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Drought Periods in Non-Mountainous Part of South Bulgaria on the Background of Climate Change

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Abstract

The scientific investigations and various analyses show a trend towards a significant extension of water scarcity across Europe. Decreasing of precipitation totals and increasing of drought periods are characteristic for many regions of Bulgaria. Often high temperatures, strong winds and low relative humidity occur in conjunction with the drought. This makes the drought very strong expressed.

The present work aims to analyze drought periods in South Bulgaria in terms of its temporal variability, intensity, seasonal and territorial differences. The study areas are one of the main agricultural areas in Bulgaria and because of this investigation of drought in this region is very important. Drought periods are investigated on the base of seasonal precipitation totals and precipitation indices. The data for monthly precipitation from nine meteorological stations situated at the regions with different geographical conditions are used.

The deviations of the seasonal and annual precipitation from normal (precipitation for the period 1961-1990) are used to determine drought periods in investigated stations. The duration of drought event is determined by Cumulative Precipitation Anomalies (CA). The Standardized Precipitation Indices (SPI) are calculated in order to determine moisture conditions and occurrence of drought periods in the investigated stations. The results from the research show that drought was widespread in 1945 and 1949. The years with dry seasons are more often during 80's and 90's but drought during these periods was observed in a few of the investigated stations.

Keywords: precipitation, drought periods, drought indices, South Bulgaria

Introduction

There are many definitions of drought in the scientific literature but one of them is very characteristic: Drought is a condition of insufficient water to meet needs (Redmond, 2002). Motha (2000) defines four main types of drought: 1) meteorological drought, which is connected to the period with precipitation averaging below a critical threshold; 2) agricultural drought refers to the lack of sufficient moisture available for crops, forests, rangelands, and livestock; 3) hydrological drought, associated with water supply systems such as river drainage basins and aquifers; and 4) social or economic drought which is complex interaction of the natural phenomenon, environmental degradation, and human impact.

Many analyses show that recently the number and intensity of droughts in the EU have dramatically increased. The number of areas and people affected by droughts went up by almost 20% between 1976 and 2006. One of the most widespread droughts occurred in 2003 when over 100 million people and a third of the EU territory were affected (COM/2007/0414). Total economic cost (primarily from agriculture) of the drought in 2003 was approximately US$13 billion, and in general higher than for floods (DG JRC, 2005).

Common to all types of drought is a lack of precipitation (WMO, 1993). The precipitation is one of the main climate elements with important impact on various aspects of anthropogenic activity. The

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quantity of precipitation determines quantity of river runoff and underground water. The analysis of trend of annual precipitation total for the period 1901-2005 shows increasing of precipitation in many regions from Northern hemisphere with 20 to 40% (IPCC, 2007, WG I). In the other hand, Balkan Peninsula is characterized by a general decreasing trend of precipitation since the beginning of the 1980s (Alexandrov, 2004). One of the features of contemporary climate in many regions in Europe and Bulgaria also is increasing of occurrence of extreme events – heavy precipitation or droughts. In the last years, the interest in scientific investigations related to many-years variability of precipitation increases because of the importance of the problems caused by intensive or insufficient precipitation. Many publications analyze variability of precipitation in Bulgaria (Koleva, 1995; Vekilska, Rathcev, 2000, Topliiski, 2005, etc.). Petkova et al. (2008) show overall decrease in winter precipitation in many areas in North Bulgaria during the period 1931-2005. In the scientific literature there are many publication related to the methods of investigation of drought or to the analysis of draught regarding its occurrence, intensity and factors (Afonso do Ó, 2005, Vicente-Serrano et al., 2005, Keyantash, Dracup 2002, Heim, 2002, Knight et al., 2004).

Scientific investigations on the regime and many-years variability of precipitation in Bulgaria show the tendency to decreasing of precipitation totals and drought in various regions in the country. Tran et al. (2002) point out that the drought can occur at any time and extend over a long period and over large areas to a very severe level in Bulgaria. Alexandrov (2011) shows three drought periods in Bulgaria: 1902-1913, 1942-1953 and 1982-1994. During the first period the dry years are about 20%, in the second period dry years increase to 40% and during the period 1982-1994 about 50% of the years are dry. During the period 1931-2005 and mainly during the last decades extreme dry months occurred more often than extreme wet months (Nikolova, 2008). Despite of many publications on precipitation in Bulgaria deep statistical analyses are needed in order to answer to various questions related to contemporary climate change in regional scale.

The aim of this research is to estimate temporal variability and intensity of dry periods and to analyze seasonal and spatial differences in occurrence of drought. This paper specifically aims to show utilization of precipitation indices for studying drought periods. That is why the objectives of present research work are monthly and seasonal precipitation. The following tasks are solved for achieving the aim of the research: 1) investigation of multiannual variability of seasonal precipitation by means of cumulative anomalies (CA) and 2) calculation and analysis of Standardized precipitation index (SPI).

Data and methods

Data

The data for monthly precipitation totals from nine meteorological stations for the period 1931-2008 are used to achieve the aim of the investigation. The information from these stations is representative for the study area. To obtain the most reliable results the quality of initial data has been verified. The data have been checked for missing values and have been tested for homogeneity. There are not missing values in the investigated time series. The AnClim software (Stepanek, 2006) has been used to test the homogeneity of monthly precipitation with the Alexandersson test. Non-homogeneities have been detected mainly after the 80s. The non- homogeneities may be due to the different data sources. All the series of monthly precipitation totals where non-homogeneities were detected have been adjusted with the AnClim software. After the homogenization of monthly precipitation totals the seasonal and annual totals have been calculated as follow: Winter – December, January, February; Spring – March, April, May; Summer – June, July, August; and Autumn – September, October, November.

Study area

The stations are situated at the non-mountainous regions in South Bulgaria (Figure 1., Table1). As non-mountainous area, we consider the territories with altitude above 600 m (Geography of Bulgaria, 2002). The relief is presented by lowlands and valleys. The climate is transitional between moderate continental and Mediterranean. Monthly temperature in winter is positive but close to 0°C and it reaches about 22 – 23°C during July and August. The annual precipitation is about 450 – 600 mm with clearly manifested tendency toward equalization of seasonal precipitation. The Mediterranean influence on climate is well expressed in the most southern part of the study area (stations Sandanski, Kardzali and Haskovo) where monthly and annual temperature are with 2-3°C higher than in other stations. The Mediterranean rainfall regime - with the autumn-winter maximum and summer minimum is typical for this area. The study area is a part from the main agricultural regions in Bulgaria where the anthropogenic activity is considerable and natural vegetation is replaced by agriculture crops. That is way the investigation of precipitation and drought is very important for this area.

Figure 1. Meteorological stations used in the study

Table 1. *List of meteorological stations used for the research*

Meteorological stations	Latitude	Longitude	Altitude (m)
Kyustendil	42°17′	22°41′	521
Kazanlak	42°37′	25°24′	382
Sliven	42°42′	26°19′	264
Karnobat	42°39′	26°59′	196
Haskovo	41°.56′	25°33′	191
Kardzali	41°39′	25°22′	241
Sandanski	41°34′	23°19′	193
Blagoevgrad	42°01′	23°06′	410
Plovdiv	42°09′	24°45′	160

Methods

Cumulative precipitation anomalies (CA) are used in order to study the duration of drought event. Cumulative Precipitation Anomalies directly measure the shortage of rainfall by calculating the difference between the observation and the long-term climatological record. We have obtained the values of CA as follow: 1) the differences between seasonal or annual precipitation for each year (P_i) and average values for the period 1961-1990 ($\bar{P}$) are calculated; and 2) those anomalies are cumulated.

The graph of CA gives a tool to determine the positive and negative phases in precipitation variability. The drought event can be seen in the negative slopes of the graph (Hänsel and Matschullat, 2006).

$$CA = \sum_{i=1}^{n} (P_i - \bar{P}),$$

Standardized Precipitation Index, (SPI) is used in order to determine the moisture condition and occurrence of dry periods at the investigated stations. Mckee et al (1993) suggest utilization of SPI for determination the precipitation deficit for various time scales. The computation of SPI is based on the long-term precipitation record for the desired time scale. The long-term record is fitted to a gamma probability distribution. The function will have a standard deviation and a mean which depends on the rainfall characteristics of that area. If a probability function for a station in a different area is calculated, it will most likely have a very different standard deviation and a different mean. Therefore it will be very difficult to compare rainfall events for two or more different areas in terms of drought, as drought is really a "below-normal" rainfall event. SPI indicates the number of standard deviations that a particular event deviates from normal conditions. Many studies have indicated the usefulness of the SPI to quantify different drought types (Szalai et al., 2000; White et al., 2000, Vicente-Serrano, L´opez-Moreno. 2005.). The main advantage of the SPI in comparison with other indices is the fact that the SPI enables determination of drought conditions at different time scale. In the present paper SPI is calculated for 3-months scale. This can be related to soil moisture conditions, which respond to precipitation anomalies on a relatively short scale. The software provided by the National Drought Mitigation Center, University of Nebraska (http://drought.unl.edu/MonitoringTools/ClimateDivisionSPI.aspx, accessed by 11 February, 2012), is used for calculation of SPI.

The computation of the SPI index in a given year *i* and calendar month *j*, for a *k* time scale requires (Paulo et al., 2002):

1. calculation of a cumulative precipitation series $X_{i,j}^{k}$, (i=1,...,n) for that calendar month j, where each term is the sum of the actual monthly precipitation with precipitation of the k-1 past consecutive months;
2. fitting of a gamma distribution function to the series;
3. computing the non-exceedence probabilities corresponding to the cumulative precipitation values;
4. computing of SPI values by transforming those probabilities into standard normal variable values.

A drought event occurs any time the SPI is continuously negative and reaches intensity where the SPI is -1.0 or less. The event ends when the SPI becomes positive. The intensity of drought is determined by SPI as follow: moderate drought with SPI between -1 and -1.49; severe drought – SPI vary from -1.5 to -1.99 and extreme drought with SPI -2 and bellow (Bordi et al., 2001, Ceglar et al., 2008)

Results and discussion

Cumulative Anomalies (CA) show that winter precipitations are characterized by a negative phase lasting from 1941 (1942) to 1950 (1951), Figure 2. In Kazanlak, Plovdiv and Sandanski the above-mentioned winter drought is not observed in the first part of the investigated period. In Kardzali the negative phase of winter precipitation is well expressed from 1947 to 1950. The negative phase on the graph of winter precipitation, which begin in 1970 (1971) and continues with some interruption until the end of investigated period, makes impression. The drought period at the stations Kazanlak, Plovdiv and Sandanski is shorter than in other observed stations.

According to the course of the cumulative anomalies during the spring drought occurs from 1931 to 1950 (1954) at stations of the southern part of the studied area, while in the north more marked drought was observed from 1941 to 1952 (1954), Figure 3. The negative phase from the early 80's to late 90's has synchronous manifestation in most of the investigated stations. At some stations (for example Kyustendil) this phase lasts until the end of the investigated period.

The beginning of the investigated period is characterized by a slight negative phase of the summer precipitation, which continued until 1952 (1954), and observed in Haskovo, Plovdiv and Sandanski, Figure 4.

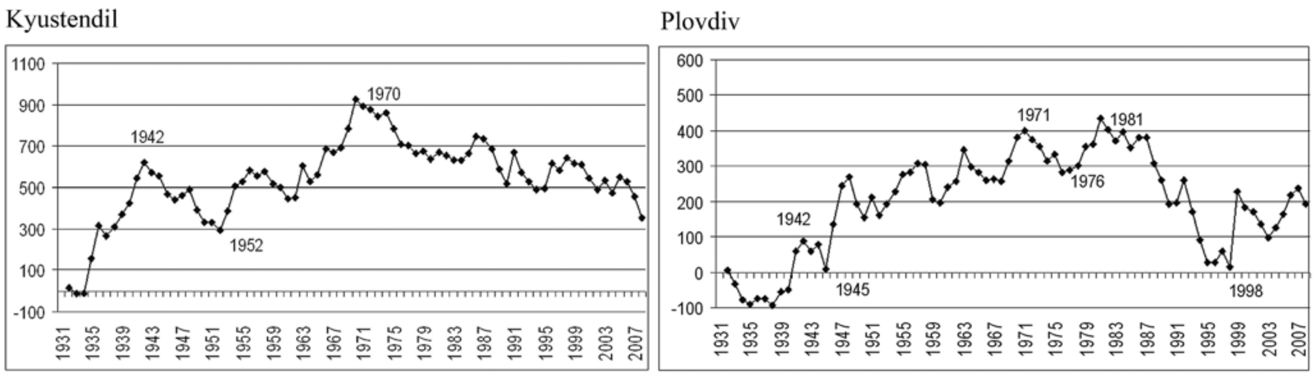

Figure 2. Cumulative anomalies of winter precipitation

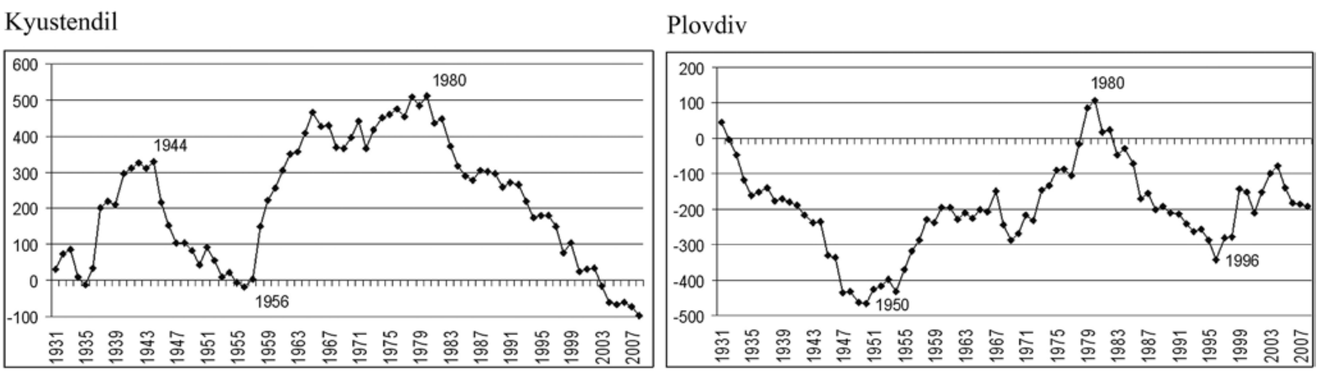

Figure 3. Cumulative anomalies of spring precipitation

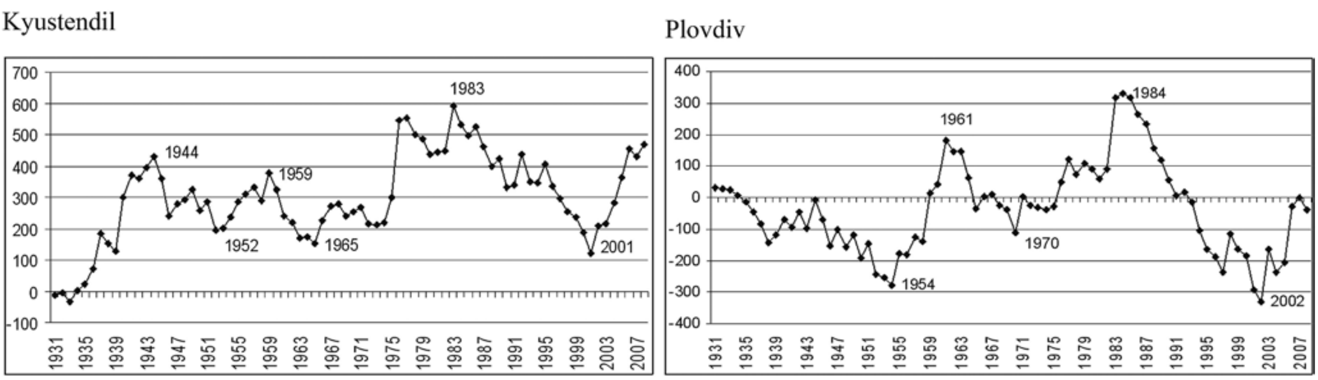

Figure 4. Cumulative anomalies of summer precipitation

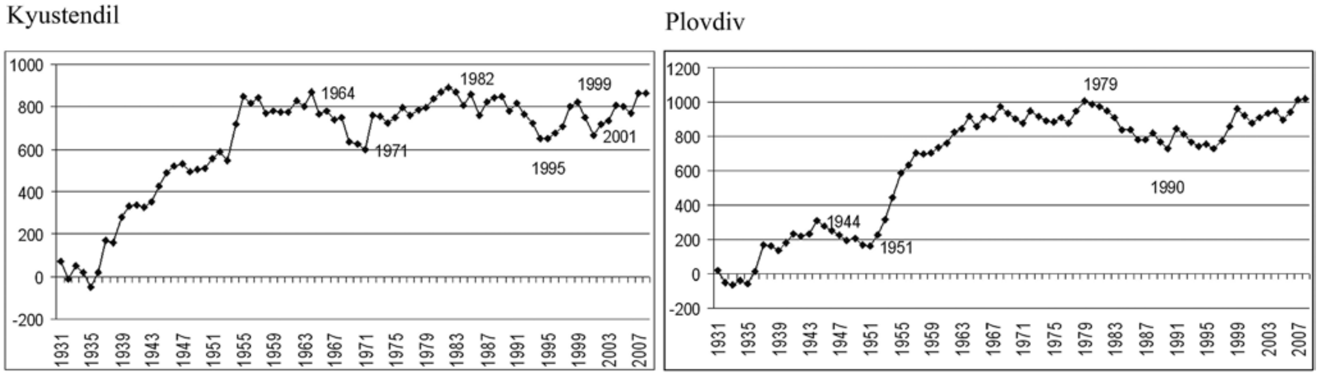

Figure 5. Cumulative anomalies of autumn precipitation

In the north part of the study area (stations Kyustendil, Kazanlak etc.), the drought was observed from 1944. Here the negative phase in the course of the cumulative anomalies continued until 1952 (1954). For most part of the study area, the summer drought starting in 80's has been observed. The last negative phase in the curves of cumulative anomalies continued in most of the surveyed stations to the year 2000 (2002).

According to cumulative precipitation anomalies for the period 1931 – 2008 the drought is not clearly established during autumn (Figure 5). The beginning of the investigated period is characterized by slight asynchrony and weakly pronounced manifestation of drought in the autumn. In the most of studied stations, except Kyustendil and Sandanski, drought from 1944 to 1951 has been observed, Figure 5. The negative phase in autumn precipitation from 1964 to 1971 has been observed in stations situated in western part of study area - Kyustendil, Blagoevgrad and Snadnaski. As in spring and summer, after 1979/1980, the negative phases in autumn cumulative precipitation anomalies, with varying lengths for individual stations, are characteristic.

The data from the calculation of the standardized precipitation index (SPI) for the time scale of 3 months allow us to determine the periods with different intensity of drought. In the present study, we examine the expression of a severe drought (with values of the SPI from -1.50 to -1.99) and extreme drought (with SPI -2 and lower).

According to SPI severe drought in the winter occurred in the 40's, 70's and late 80's, as well as in 2001 and 2002. Severe winter drought was expressed in most of the surveyed stations in 1976 and 1979 (Figure 6). The greatest frequency of winter drought is established in Haskovo, Karnobat and Plovdiv. The years with spring drought almost coincided with the years when there was a winter drought. The difference is the fact that spring drought has been observed also in 1934 and 1935. The severe spring drought is most frequently observed in the valley of the Struma River and

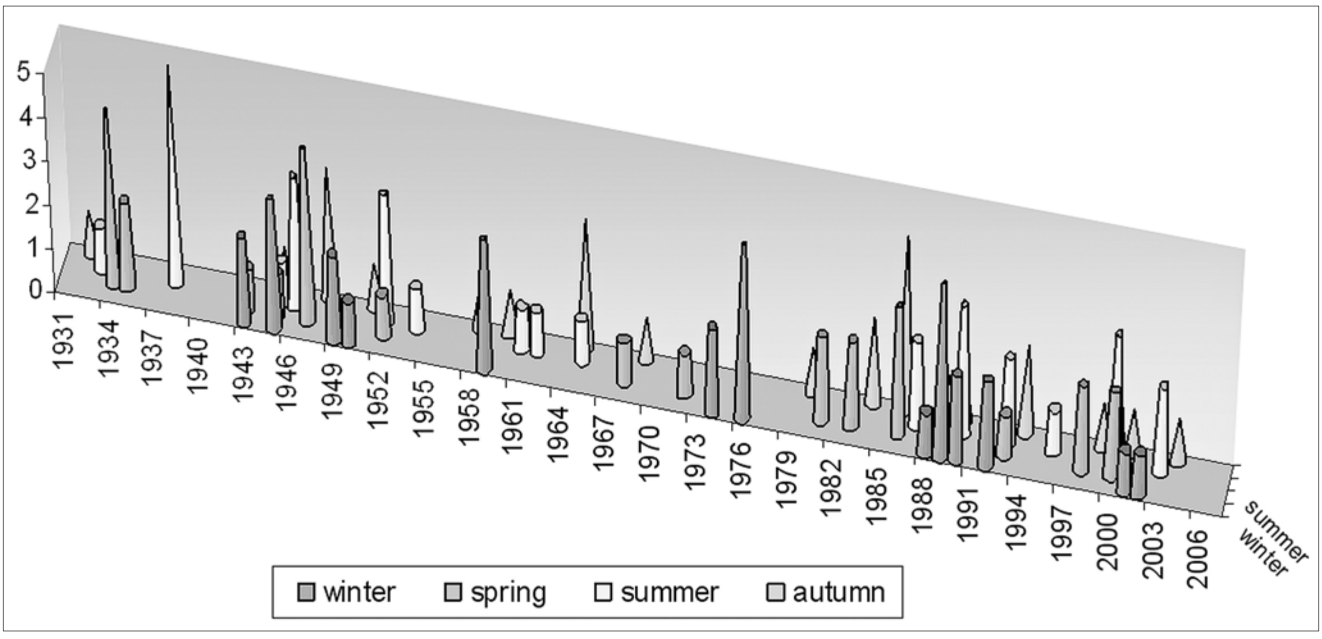

Figure 6. Number of stations with severe drought during the seasons (SPI between -1.5 and -1.99)

Kyustendil (western part of study area). As in the spring, the beginning of the investigated period is characterized by drought in the summer also. It is most pronounced in 1938. Summer and autumn droughts have been observed most often in Kazanlak, Plovdiv and Kyustendil. Since 80's until the end of the investigated period the number of stations at which the drought occur increases.

Extreme winter drought is widespread in 1949 when the values of SPI are below -2 in 70% of investigated stations. In most of investigated stations (exceptions are Kazanlak and Sandanksi) winter drought is characteristic for the end of 80's (1987, 1989) and beginning of 90-s (1992, 1994), Table 2.

Table 2. *Years with extreme winter drought*

Meteorological stations	Years with SPI $_{(winter)}$ < -2					
Blagoevgrad	1989	1992	1994	2001		
Haskovo	1949	1987	1992			
Karnobat	1946	1949	1989			
Kyustendil	1949	1992	1994	2001	2002	2008
Plovdiv	1959	1987	1990			
Kardzali	1949	1959	1987			
Kazanlak						
Sliven	1949	1994	2001			
Sandanski	1949	1959				

Extreme spring drought is established most often in 40's (1945, 1947 and 1949). In 1934 it is characteristic for north part of the study area and in 1968 - for the stations from south part, Table 3. Spring drought has manifested more often since 80's, but has happened in a few of investigated stations. Extreme spring drought is established in more than 50 % of investigated stations in 1945 (67%) and 1968 (56%). In 44% of investigated stations extreme spring drought in 1934, 1947 and 1986 has been observed.

An extreme summer drought in 1945 has been observed in 78% of investigated stations. There are two periods with extreme summer drought, which make impression: second part of 40's – beginning of 50's and second part of 80's – 90's (Table 4.).The number of stations with extreme summer drought decreases during the second period in comparison to first one.

The extreme autumn drought was quite intensive and widespread in 1945 (65% of investigated stations) and 1932 and 2000 (in 56% of stations). The extreme autumn drought was observed during 40's, 60's, 80's and 90's. The years with extreme dry autumns are more in 80's and 90's but the number of stations where the drought manifested is lower that during 40's and 60's (Table 5).

Table 3. *Years with extreme spring drought*

Meteorological stations	Years with SPI $_{(spring)}$ < -2							
Blagoevgrad	1934	1949	1989	1994	2000	2001		
Haskovo	1945	1947	1949	1968	1976			
Karnobat	1943	1945	1949	1968	1983	1986	2003	
Kyustendil	1945	1994						
Plovdiv	1945	1947	1949	1968	1981	1986		
Kardzali	1934	1945	1947	1959	1968	1976	1989	
Kazanlak	1934	1947	1986					
Sliven	1934	1949	1968	1986	1994	2001	2003	2004
Sandanski	1943	1945	1949	1990				

Table 4. *Years with extreme summer drought*

Meteorological stations	Years with SPI $_{(summer)}$ < -2						
Blagoevgrad	1938	1945	1949	1961	1993	1998	2000
Haskovo	1945	1946	1950	1952			
Karnobat	1945	2003					
Kyustendil	1945	1946	1993				
Plovdiv	1945	1965	1986	1988	1990		
Kardzali	1945	1950	1965	1968	1985		
Kazanlak	2000						
Sliven	1994	1996	2000	2003			
Sandanski	1945	1946	1949	1993	2000		

Table 5. *Years with extreme autumn drought*

Meteorological stations	Years with SPI $_{(autumn)}$ < -2						
Blagoevgrad	1945	1948	1965	1984	1993	1994	2000
Haskovo	1932	1945	1948				
Karnobat	1932	1945	1948				
Kyustendil	1945	1965	1969	1986	1990	1993	2000
Plovdiv	1945	1965					
Kardzali	1932	1945	1984				
Kazanlak	1932	2000					
Sliven	1932	1948	1969	1994	2000	2003	
Sandanski	1969	1986	1990	1993	2000		

The results of present research correspond to the result from previous investigations. Drought does not occur in all regions of the country. There are no years in which all months have precipitation bellow or above climate normal. Even in the driest years there are some months with significant rainfall (120% and more than average), Alexandrov, 2011.

Conclusion

The following conclusions can be drawn based on the underlying analysis:

- The drought in non-mountainous areas of Southern Bulgaria is mainly seen in the 40's, late 80's and early 90's of 20th century. A prolonged drought in the second period has been observed. The years 2000 and 2003 make impression as dry years. Greater synchronicity in the occurrence of drought in various stations is established in relation to winter and spring precipitation. On the other hand, the occurrence of summer drought is characteristic by the considerable asynchrony in the study area.
- Standardized precipitation index shows that the extreme drought in 40's was observed in a larger number of stations compared to the second half of the investigated period, but in the second period the years with extreme dry seasons were more often. The extreme drought was widespread in winter 1949, in spring 1945 and 1968, in summer 1945 and 2000 and in autumn 1932, 1945 and 2000.
- The results from the research show that the drought is a typical phenomenon for non-mountainous part of South Bulgaria. This underlines the need for such research not only for this region but for all territory of the country. In regards of the results from scientific investigations, the agriculture has to focus on crops that are less vulnerable to drought.

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