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METEOROLOGICAL DROUGHT IN SOUTHWEST BULGARIA DURING THE PERIOD 1961–2020

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Abstract: Although drought is a common phenomenon in Southern Europe, including Bulgaria, it can have adverse effects on human life and economic activities (water scarcity, reduced agricultural production, and economic losses to agriculture). This event occurs regionally, but it can spread over large areas. Whether it will be perceived as a hazard depends on the affected areas and the degree of impact. The article aims to provide new insight into the meteorological drought in the most densely populated NUTS 2 region of Bulgaria—the Yugozapaden (Southwestern). Based on Standardized Precipitation Indices (*SPI*-1 and *SPI*-3), its occurrence during the period 1961–2020 was analysed in terms of duration, intensity, and magnitude. The maximum drought duration and average drought intensity were determined using *SPI*-1. The seasonal distribution of drought shows its higher frequency in spring and summer, but on the other side, extreme drought was more common in winter and autumn. The maximum drought duration was observed mainly in the 1990s.

Keywords: seasonal drought; Standardized Precipitation Indices; drought frequency; drought intensity

1. Introduction

During recent years, in a number of regions of the world, more frequent and severe extreme weather events such as cold and hot waves, floods, droughts, forest fires, and storms have been observed. According to climate models, an increase in dry events and prolonged dry periods combined with high temperatures is expected in many regions of the world and in particular in Southern Europe, including Bulgaria (Dai, 2013; Spinoni et al., 2018; Trnka et al., 2015; Trnka et al., 2011).

Unlike climate aridity, drought is a temporary phenomenon caused by natural factors such as lack of or low rainfall, insufficient soil moisture, high air temperatures, anticyclonic atmosphere, etc. (Djebou, 2017; Eslamian & Eslamian, 2017; Mishra & Singh, 2010; Van Loon, 2015) but exacerbated by anthropogenic activity (water consumption, land use and cultivation, etc.; Wilhite et al., 2000). According to the definition given by the Intergovernmental Panel on Climate Change (2014), drought can be assessed as a hazard and a risk depending on the likelihood of impact on people's lives and economic activities. As one of the most complex

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natural events, droughts have a significant socio-economic effect, but unlike other natural hazards, it causes mostly non-structural losses (for example, land value decline or failure of agricultural yield; Markandya & Mysiak, 2010).

Common to all types of droughts is the lack of precipitation (Kerang & Makarau, 1994). From a meteorological point of view, drought is associated with a lack of precipitation and the occurrence of dry periods of different duration and severity. When this phenomenon persists for a long period of time, rainfall is insufficient to meet the needs of human activities and ecosystems. According to Anđelković and Živković (2007), dry periods are considered an adverse phenomenon when they are longer than a month.

Nevertheless, the established negative trend in the multi-year changes in precipitation during the last century (1900–1990) for many regions of Southeast Europe shows that there is a high probability of frequent and intense droughts in Bulgaria (Tran et al., 2002). The tendencies toward their increase and severity in Southern and Eastern Europe, especially in summer and autumn, have been pointed out in scientific publications (Spinoni et al., 2017; Vicente-Serrano et al., 2014). Observation data from the last two decades show an increase in the frequency of dry events in Bulgaria (Koleva & Alexandrov, 2008; Popova et al., 2015; Radeva et al., 2018). On the other hand, as a consequence of climate change, there has recently been an increase in the frequency of extreme rainfall events in Bulgaria (Bocheva et al., 2010; Spiridonov & Balabanova, 2021).

Drought in Bulgaria has been investigated by many authors (Nikolova et al., 2022; Popova et al., 2014; Popova et al., 2015), but most of the analyses refer to the lowland areas such as the Danube Plain and the Upper Thracian Lowland, which are the main agricultural regions of the country. Based on the observed monthly precipitation, this article aims to quantify the meteorological drought in the Yugozapaden region, which is the most densely populated NUTS 2 region in Bulgaria. To achieve the aim of the study, the duration of dry periods, drought magnitude (*DM*), and intensity are analysed, and the seasonal peculiarities of drought occurrence are shown.

2. Study area

The NUTS 2 Yugozapaden region occupies 18.3% of the territory of Bulgaria (Figure 1). It is a cross-border region that is leading in the socio-economic development of Bulgaria with a relatively dense settlement network of large cities (Stoychev et al., 2021). The area is characterized by a complex relief, represented by mountains, valleys, river valleys, and gorges. Most of the region is included in the European-continental climate zone, and the southern valley of the river Struma, south of the Kresna gorge is part of the continental-Mediterranean climate area (Topliiski, 2006). According to Köppen's classification, the climate in most parts of the study area is characterized by Cf type (warm temperate climate, fully humid) and in the mountainous area, the climate type is D (Snow climates), while in the southern part of the region, the climate type is Cs (warm temperate climate with dry summer). The highest parts of the mountains (Cherni vrah and Musala peaks) are characterized by climate type E (cold climate, without forest vegetation; Table 1; Rachev & Nikolova, 2009).

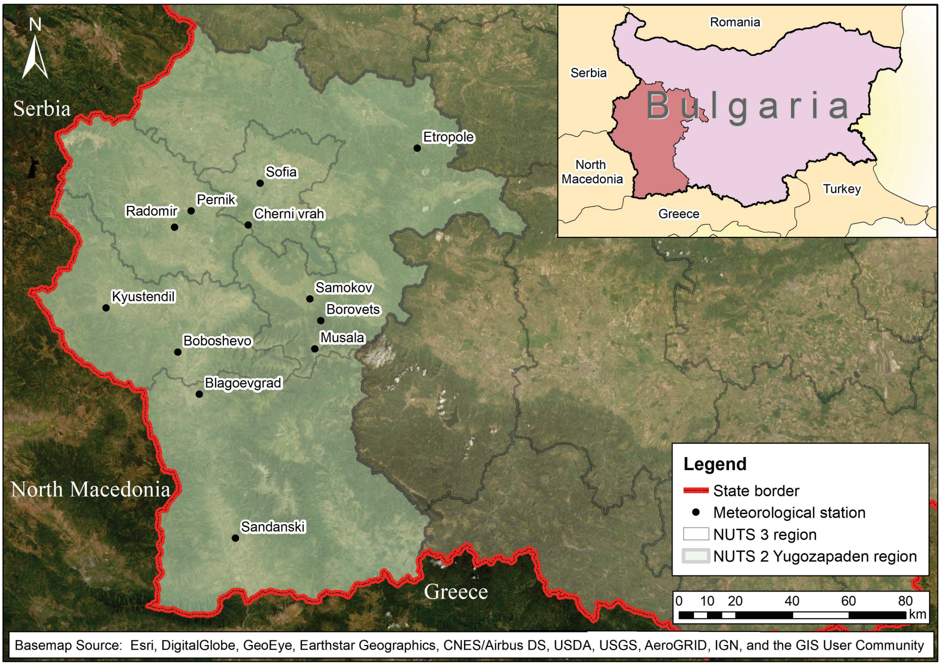

Figure 1. Study area and location of meteorological stations.

Table 1. Geographical coordinates of the meteorological stations used in the research (from north to south of the study area)

Meteorological stations	Latitude (°N)	Longitude (°E)	Altitude (m a.s.l.)	Climate type (Köppen classification)
Etropole	42.83	24.00	618	Cfb
Sofia	42.69	23.32	550	Cfb
Pernik	42.61	23.03	710	Cfb
Cherni vrah	42.56	23.27	2,290	E
Radomir	42.54	22.96	964	Cfa
Samokov	42.33	23.33	950	Dfb
Kyustendil	42.29	22.69	560	Cfb
Borovets	42.27	23.61	1,350	Dfb
Musala	42.18	23.59	2,925	E
Boboshevo	42.15	23.00	386	Cfb
Blagoevgrad	42.02	23.09	410	Cfb
Sandanski	41.57	23.28	296	Csa

The annual precipitation totals vary in the ranges 500–550 and 1200–1300 mm. In most of the study area, the precipitation falls in June, and in the southern parts—in winter (Topliiski, 2006). From north to south, the frequency and amount of snowfall, as well as the number of days with snow cover, are decreasing across the territory of the entire reviewed region. The Yugozapaden region includes parts of the catchments of the largest rivers in Bulgaria—Iskar, Struma, and Mesta. In the Yugozapaden region, 22% of the volume of rivers and 24% of the volume of groundwater in the country are found (Stoychev et al., 2019). In general, the quality of surface and underground water is good, which is a prerequisite for the development of agricultural activities. The Yugozapaden region is characterized by the spread of Vertisols, Luvisols, Cambisols, humic Cambisols, Umbrosols, and Fluvisols (Traykova, 2007). These soil types are essential for the development of agricultural production. The Yugozapaden region has about 10% of the country's arable land and about 25.6% of the country's forests (Stoychev et al., 2019). Deciduous (oak and beech) and coniferous species (pine, fir, and spruce) are widespread.

3. Data and methods

The present study is based on monthly precipitation data for the period 1961–2020 from 12 meteorological stations located in the southwestern planning region (Yugozapaden; Figure 1; Table 1). Data were provided by National Institute of Meteorology and Hydrology, Bulgaria. The stations are in areas with various relief and climatic conditions. Meteorological drought occurrence, duration, and intensity in the study area are analysed by Standardized Precipitation Index—*SPI* (McKee et al., 1993), calculated based on monthly precipitation for the period 1961–2020. World Meteorological Organization (WMO) recommended SPI as the main indicator for drought analyses (European Commission, 2020) and the index was widely used in scientific publications (Aladaileh et al., 2019; Alexandrov, 2011; Alexandrov & Radeva, 2010; Caloiero et al., 2018; Ceglar et al., 2008; Cheval, 2015; Deniz et al., 2016; Leščešen et al., 2019; Nikolova & Radeva, 2019; Živanović & Gocić, 2022).

The *SPI* values correspond to the standardized series of precipitation values transformed to a gamma distribution. Therefore, at *SPI* = 0 there is no deviation from the average value of precipitation in the selected time scale for the analysed period. Positive SPI values indicate that precipitation is above average, and negative SPI values indicate that precipitation is below average (Alexandrov & Radeva, 2010; McKee et al., 1993, 1995; Svoboda et al., 2012). According to McKee et al. (1993), the following classes of drought severity were determined (Table 2).

When *SPI* has values between –0.99 and 0.99, the conditions are near normal. Drought event starts when *SPI* reaches a value of –1 and continues until index values become equal to or higher than 0 (Svoboda & Fuchs, 2016; Svoboda et al., 2012). In cases where the *SPI* decreases from 0 to –1, the conditions are close to normal.

For the present analysis, we consider as dry events (seasons) all cases with *SPI* ≤ –1 while extremely dry events (seasons) occur when *SPI* becomes –2 or less. The *SPI* values were calculated using SPI program (SPI Generator; Version 1.7.5; National Drought Mitigation Center, 2018). One of the advantages of *SPI* is that the indices can be calculated for multiple timescales. Generally, meteorological drought is evaluated based on short-term timescale *SPI* (1, 2, or 3—month *SPI*) while *SPI* for one to six months is associated with agricultural drought and SPI for 12-months—with hydrological drought (Nikolova et al., 2016; Svoboda et al., 2012; Wang et al., 2022).

Table 2. Classification of droughts according to *SPI* values

Drought class	SPI values
Moderate	–1.0 to –1.49
Severe	–1.5 to –1.99
Extreme	–2.0 and less

Note. Adapted from *Standardized Precipitation Index: User Guide* (WMO-No. 1090; p. 4), by M. Svoboda, M. Hayes, and D. A. Wood, 2012, World Meteorological Organization (https://library.wmo.int/doc_num.php?explnum_id=7768). Copyright 2012 by World Meteorological Organization.

For the present analysis we investigated drought events based on *SPI*-1 and *SPI*-3. We used *SPI*-1 to determine drought duration, magnitude, and intensity. Following Svoboda and Fuchs (2016), drought duration (*D*) was determined as a period that starts when *SPI* reaches –1 or less and ends when *SPI* is 0 or a positive value. *DM* represents the positive sum of the *SPI* for all the months during a given drought event. *DM* was calculated as follows (McKee et al., 1993):

$$DM = -\left(\sum_{i=j}^{x} SPI_{ij}\right) \tag{1}$$

where *j* is the first month when *SPI* becomes equal to or less than –1 and *x* is the last consecutive month with a negative *SPI* value.

Average drought intensity over the duration (*ADI*) is determined by Equation 2 (Bonaccorso et al., 2003; McKee et al., 1995).

$$ADI = \frac{DM}{D} \tag{2}$$

Drought occurrence and severity at a seasonal level were analysed by *SPI*-3. We extracted the following *SPI*: *SPI*-3 (February) which was calculated using precipitation totals for December, January, and February and corresponds to the winter, *SPI*-3 (May) for spring, based on monthly precipitation for March, April, and May, *SPI*-3 (August) as a result of calculation for June, July, and August— for summer and *SPI*-3 (November) as a result from September, October, and November—for autumn.

3. Results and discussion

3.1. Drought frequency

The analysis of the seasonal distribution of drought frequency in the Yugozapaden region of Bulgaria shows the highest frequency of dry events (*SPI*-3 ≤ –1) in spring (15.8%) and summer (15.4%) of all years in the period 1961–2020 (Figure 2). The frequency of extremely dry seasons (*SPI*-3 ≤ –2) is higher in winter and autumn and the lowest in spring. It varies between 3.8% (winter) and 2.4% in spring.

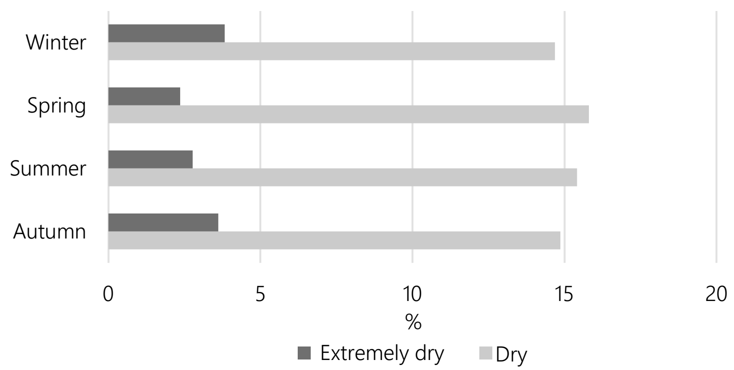

Figure 2. Seasonal distribution of drought frequency, average for all stations (as a percentage of all years for the period 1961–2020).

Extreme winter drought is most common in the valleys of the northern and central parts of the Yugozapaden region. In the summer, the high mountain stations of Cherni vrah and Musala, as well as the valleys in the central part of the region, are characterized by more frequent manifestations of dry events.

3.2. Drought occurrence—temporal and spatial characteristics

For the observed period, the driest winters were established in 1989 and 1990, when drought occurred in all the 12 studied stations. In 17% of the studied stations, the winter drought in 1989 was extreme. In 1976 and 1993, drought was observed in 83% of the surveyed stations (Figure 3). The years 1967, 1976, and 1983 are pointed out by Koleva and Alexandrov (2008) as years with long dry periods in the cold half of the year in Bulgaria.

The only exceptions are the high mountainous stations Musala and Cherni vrah where *SPI*-3 did not show dry winters in 1976 and 1993. Drought was relatively widespread in the winters of 1992 and 2014, when it was observed in 75% of the surveyed stations. According to *SPI*-3, extreme drought in winter was most widespread in 1992 and 2014 when it was established in 50% and 42% of the stations surveyed, respectively. For less than 20% of the studied stations, extremely dry winters occurred in 1976, 1989, and 2008.

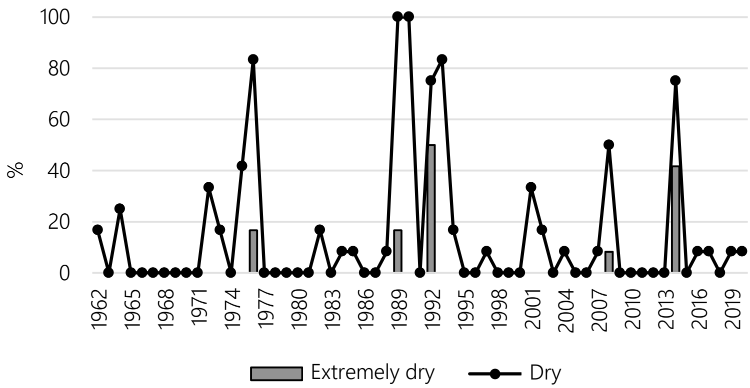

Figure 3. Percentage of studied stations with dry and extremely dry winters.

Dry winters were observed most often (about 17–18% of the studied years) in the stations Sofia and Samokov (temperate-continental climate) and Kyustendil and Blagoevgrad (transitional-continental climate). Based on the calculations of *SPI*-3, the periods in which no drought was observed in any of the studied stations during the winter seasons can be indicated. Such long periods were observed in the periods 1965–1971, 1977–1981, and 2009–2013 (Figure 3).

During the period 1961–2020, dry spring seasons were reported in 67% to 75% of the surveyed stations. These dry seasons were in 1968, 1972, 1983, and 2000. Drought in the spring of 1985, 1993, 1998, and 2019 was observed in a relatively large number of surveyed stations, between 42 and 50% of the total number of surveyed stations (Figure 4).

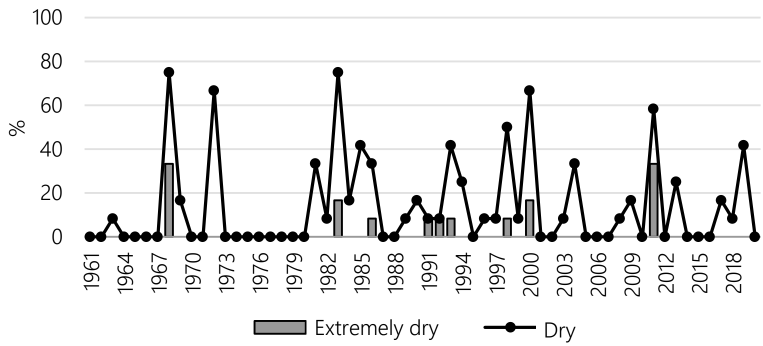

Figure 4. Percentage of studied stations with dry and extremely dry springs.

During the spring seasons, extreme drought was most widespread in 1968 and 2011, when it was observed in 33% of the surveyed stations. It also occurred in the spring of 1983, 1986, 1991–1993, 1998, and 2000, but with less territorial coverage (less than 17% of stations were affected). On the other hand, the period 1973–1980 is characterized by no drought in the spring. Spring drought was observed most often in the central part of the studied area (stations Blagoevgrad, Boboshevo, and Samokov), and also in the high parts of the mountains (stations Cherni vrah and Musala). It should be noted that no extreme drought was recorded in the high mountain stations in spring. Despite analysing different periods (1931–2012) for studying dry events in the non-mountainous part of South Bulgaria (Nikolova et al., 2012), it is found that severe spring drought is most frequently observed in the valley of the Struma River and Kyustendil. For the period 1961–2020, the driest was the summer of 1993, when drought was found in all 12 studied stations (Figure 5), and for 67% of the stations, *SPI*-3 showed extreme drought, situated in the regions of Blagoevgrad, Boboshevo, Pernik, Radomir, Sandanski, Sofia, Musala, and Cherni vrah. In almost all stations (92% of the total number), except for Kyustendil station, a drought was observed in 2000, which proved to be extreme in 42% of the surveyed stations. Similar results were found by Gocheva et al. (2010), based on *SPI*-3 for the period 1960–2009. Summer droughts were also relatively widespread in 1987, 1996, and 2012. Extremely dry summers were observed in 25% of the surveyed stations in 2012. On the other hand, the period 1971–1977 is characterized by the absence of dry summers.

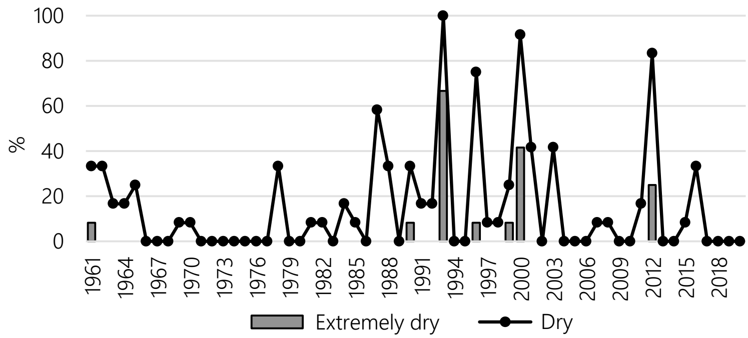

Figure 5. Percentage of studied stations with dry and extremely dry summers.

The driest autumn was in 1986, when drought was found in 100% of the stations surveyed. In most of the stations (92%) there was a drought in the autumn of 1965 (the only exception is the high mountain station Cherni vrah, where drought was not observed in the autumn of 1965). In the autumn of 1965 and 1969, extreme drought was found in half of the stations surveyed. Droughts were relatively widespread in 2000 (83% of stations), 1969, and 2001 (67% of stations). Autumn droughts were also observed in a significant number of stations during 1984, 1994, and 2012 (Figure 6).

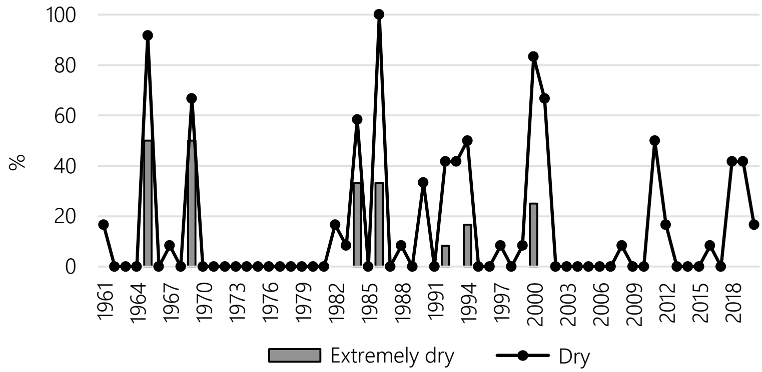

Figure 6. Percentage of studied stations with dry and extremely dry autumns.

Extreme droughts also occurred in the autumn of 1984 and 1986 (in 33% of stations), as well as in the autumn of 2000 (in 25% of the stations). The autumns of 1992 and 1994 were extremely dry in 8 to 16% of the stations. The extreme autumn drought was most common in the high valleys in the northern part of the regions of Samokov, Pernik, and Radomir. During autumn, no drought was observed in the periods 1970–1981 and 2003–2007.

3.3. Maximum drought duration, drought magnitude, and average drought intensity

According to *SPI*-1, the maximum duration of drought in the individual study stations varies from five to 20 months, with up to 10 consecutive dry months observed mainly in the northern part of the study region, and dry periods lasting for 11 to 20 months are typical for the south of the region. In the high mountainous stations Musala and Cherni vrah, the longest periods of drought were 11 and 12 months long, respectively (Table 3). Drought in mountainous areas can have a significant negative effect on the environment and economic activities. It can lead to a reduction in water resources and unfavourable conditions for forest development (Raev & Rosnev, 2018). Tran et al. (2002) point out that by reducing precipitation and snow cover, winter drought affects river runoff. In addition, the higher frequency of extreme drought in the cold half of the year may have a negative impact on winter tourism, as in the southwestern region of Bulgaria some of the largest ski resorts in the country are located (Mochurova et al., 2010).

In most of the studied stations, the periods with a maximum duration of drought were established in 1992–1993, and for the western parts of the studied territory (Pernik, Radomir, Sofia, and Kyustendil), these periods are in different decades (the 60s, 70s, or 80s of the 20th century). Calculating the Palfai aridity index, Gocheva et al. (2010) also found a drought peak in 1993 for Blagoevgrad and Sandanski. Extreme drought (*SPI*-1 ≤ –2) was observed in most of the studied stations during the longest periods of drought, although the average intensity of drought decreased with the increasing duration of dry periods.

According to *SPI*-1, the maximum duration of the drought for the period 1961–2020 was established at the station Blagoevgrad, where in the period from August 1992 to March 1994 there were 20 consecutive dry months (*SPI*-1 ≤–1). The magnitude of this event was –15.24, and the average intensity of drought was –0.76.

Table 3. *D* for the period 1961–2020 (in months), determined by *SPI*-1, lowest value of *SPI* (Peak), *DM* and *ADI*

Meteorological stations	Start month	End month	*D*	Peak	*DM*	*ADI*
Etropole	August 1992	April 1993	9	–1.76	7.73	–0.86
Sofia	January 1972	June 1972	6	–1.78	5.69	–0.95
Pernik	May 1962	September 1962	5	–2.29	6.67	–1.33
Cherni vrah	December 1992	November 1993	12	–2.2	11.77	–0.98
Radomir	May 1982	October 1982	6	–1.29	3.69	–0.61
Samokov	May 2000	December 1999	8	–2.13	12.79	–1.6
Kyustendil	May 1969	November 1969	7	–2.61	7.48	–1.07
Borovets	March 1992	April 1993	14	–3.01	15.57	–1.11
Musala	December 1992	October 1993	11	–1.87	11.72	–1.07
Boboshevo	April 1993	November 1993	8	–2.62	8.94	–1.12
Blagoevgrad	August 1992	March 1994	20	–1.99	15.24	–0.76
Sandanski	January 1993	October 1993	10	–2.06	9.8	–0.98

From March 1992 to April 1993, 14 consecutive dry months were established at Borovets station. This drought had a magnitude of –15.57 and an average intensity of –1.11. For the region of the capital (Sofia station), as well as for the regions of the stations Pernik, Radomir, and Kyustendil (located in the western part of the study area) the lowest number of consecutive dry months was established (maximum duration of the drought was 5–7 months).

The results of the present study show that drought is more pronounced in the valleys of the central and northern parts of the investigated region. The spatial distribution of meteorological drought in the Yugozapaden region, established by SPI-3, confirms the role of orography for the regime and amount of precipitation, discussed by Matev (2020). Another factor influencing the manifestation of drought is atmospheric circulation. Tran et al. (2002) show synchronicity between drought occurrence in Bulgaria and synoptic conditions related to the anticyclonic activity over Central Europe. Despite several publications analysing the occurrence of drought in Bulgaria, there are still many questions regarding the causes of the occurrence of drought. In the future, more research on specific synoptic conditions during dry periods and also on large-scale circulation patterns is needed to determine the causes of drought occurrence.

4. Conclusion

Based on monthly precipitation amounts, the spatio-temporal features of the meteorological drought in in the Yugozapaden region, the most densely populated NUTS 2 region in Bulgaria, are analysed. The seasonal drought characteristics were determined by calculating *SPI*-3. Drought was most common in spring and summer, but on the other hand, cases of extreme drought were more common in winter and autumn than in spring and summer. During the 1980s and 1990s, drought was observed in a significant part of the study area. Spring and summer are also characterized by drought at the beginning of the 21st century, manifested in a significant number of the studied stations.

In the southern part of the study area and in the mountain stations, a higher number of consecutive dry months (from 10 to 20) was found in comparison with the northern part (5–9 months). In most of the studied stations, the maximum duration of the drought was observed mainly in the 90s. The stations located in mid- and high-mountain areas have the lowest values of *SPI*-1, showing extreme drought and also the highest values of *DM*.

Through the analysis of *ADI* and *D* of dry periods, the present study contributes to the theoretical basis of drought research in Bulgaria. The practical significance of the results is determined by the presented information regarding the peculiarities in the manifestation and intensity of the drought in a regional and local aspect. Although drought is a frequent phenomenon in Bulgaria with negative consequences for agriculture and the water sector, there is still no drought management plan developed in the country. Knowledge of the frequency of occurrence of droughts of different intensities can be applied to water resource management and to effectively tackle environmental and economic issues related to water scarcity and drought. Future research will focus on assessing drought hazard and vulnerability, which can be used as a basis for developing and implementing measures to reduce and possibly eliminate the risk of water scarcity and drought.

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