wet conditions, while SPEI shows a significant increase in the drought frequency during the last decades for Central Europe and the Mediterranean. The discrepancies between the two indices can be explained by the increasing temperature and evapotranspiration that are fundamental components of drought occurrence in Europe. The SPI12 index managed to identify the drought of August 2022 in many regions in Europe, but with less intensity than it was recorded. Conversely, SPEI12 was able to identify the intensity of the drought.

Keywords: drought; SPI; SPEI; summer 2022; Europe

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1. Introduction

Drought can be considered as a very important issue worldwide over the past few decades as a result of climate change, and has considerable societal, environmental, economic and agricultural impacts [1]. The monitoring and the understanding of drought events is difficult due to the lack of a unique definition, the variety of its duration and the various meteorological indicators that a researcher can use, according to his goals [2,3].

Drought is considered as a multifaced phenomenon. Generally, drought starts as a decrease in precipitation total, but in recent years, drought [4] has been characterized by the decrease in precipitation combined with high temperatures and high evapotranspiration driven by the general circulation of the atmosphere. The absence of rainfall (meteorological drought) leads to dry soil and deficits in streamflow and groundwater (hydrological drought). Further knowledge about the phenomenon of drought is important in light of climate change, which has a variety of consequences and is related to different aspects of drought (drought characteristics and impacts).

As far as Europe is concerned, meteorological and hydrological droughts are of great importance, especially in spring and summer. More specifically, southern Europe shows a tendency towards drier conditions as a result of increasing drought frequency and severity [1]. In addition, long-lasting drought events take place in Western and Central Europe, Eastern Europe, Russia, Scandinavia and the British Isles [5]. The most notable drought events were recorded in 1976 (Northern and Western Europe), 1989 and 2003 (most of Europe), 2005 (Iberian Peninsula) [6] and 2018, with positive temperature anomalies, precipitation deficits and warm winters (Central and Northern Europe) [7].

The latest climate change projects indicate higher temperatures and thus higher evaporation, which lead to changes in the seasonality of precipitation patterns over Europe. In detail, winters and summers are becoming wetter and drier, respectively. In combination with the increase in the frequency and intensity of extreme climate events, droughts will be more frequent, severe and persistent in Europe [6]. Recent studies conclude that the drought frequency will be decreased in Northern Europe and increased in Southern Europe [7].

For drought monitoring, meteorological indices are widely used, such as the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) [8,9]. SPI is one the most widely used meteorological drought indices in Europe and is suggested by the "Lincoln declaration on drought indices". In comparison with SPI, the SPEI is computed with similar methods, but it detects drought better [10]. Both indices are simply calculated and interpreted and their use accumulates short or long anomalies. Consequently, these indices may be beneficial for the approximation of agricultural, hydrological and socioeconomic droughts.

In this study, the drought over six stations with representative European climate zones according to Köppen classification was analyzed for the last three decades, using the SPI and the SPEI indices.

2. Data and Methodology

2.1. Data

Daily precipitation data were utilized from the last three decades (1991–2022) for 6 European stations (Bologna-Cfa, Toulouse-Cfb, Helsinki-Dfb, Frankfurt-Cfb, Cambridge-Cfb, Thessaloniki-Csa, Name of the station-climate type of Köppen classification). These data were taken from the European Climate Assessment and Dataset (ECA&D) database (non-blended data) [11]. Additionally, PET was taken from CRU data for the same period (1991–2022) (https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.01/cruts.1709081022.v4.01/pet/, accessed on 15 December 2022). The geographical distribution of the study area is presented in Figure 1.

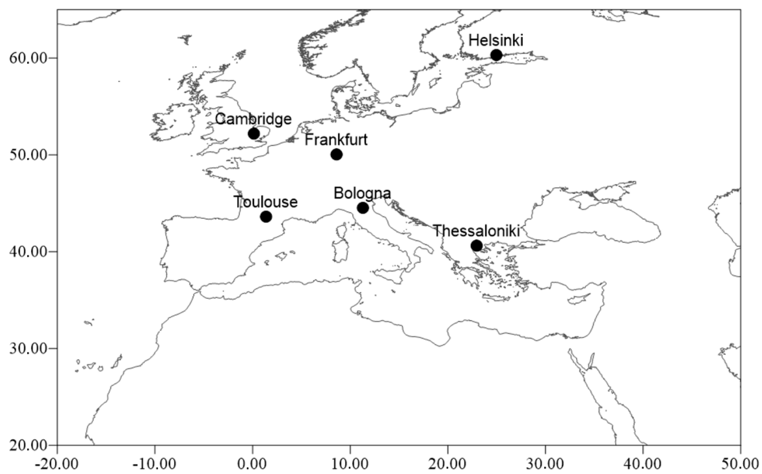

Figure 1. Geographical distribution of the study area.

2.2. Methodology

SPI is computed by summing precipitation over k months, termed accumulation periods, and fitting these accumulated precipitation values to a parametric statistical distribution from which probabilities are transformed to the standard normal distribution ($\mu = 0$, $\sigma = 1$). SPEI is defined as the difference between precipitation and PET. Both indices are interpretated as the number of standard deviations from typical accumulated precipitation for each station and time of year.

In this study, the indices were calculated on two time scales, 6 months (SPI6 and SPEI6) and 12 months (SPI12, SPEI12). For example, the SPI6 and SPEI6 for February 2000 was calculated using the monthly precipitation from September (1999) to February (2000). Correspondingly, the SPI12 and SPEI12 for December 2000 was calculated using the monthly precipitation from January (2000) to December (2000). According to McKee et al. [12], dry conditions are represented by negative SPI values categorized as moderate (−1 to −1.5), severe (−1.5 to −2) and extreme (<−2).

3. Results

The drought characteristics (number of dry episodes, max duration of drought period, peak and date of occurrence), based on the SPI and SPEI at the time scales of 6 and 12 months, are presented in Table 1. The highest number of dry periods according to SPI12 occurred in Toulouse, the longest drought periods happened in Thessaloniki, and the most intense peak was −3.28 in Thessaloniki (February 2002). The corresponding highest number of dry periods for SPEI12 was observed in Thessaloniki and the longest dry periods presented in Bologna. The higher intense drought was −3.61 in Toulouse (February 2012). As far as the SPI6 is concerned, most of the dry periods happened in Toulouse, and the longest drought period was in Thessaloniki at 45 months. SPI6 was equal to −3.38, the biggest value, in Frankfurt during November 2018. Finally, according to SPEI6, 30 dry periods were detected in Thessaloniki. Furthermore, the longest drought periods were detected in Cambridge, and the index was maximized (−2.46) in Cambridge at February 2012.

Table 1. Drought characteristics based on the SPI and SPEI at the time scales of 6 and 12 months.

		Bologna	**Toulouse**	**Helsinki**	**Frankfurt**	**Cambridge**	**Thessaloniki**
Number of dry episodes	SPI6	26	27	0	21	23	17
	SPI12	11	19	0	15	14	12
	SPEI6	24	22	28	22	23	30
	SPEI12	12	16	20	15	16	22
Max duration of drought period (month)	SPI6	28	25	1	18	27	45
	SPI12	32	31	0	33	30	62
	SPEI6	31	25	25	21	34	23
	SPEI12	61	27	27	50	35	30
Peak	SPI6	−2.63	−2.84	0.0	−3.38	−3.12	−2.72
	SPI12	−2.70	−2.83	0.01	−2.75	−2.61	−3.28
	SPEI6	−2.21	−2.35	−2.24	−2.16	−2.46	−2.35
	SPEI12	−2.43	−3.61	−2.31	−2.43	−2.40	−3.10
Date of Occurrence	SPI6	January 2012	March 2012	June 1991 June 2004	November 2018	September 2022	December 2000
	SPI12	July 2012	March 2012	October 2019 December 2021	April 2019	November 2011	February 2002
	SPEI6	June 2008	August 2003	November 2002	October 2018	February 2012	October 2001
	SPEI12	July 2019	February 2012	May 2003	May 2020	July 2022	January 2001

Comparing all indices, it was observed that SPEI12 had the highest values, regarding the max duration of drought periods and detected longest drought periods (61 months in Bologna and 50 months in Frankfurt). In addition, the SPEI12 and SPEI6 peaks generally were lower than SPI12 and SPI6 correspondingly.

Figures 2 and 3 illustrate time series of SPI and SPEI indices in time scales 6 and 12 months for Toulouse and Frankfurt, respectively. Both indices present high variability in accordance with the time scales. Furthermore, as the time scale increases, the dry episode duration also increases, but the indices frequency simultaneously decreases. This means that for time scale 6, the dry episodes are more and of low duration, while for the 12 time scale, these episodes become less and of higher duration. From 2018 to 2020, the use of SPEI12 resulted in drought episodes with higher duration, and with higher intensity. This coincides with recorded droughts in Europe. According to SPEI2, dry and wet episodes are clearly separated, and the most extreme dry episode was observed in Toulouse during February 2012, when the SPEI12 maximized (Figure 2). On the other hand, the maximum negative index value in Frankfurt was recorded in November 2018, when the SPI6 maximized (Figure 3). During 2022, SPI managed to identify the drought of August 2022, but with less intense, whereas SPEI12 identified the intensity of drought. Based on the SPEI12 values, it is shown that, from 2018 to 2022, the drought period lasted for a very long period in Frankfurt (Figure 2). Conversely, the longest dry period in Toulouse was evident during 2010–2012 (Figure 1). Overall, taking into consideration the results of SPEI12, it is revealed that at the end of the study period, the dry events become significantly longer (Figures 2 and 3).

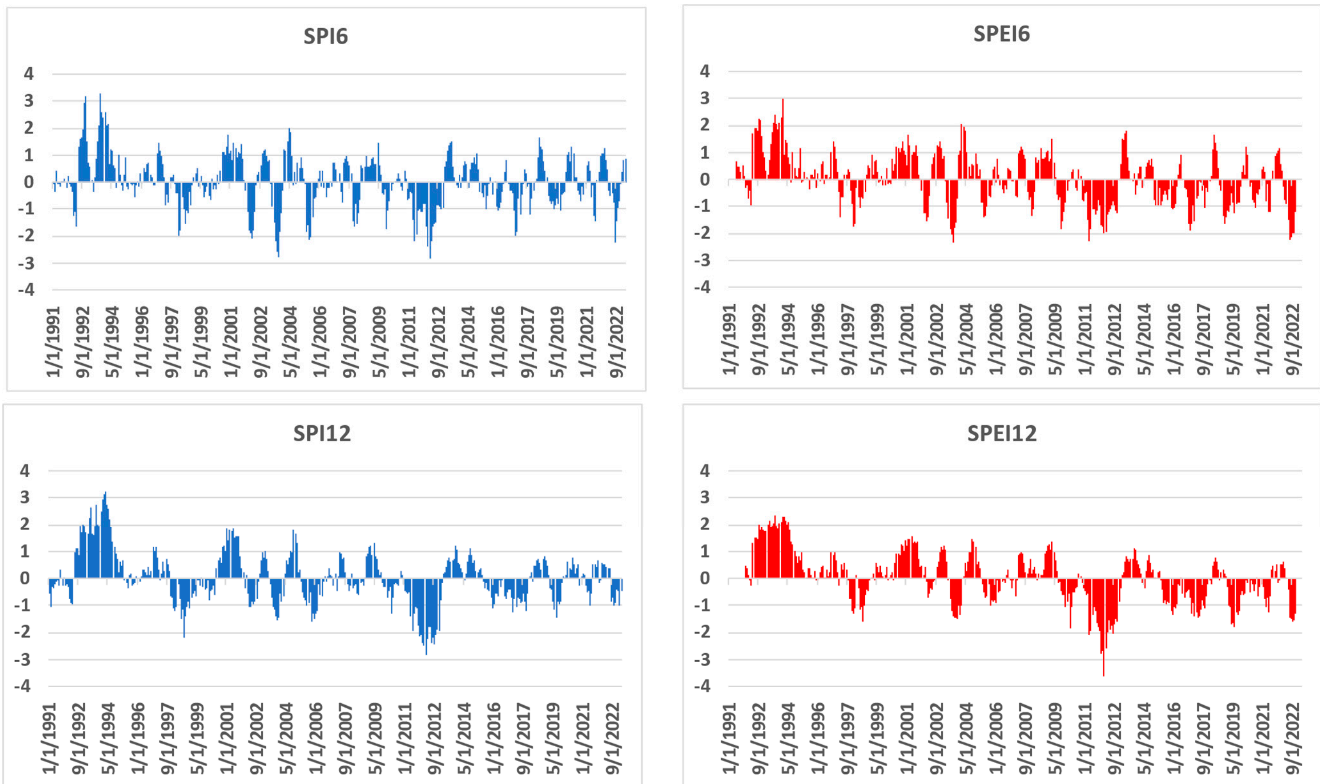

Figure 2. Time series of SPI and SPEI indices in time scales 6 and 12 months for Toulouse.

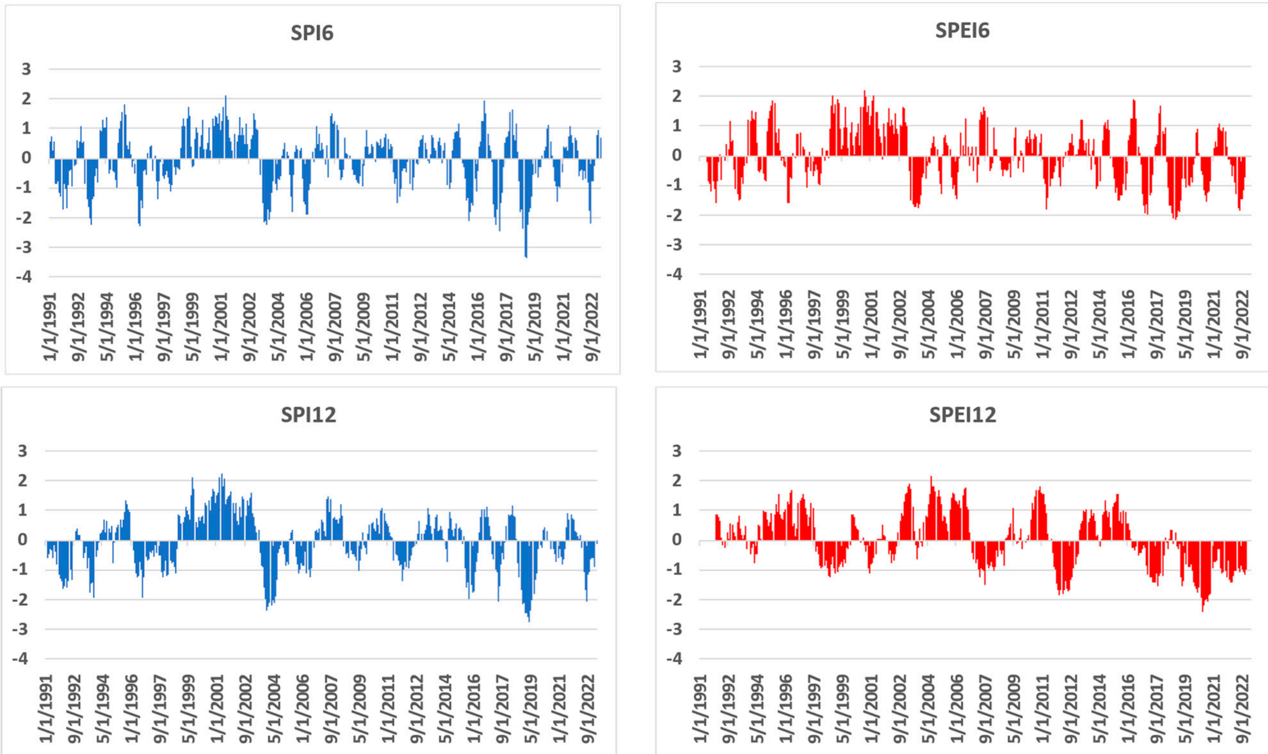

Figure 3. Time series of SPI and SPEI indices in time scales 6 and 12 months for Frankfurt.

4. Conclusions

In this study, European drought was explored by using the SPI and SPEI indices for six European stations over the past few decades. The main characteristic of SPEI is that the dry periods are of higher duration, in comparison with the SPI. Moreover, indices frequencies increase, and the duration of the dry periods decreases for the low time scales. The opposite behavior is obvious for the high time scales [13]. One important characteristic was the significantly high max values of SPEI12 in terms of the duration of drought events [14].

Generally, both indices have multi-scalar character, and this makes them appropriate for drought detection. What differentiates SPEI from SPI is that SPEI includes potential evapotranspiration (PET). The results obtained for the SPEI index was a combination between the increasing average temperature and increasing PET [15]. SPEI is possibly a more suitable index than SPI for the detection of droughts spatially and temporally in Europe, mainly in the Mediterranean [4]. As it seems, the existence of European drought over the last few decades was triggered mainly by the rise in air temperature and evapotranspiration, rather than precipitation deficit, under climate change [16]. Last year's drought in northern Europe underlined the interaction between climate, seasonal meteorology and hydrological characteristics. As a result, it is not enough to focus only on meteorological drought if its negative effects on the wider hydrological cycle are to be studied.

Given that Europe will be one of the most important hot spots of climate change in the future, it is necessary and crucial to investigate more effective drought detection mechanisms, in order to provide the suitable adaptation strategies and reduce risk.

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