

SPATIOTEMPORAL VARIABILITY OF DROUGHT IN ROMANIA DURING 1901-2021 USING THE STANDARDIZED PRECIPITATION EVAPOTRANSPIRATION INDEX (SPEI)

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Abstract: Drought represents one of the most frequent climatic events with impact on the environment, economy and society. In this study, we analyse the drought characteristics in Romania during the period 1901-2021, using a meteorological drought index: the Standardized Precipitation Evapotranspiration Index (SPEI). To provide a clear image over time, we have divided the data into four time periods: 1901 – 1930, 1931 – 1960, 1960 – 1990, and 1991-2021. The results indicate that the period between 1901 to 1930 is characterized by moderate droughts, in contrast to the period between 1991-2021 when extreme droughts prevailed. Also, the SPEI's spatial analysis indicates that Romania's eastern and southeastern parts are becoming drier. This study provides a clear image of climate change and indicates that the extreme drought events affected Romania in the previous decade.

Keywords: drought, SPEI index, spatiotemporal variability, Romania

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INTRODUCTION

The ongoing and projected climate changes affect present-day biodiversity and the services it offers, as well as the functioning of human society and its capacity to mitigate and adapt to these changes (IPCC, 2018). Global warming is already documented by the increase in temperature anomalies over the past century and exemplified by the numerous extreme climate events that have occurred in the past decade (Coumou & Rahmstorf, 2012). It is expected that the regions most impacted by climatic changes are those where biomes and land-use experienced different socio-economic and political regimes, for example, Southern and Central-Eastern Europe. In these regions, the unconsolidated political and governance systems and their failure to cope with fast-changing climate conditions add more pressure on the already fragilized environment, increasing the vulnerability of these countries and communities. Moreover, the interlinked changes in climate and biomes are superimposed on land-use changes; the land influences the fluxes and energy of the Earth system and is an essential sink of greenhouse gasses, and if there is any change among one of these vectors, all fluxes will be altered (Dale, 1997). One of the most affected sectors by climate change is agriculture, situated at the interface between ecosystems and society (Olesen & Bindi, 2002). In Romania, recent studies show that over the last 30 years, a period known for significant changes in climatic and socio-economic conditions (Prăvălie, et al., 2020), increasing temperatures (Croitoru, Piticar, Imbroane, & Burada, 2013; Bădăluță, Perșoiu, Ionita, Nagavciuc, & Bistricean, 2019), changes in precipitation and evapotranspiration (Prăvălie, et al., 2019) have had a significant impact on agriculture.

Droughts represent one of the most frequent extreme events impacting natural systems, society and the economy. Current climate change affects drought severity and risks through changes in snowpack storage (Huning & AghaKouchak, 2020; Livneh & Badger, 2020), precipitation (Cook, et al., 2020), evaporation and evapotranspiration (Wang, et al., 2020). In Europe, there is a significant increase in the occurrence of extreme events (Meehl & Tebaldi, 2004; Della-Marta, Haylock, Luterbacher, & Wanner, 2007; Twardosz & Kossowska-Cezak, 2013), especially droughts and heat waves, among which we mention: i) the heat waves of 2003, which determined the hottest summer of the last five centuries, affecting the entire European continent (Rebetez, et al., 2006), ii) those of 2010, which mainly affected Eastern Europe and Russia and determined the hottest summer of the last five centuries (Dole, et al., 2011), iii) the summer of 2015, known as the hottest and driest summer of the last five decades (Ionita, et al., 2017). At the same time, according to the European Commission (EC) report from 2007, the losses from period 1976-2006 droughts in Europe were estimated at around 100 million Euros (EC, 2007). To quantify droughts and monitor wet and dry periods, a series of indices have been developed such as Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI); Standardized Precipitation and Evapotranspiration Index (SPEI), Precipitation Anomaly Index (RAI); Crop Moisture Index (CMI); Surface Water Supply Index (SWSI). The purpose of the current study is to evaluate the Romanian level of the drought phenomenon every three months in the last 120 years, based on the Standardized Precipitation and Evapotranspiration Index (SPEI).

STUDY AREA

Romania is located in Central-Eastern Europe, north of the Balkan Peninsula, and on the western part of the Black Sea (Figure 1). Climatic conditions depend on the country's varied topography (Figure 1). The Carpathians serve as a barrier to Atlantic air masses, limiting their oceanic influences to the west and center of the country, which experiences milder winters and heavier rainfall as a result. In the eastern part, the Carpathians also block the vast Russian Plain's continental influences, resulting in frosty winters and less rain in the south and southeast.

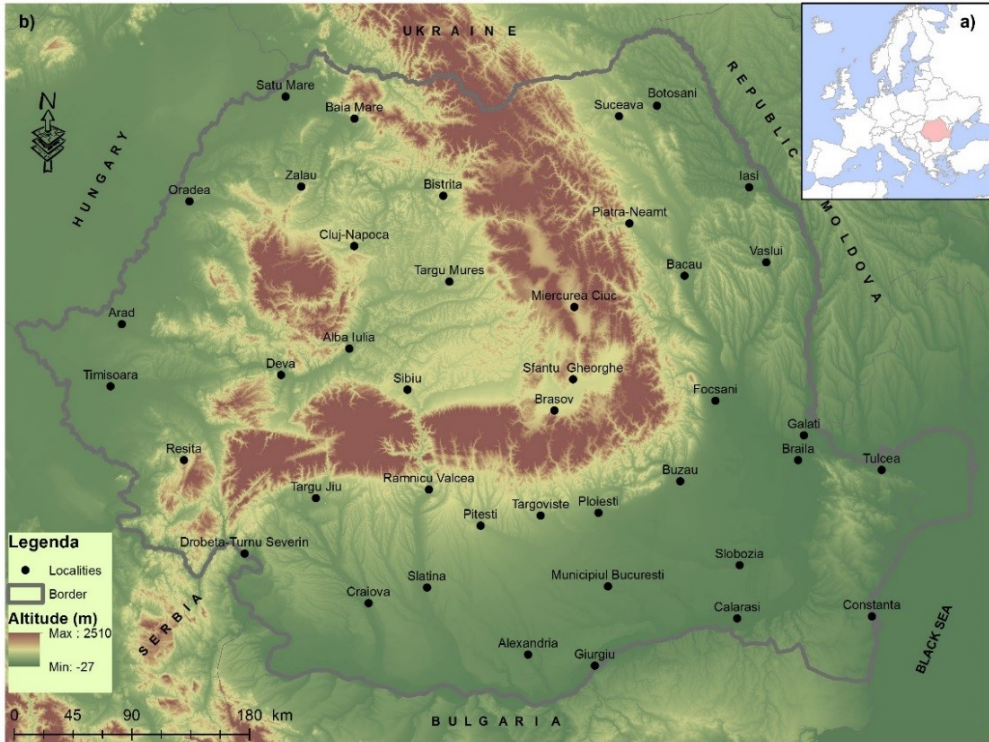


Figure 1. Location of Romania in a) Europe and b) the distribution of localities taken into account for the SPEI 3 analysis from 1990 to 2021

The distribution of the amount of precipitation and the average air temperature in Romania is defined by the orography, they show variations from one region to another. The average annual temperature has values between 0 - 12°C, with the minimums being recorded in the high areas of the Carpathians (above 2000m), while the maximums are recorded in the low areas (e.g., the Danube meadow in S and SE Romania).

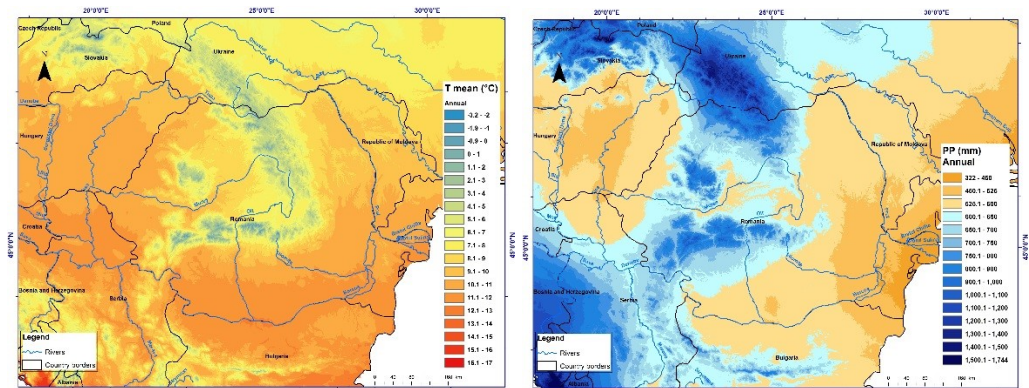


Figure 2. a) Distribution of mean annual temperature and b) multiannual precipitation during the period 1970 – 2000 according to the WorldClim database version 2 at a resolution of 30 seconds (Source: Fick & Hijmans, 2017)

The position of Romania at a distance of about 1500 km from the Atlantic Ocean and with air masses from the Atlantic crossing the Alps Mountains mean that the precipitation in Romania is diminished (Kondracki, 2014). The multiannual average amount of precipitation in Romania presents values between 350 – 1400 mm (Figure 2b), with the minimum recorded in the SE areas, and the maximum in the high altitude mountain areas (Fick & Hijmans, 2017).

DATA AND METHODS

To analyze the climate characteristics of Romania, we used the monthly mean air temperature (T) and monthly precipitation amount (PP) from the WorldClim database (Fick & Hijmans, 2017). The climate dataset (e.g., average temperature, precipitation amount) used in this study has a high spatial resolution (30 seconds) and is related to the climatic period between 1970 - 2000. To analyze the spatial distribution of T and PP, we used the interpolation method of the ArcGIS 10.7.1 package.

This study is based on monthly analyses of the Standardized Precipitation Evapotranspiration Index (SPEI) from the GLOBAL SPEI dataset for 41 localities - county residences (Figure 1b). We obtained the SPEIs from the CRU TS 4.06 dataset (Harris, Osborn, Jones, & Lister, 2020), which spans the period from January 1901 to December 2021. Data are available monthly and have a spatial resolution of $0.5^\circ \times 0.5^\circ$. In this study, we have analyzed the short timescale (3 months) of SPEI index. The variation of SPEI values depicts the intensity of droughts and rainfall surpluses. Negative values represent the driest conditions, while positive values suggest wet conditions (Table 1).

Table 1. Classification of the intensity of droughts and rainfall surpluses according to SPEI index classes
(Source: Vicente-Serrano, Beguería, & López-Moreno, 2010)

SPEI index value	Drought type
$\text{SPEI} \leq -2$	Extremely dry
$-2 < \text{SPEI} \leq -1.5$	Severely dry
$-1.5 < \text{SPEI} \leq -1$	Moderately dry
$-1 < \text{SPEI} \leq 1$	Near normal
$1 < \text{SPEI} \leq 1.5$	Moderately wet
$1.5 < \text{SPEI} \leq 2$	Very wet
$\text{SPEI} > 2$	Extremely wet

RESULTS AND DISCUSSIONS

Temporal analysis of the SPEI 3 index

The key feature of the SPEI index is that it can be used to quantify the effect of global warming on drought severity (Vicente-Serrano, Beguería, & López-Moreno, 2010). Thus, SPEI considers temperature values (maximum and minimum values), evapotranspiration values with a stationary character, and precipitation values that do not have a normal distribution.

In this study, a single time scale was used, 3 months respectively, the average monthly values at the country level are represented in Figure 3. Thus, at the level of Romania, dry periods were identified between 1903 - 1910, 1925 - 1933, 1944 – 1955, 1982 – 1996 and 2010 -2021, the last three periods presenting the highest degree of severity.

At the analyzed time scale, SPEI indicates a high frequency of changes between wet and dry periods (Figure 3). Therefore, SPEI 3 tends to fluctuate near 0 values, with dry periods being those with values less than -1 (1903 – 1910, 1925 – 1933, 1944 – 1955, 1982 – 1996 and 2010 -2021) and wet periods with values greater than 1 (the periods between 1911 – 1924, 1934 – 1943, 1956 – 1981 and 1997 – 2009). Ionita, Scholz, & Chelcea (2016) and Ionita (2015) identified similar results of dry periods based on the SPI index at both the country level and the Danube River basin level. A severe drought affected Romania in 1903, 1921, 1934, 1946, 1950, 1983, 1986, 1990, 1992, 1994, 2003, 2007, 2011, 2015, 2019 and 2022 (see Figures 3 and 4). In the years listed above, droughts occurred mostly during spring, summer and autumn, and in some years even in winter.

The period between 1945 and 1946 is known as the great drought, with significant consequences for the harvests, so the lack of food led to one of the greatest periods of famine in Romania. Thus, this period counted no less than 21 calendar months (from February 1946 to October 1947) where the SPEI 3 index shows values between - 0.3 and - 2.1 (over 85% of months with SPEI 3 values lower than -1). The values of the SPEI 3 index and the revelations of the people from that period clearly show that Moldova was the most affected area.

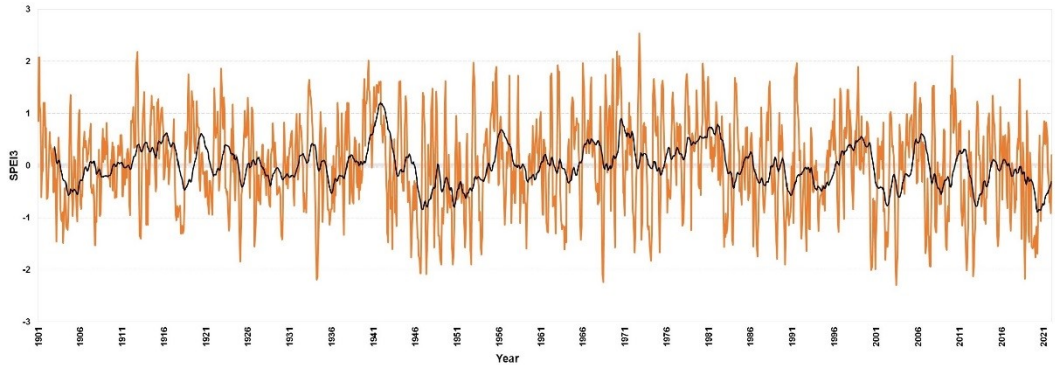


Figure 3. Monthly SPEI variation over Romania during the period between 1901 – 2021

At the same time, our results (Figure 6a) indicate that the decadal period between 1941-1950 was characterized by the highest increase in the frequency of extreme dry months (more than 13 months of severe drought during 10 years), which is similar to the results of the SPEI 12 index (Ionita & Nagavciuc, 2021).

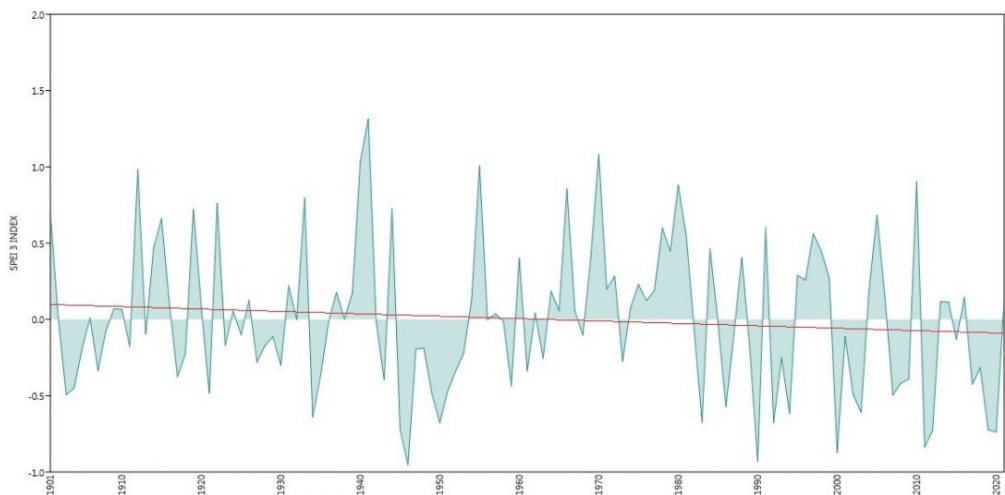


Figure 4. SPEI3 variability and the trend (red line) over Romania during the period between 1901 – 2021

Analyzing the SPEI trend (Figure 4), we found that starting from the second half of the 20th century, there is a downward trend in SPEI, which translates into increased dryness and, respectively, an increase in the frequency of droughts. Considering that the SPEI 3 index trend is decreasing (Figure 4) and the average temperature is rising, we expect droughts to increase until the end of the 21st century.

Analysis of the spatial distribution of drought severity

To provide a complex picture of drought severity on an average time scale (3 months) over the past 120 years, we have divided the data into four time periods (30 years): 1901 – 1930, 1931 – 1960, 1960 – 1990, and 1991-2021. The data was divided into four different periods to test if there were significant changes in drought conditions between different periods. The analysis is performed for SPEI3, for three different categories of drought (McKee, Nolan, & Kleist, 1993) moderate ($-1.5 < \text{SPEI} \leq -1$), severe ($-2.0 < \text{SPEI} \leq -1.5$) and extreme ($\text{SPEI} \leq -2$). Frequency in each category (moderate—Figure 5, severe—Figure 6, and extreme—Figure 7) is expressed as the number of months/time period.

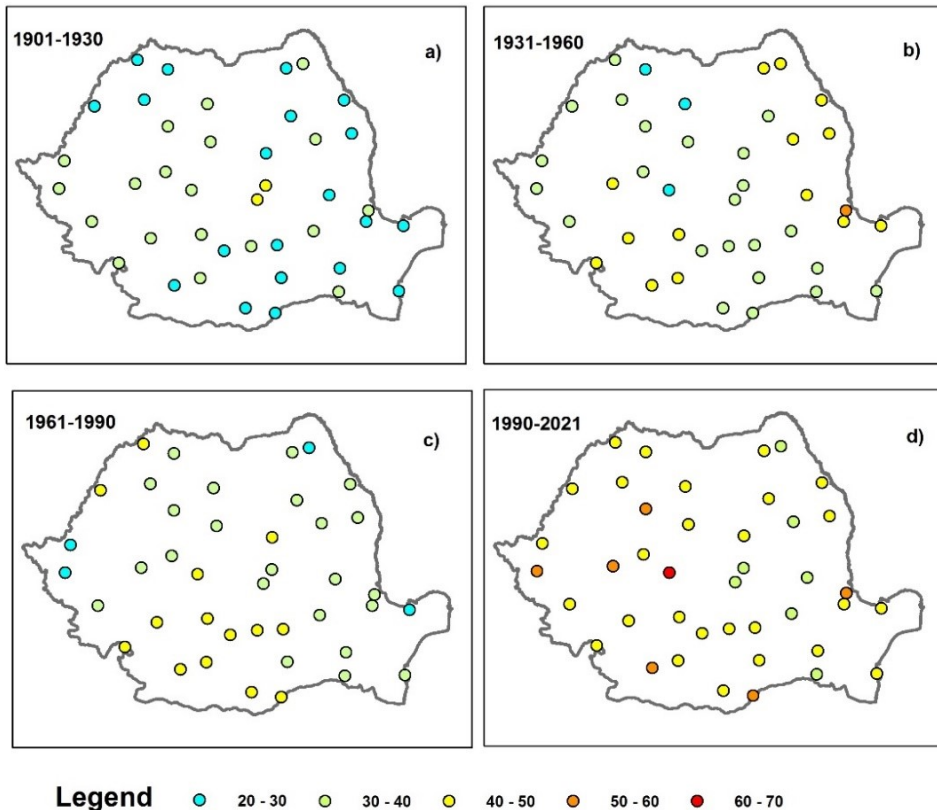


Figure 5. Total duration of moderate drought ($-1.5 < \text{SPEI} \leq -1$) for the periods: a) 1901-1930, b) 1931 – 1960, c) 1961-1990 and d) 1991-2021. Unit: number of months/period

The period between 1901 and 1930 was characterized by moderate droughts (20 - 41 months), located in NE Romania, a large part of Transylvania and Oltenia. At the same time, a predisposition to severe droughts is observed in the area of Moldova, southern Dobrogea, Bărăgan and Oltenia Plains, with frequencies of 10-20 months. On the other hand, during this period, an extremely low number of extreme droughts is observed throughout Romania. For the period between 1931 and 1960, a predominance of moderate droughts was observed in Moldova and Oltenia (50 - 70 months), followed by a decrease in the number of months to 20 - 40 months in the case of severe droughts throughout Romania. In contrast, the total duration of extreme droughts varies between 0-12 months, being prone to NW Romania, the northern half of Transylvania, Moldova, Muntenia, the southern half of Dobrogea and Oltenia (with several 6-12 months).

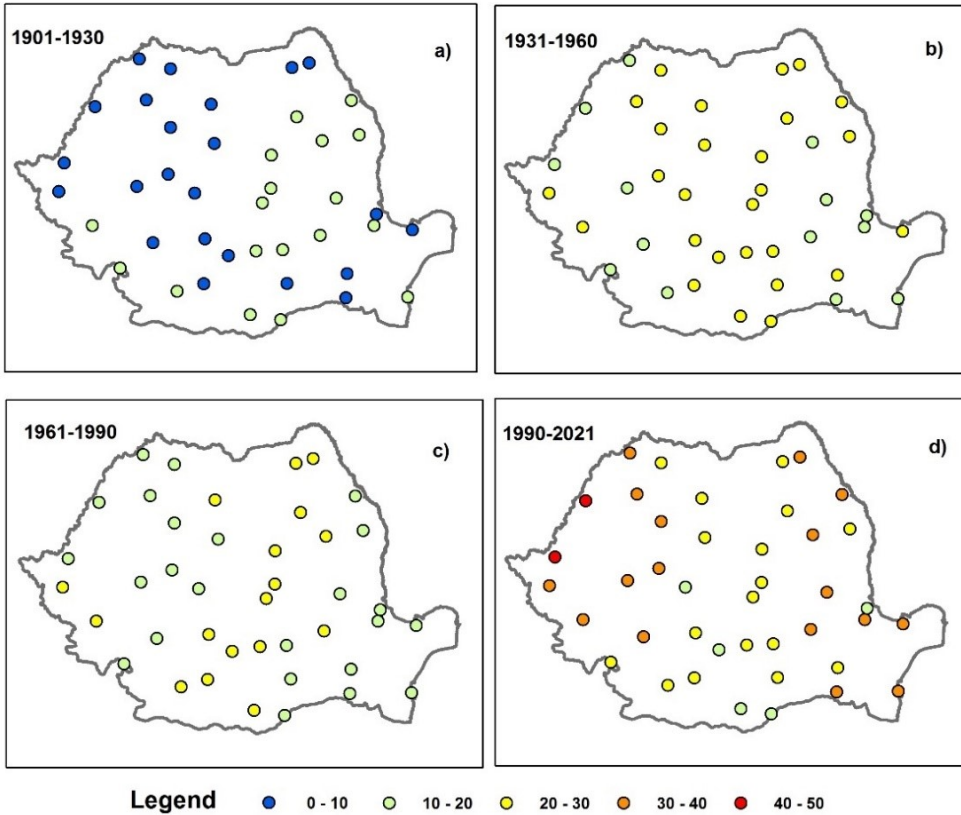


Figure 6. Total duration of severe drought ($-1.5 < \text{SPEI} \leq -2$) for the periods: a) 1901-1930, b) 1931 – 1960, c) 1961-1990 and d) 1991-2021. Unit: number of months/period

As in the case of the previous periods, the period 1961-1990 presents the highest number of months of moderate drought, with the highest number of months (40-50 months) being recorded in Oltenia and Câmpia Someșului Mare, followed by 30-40 months for most of Romania's territory (Figure 5). Also, the total duration of the number of months with severe drought is 10-30 months, with the highest number of them (20-30 months) recorded in the northern half of Moldova, Oltenia, Bărăgan and Banat. The extreme droughts from 1961 to 1990 are characterized by a low number of months of their occurrence (0-9 months), the fewest months being recorded in Moldova, Banat, N Dobrogei and Bărăgan, and the most months in N Romania (6-9 months). In the rest of Romania's territory, extreme droughts are present between 3-6 months. The last period, from 1991 to 2021, stands out as the driest, with the total number of months of drought reaching its highest level since 1901 and 1921.

Thus, the number of the duration of the moderate drought has values between 37-61 months, the severe one between 17-49 months, and the extreme one between 4-17 months. Thus, the longest duration of moderate drought was recorded in Banat, Oltenia and southern Transylvania, while in the case of severe drought, it was recorded in Crisana and the southern half of the Danube Delta, followed by Moldova, Bărăgan, Dobrogea. The extreme drought for the period 1991-2021 is represented in Fig 6d. For this period the number of dry months is between 0 – 17, but nevertheless it is the period with the most months of SPEI 3 index registration with values ≤ 2 .

This indicates an increase in the frequency of extreme droughts over the past 120 years.. Analyzing Figure 7d, an increase in the duration of the extreme drought can be observed in the south of Moldova, Bărăganu, Dobrogea, followed by values of 9-12 months in Banat, southern Transylvania and the northern half of Muntenia.

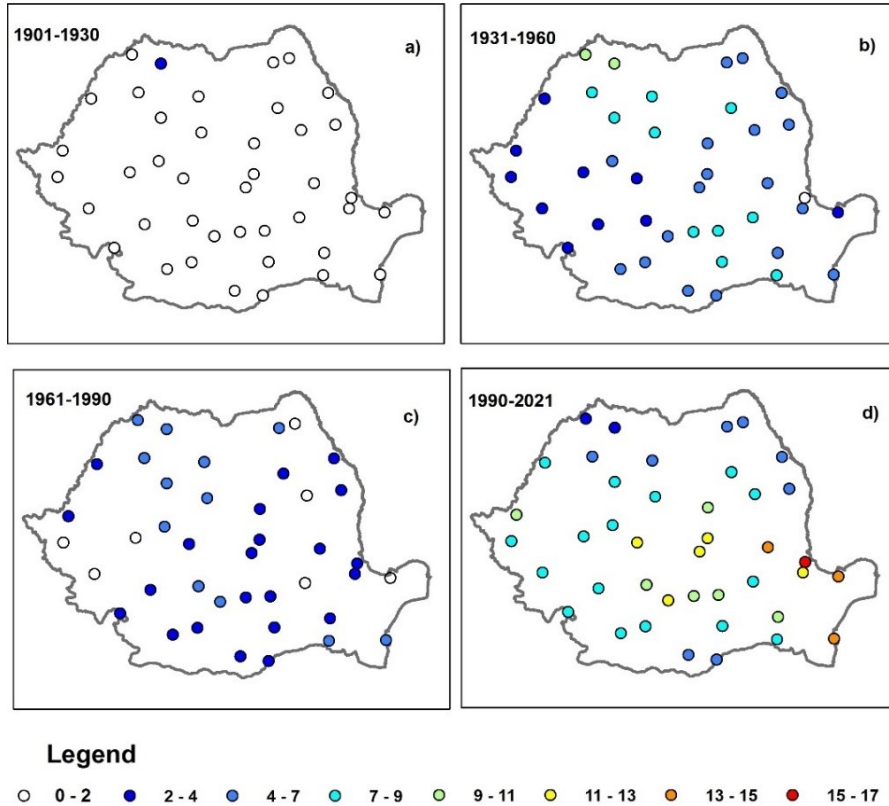


Figure 7. Total duration of extreme drought ($-2 < \text{SPEI} \leq -2.5$) for the periods: a) 1901-1930, b) 1931 – 1960, c) 1961-1990 and d) 1991-2021. Unit: number of months/period

The last period, i.e., 1991-2021, is the driest, with the total number of months of drought being the highest since 1901-1921. Thus, the duration of the moderate drought has values between 37-61 months (Figure 5d), the severe one between 17-49 months (Figure 6d), and the extreme one between 4-17 months (Figure 7d). Thus, the most extended duration of moderate drought was recorded in Banat, Oltenia and southern Transylvania.

In contrast, in the case of severe drought, it was recorded in Crisana and the south half of the Danube Delta, followed by Moldova, Bărăgan, Dobrogea. The extreme drought for 1991-2021 is represented in Figure 7d. For this period, the number of dry months is between 0 – 17, but it is the period with the most months of SPEI 3 index registration with values ≤ -2 . This indicates an increased frequency of extreme droughts over the last 120 years. Analyzing Figure 6d, an increase in the duration of the severe drought can be observed in the south of Moldova, Bărăgan, Dobrogea, followed by values of 9-12 months in Banat, southern Transylvania and the northern half of Muntenia.

CONCLUSION

In the last three decades, droughts have affected Eastern Europe (Hanel, et al., 2018; Ionita & Nagavciuc, 2021; Jaagus, et al., 2021), and Romania (Cheval, Busuioc, Dumitrescu, & Birsan, 2014; Ionita, Scholz, & Chelcea, 2016; Angearu, et al., 2020), with great impact on society and ecosystems. In the European Union, the annual economic drought losses during the period 1981-2010 it were estimated at 9 billion per year and the percentage will increase with anthropogenic warming (Naumann, Cammalleri, & Mentaschi, 2021).

In this study, we analyzed the temporal and spatial variability of droughts using the Standardized Precipitation Evapotranspiration Index (SPEI) over 120 years.

The results indicate that the region of Moldova, especially the southern part and Bărăgan, are the most vulnerable regions to drought, with the intensity and frequency of this phenomenon being influenced by climatic characteristics. Simultaneously, the identification of Oltenia and Banat as vulnerable regions came after Bărăgan and the south of Moldova. In terms of frequency, the period 1991–2021 was identified as the period with the highest number of months affected by moderate, severe and extreme drought.

The study's results recommend adjusting water resource management strategies based on the spatial extent of drought frequency. In order to better estimate the impact of climate change and drought variability and trends on Romania, additional studies should be developed for longer periods of time, which can be used for various climate change models and scenarios.

AUTHOR CONTRIBUTIONS

C.A.B. conceptualization (lead), supervision (equal), writing – original draft (lead), writing – review & editing (lead); A.H.: writing – original draft (equal), writing – review & editing (equal); R.E.S.: supervision (lead), writing – original draft (equal), writing – review & editing (equal). G.B.: writing – original draft (equal), writing – review & editing (equal).

COMPETING INTERESTS

The authors declare that they have no conflict of interest.

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