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On the relationship between atmospheric and soil drought in some agricultural regions of South Bulgaria

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Abstract: Drought is an extreme event, which affects agriculture. Soil drought occurs when the soil water balance is impaired, which causes the deterioration of the physiological state of the plants and directly affects the yields of the crops. Due to the climatic features of the country, the agricultural lands of South Bulgaria suffer from insufficient humidity during the vegetation period of the main agricultural crops.

High frequency of extreme phenomena, in particular drought, as well as the several droughts observed in the first decade of the 21st century in Bulgaria and different parts of the world, is a premise for extended monitoring. The forecast of the intensity and the probability of drought acquire high importance.

The aim of the study is to investigate the potential in application of atmospheric drought index as a predictor of soil drought in the agricultural regions of Southern Bulgaria.

For this purpose, the Standardized Precipitation Index (SPI) and Soil Moisture Index (SMI) are used in the sense of an indicator of impending soil drought during the vegetation period. Representative dry, normal and wet years were selected. The potential for implementation of SPI as an indicator of imminent soil drought has been assessed.

Keywords: atmospheric and soil moisture, drought, indices

1. INTRODUCTION

Soil drought of varying intensity and duration is a distinctive extreme phenomenon, which determines to a great extent the profitability of the agricultural production in our country. Soil drought can be observed throughout the whole growing season.

The common feature of agrometeorological and meteorological drought is a shortage of precipitation, but agrometeorological drought should be characterized with some additional indicators, such as the difference between potential and actual

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evapotranspiration and soil moisture (Wilhite, D.A., 2000). According to the same author, agrometeorological drought is a result of persistent meteorological one.

Drought monitoring, identification of its intensity and forecasting methods become actual due to increasing frequency of extreme events (IPCC, 2014), in particular drought, as well as drought periods registered in the first decade of 21th century in Bulgaria (Alexandrov, V., 2011) and around the world (Szezypta C. et all, 2012).

As early as the beginning of the last century, attempts have been made to define the concept of drought and ways of identifying it. Common to all types of drought is the fact that they originate from a deficiency of precipitation that result in water shortage. Since the middle of the 20th century precipitation amount is compared to soil water demand and vegetation cover – evapotranspiration (Heim R., 2002). In 1965 W. Palmer published his Palmer drought severity index (PDSI), creating an algorithm for assessing water balance through precipitation and temperature.

Later, McKee, et al., 1993 developed a Standardized Precipitation Index (SPI), which is currently widely used by the global scientific community to characterize moisture conditions for operational needs. To investigate the agricultural drought type, the Crop Moisture Index (CMI), the Palmer Moisture Anomaly Index (Z Index) and the Soil Moisture Anomaly Index (Keyantash J., J. Dracup, 2002) are most widely used.

Each index has both advantages and shortcomings in certain areas, and none of them uses the available water in the soil. The soil moisture index (SMI), developed in the High Plains Regional Climate Centre (HPRCC), determines the drought intensity by evaluating soil water available to plants (Hunt E., et al., 2008) regarding quantity for a given soil type. For the calculation of SMI, the measured soil moisture in agricultural crops is used, which allows to determine the degree of drought for a particular crop.

The aim of the study is to investigate the potential in application of atmospheric drought index as a predictor of soil drought in the agricultural regions of Southern Bulgaria.

2. MATERIAL AND METHODS

Areas of interest are the agricultural regions in Southern Bulgaria, covering the Thracian Lowland and Southeastern Bulgaria. Daily data for precipitation, ten-day data from soil moisture measurements for the period 1981-2010 at 8 stations (Fig. 1), and hydrological characteristics for representative soils were used.

Soil moisture is measured by the gravimetric method, according to the methodology of the National Institute of Meteorology and Hydrology (NIMH). Measurements are conducted every ten days at depths from 10 cm to 1 m during the growth season. For this investigation we used measured soil moisture under winter wheat for 0-30 cm, 0-50 cm and 0-100 cm soil layers during vegetation season (IV-IX).

According to the climatic zoning of the country, the agricultural land in the area of interest falls into two climatic areas - Moderate Continental and Continental-

Mediterranean. The precipitation regimes in these two climatic areas are different - in the first continental area (maximum is during the summer and the minimum is in the winter), in the second climatic area – maximum is in the winter and the minimum in the summer.

The main soil types on the region are Cinnamonic (typical and leached) – Sliven, Haskovo, Svilengrad, Plovdiv, Pazardhik and Vertisols (typical and leached) –Karnobat и Chirpan.

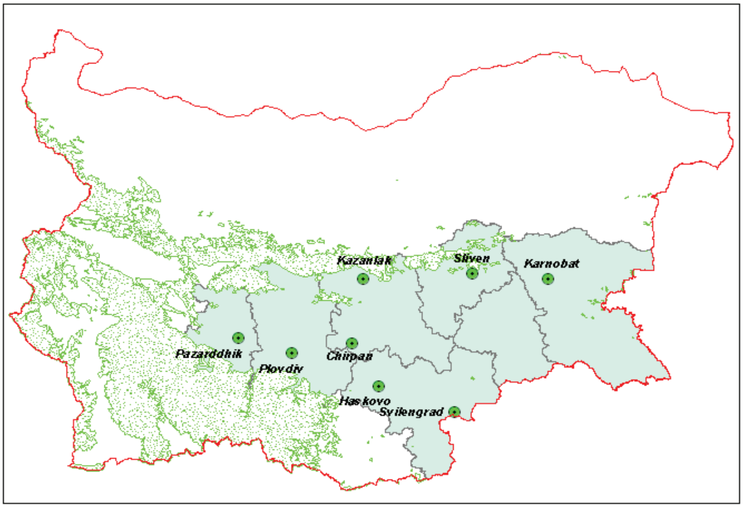


Fig. 1. Area of investigation and location of stations.

The Standardized Precipitation Index (SPI) is widely used to assess atmospheric drought. SPI is a tool which was developed primarily for defining and monitoring drought. It enables analysts to determine the rarity of a drought at a given time scale (temporal resolution) of interest for any rainfall station with historic data. It can also be used to determine periods of anomalously wet events. The SPI is not a drought prediction tool. Mathematically, the SPI is based on the cumulative probability of a given rainfall event occurring at a station. The historic rainfall data of the station is fitted to a gamma distribution, as the gamma distribution has been found to fit the precipitation distribution quite well.

The relative simplicity of the calculations, as well as the few required input data, only a quantity of precipitation, makes it a universal index of assessing moisture conditions. Its application in operational practice is significant. SPI is calculated daily for a 10 day time scale.

Table 1 Drought classification by SPI value and corresponding event probabilities

SPI value	Classification	Cumulative probability (%)
2.00 or more	Extremely wet	2.3
1.50 to 1.99	Very wet	0.4
1.00 to 1.49	Moderately wet	9.2
0 to 0.99	Mildly wet	34.1
0 to –0.99	Mild drought	34.1
–1 to –1.49	Moderate drought	9.2
–1.50 to –1.99	Severe drought	4.4
–2.00 or less	Extreme drought	2.3

The soil moisture index (SMI) classifies the land by measuring or modeling soil moisture values using the following formula:

$$SMI = \frac{5*(SM - WP)}{(FC - WP)} - 5$$

where: **SM-** Soil Moisture (cm^3/cm^3); **WP-**Wilting Point (cm^3/cm^3) and **FC-** Field Capacity (cm^3/cm^3).

SMI characterizes soil drought from normal to extreme, with the degree of drought increasing when the index decreases (Table 2).

Table 2 Classification of drought events according to SMI

Drought conditions	SMI
Less intense	0–1 or more
Moderate	–2 to –1
High intense	–3 to –2
Severe	–4 to –3
Extreme	–5 or less

3. RESULTS AND DISCUSSION

Agrometeorological dry spell and drought of varying intensity were recorded in 14 of the first 15 years of the 21st century. Dry spell and drought are recorded during each of the months of the vegetation period. In April, soil drought is a less common event, but when it happens, it can have serious consequences. An example of such an extreme phenomenon is the drought that began in April 2007. As a consequence of it is the damage of autumn crops in northwestern and northeastern Bulgaria. Often, drought occurs in May. For example, in 2000, 2003, 2007 and 2015, in some regions of the country, the soil moisture was less than 70% FC in May.

June appears to be critical for soil water supplies in spring crops, as it was in 2000, 2002, 2003, 2010, 2015. The consequences of drought in these cases are the recorded damages in winter crops, vegetables and orchards. Soil drought in July was recorded in 2000, 2001, 2004 (only in separated regions), 2007 (soil water availability reach 23% of FC in Southern Bulgaria), 2008 (beginning of drought), 2011, 2015. In August, soil water supplies reach their lowest values, even in years that are considered wet. In two-thirds of the years under review (2000, 2001, 2003, 2004, 2006, 2007, 2008, 2009, 2014, 2015) soil drought was registered in August. In some years, the summer drought passes in autumn - 2003, 2004, 2008, 2009, 2015 when the September's soil water balance was decreased. (Hydro-meteorological Bulletins of NIMH).

Rainfalls in the area under consideration are between 85% (Pazardzhik) and 98% (Svilengrad) in the average of the country (Fig.2). Only in Haskovo annual rainfall exceeds the average of the country by 9%, but this is due to the autumn-winter rainfalls, since only 44% of them are in the vegetation period. The lowest rainfall sums are recorded in Plovdiv and Pazardzhik, but over 50% of them are in the vegetation season. The highest precipitation rate during the growth season is in Kazanlak (60%), and the smallest in Svilengrad (42%).

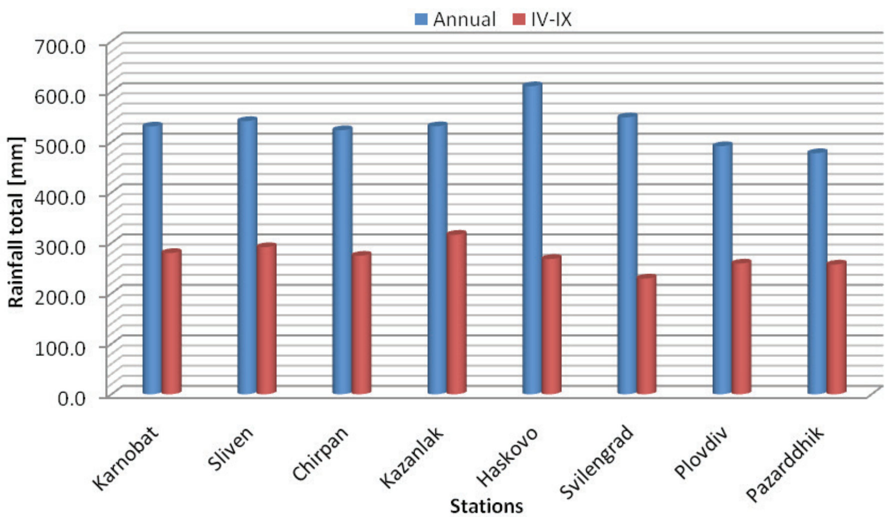


Fig.2. Long-term annual vegetation season precipitation sums (IV-IX)

SPI values were determined during the vegetation period for ten days (Fig.3). Half of the cases (between 49 and 55%) indicate atmospheric drought with moderate, severe and extreme intensity.

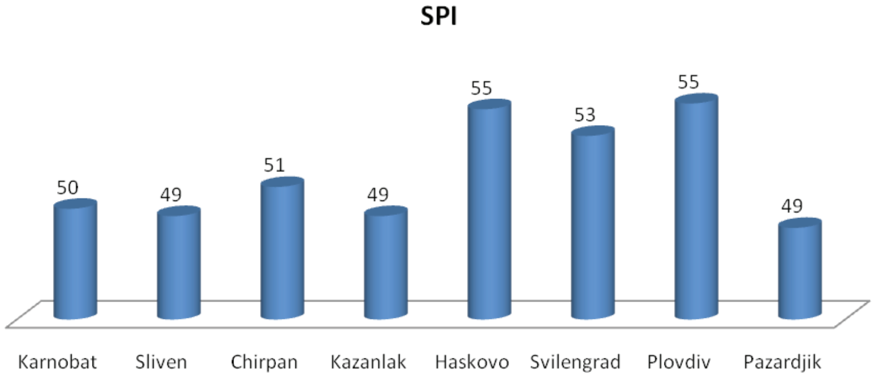


Fig. 3. Percentage of cases with extreme, severe, moderate and mild drought events according to SPI (ten days step for vegetation period)

Previous studies (Georgieva V., V. Kazandjiev, 2015) set the SMI values for which the quantities of soil moisture are less than 70% FC. It has been shown that danger for agriculture is increased, when the SMI values indicate strong and extreme drought.

The values of SMI for three soil layers - 0-30 cm, 0-50 cm and 0-100 cm for the ten-days periods have been determined and only the cases with a significant drought intensity for agriculture are selected (Fig. 4). The highest is the percentage of these cases in the upper soil layer (Fig. 5a), reaching up to 100% in Pazardzhik. In the deeper soil layers (Fig. 5 b, c) the percentage of cases decreases, but the difference is insignificant. In Karnobat the conditions of formation and utilization of water reserves in the soil differ from those in the other considered stations, because only the percentage of cases with soil drought is significantly lower than those indicated by SMI, respectively 34, 30 and 29% in the three soil layers. The remaining stations are between 56% and 100%.

The comparison between the drought cases reported by the SPI and the SMI indices shows that in a large percentage of cases, registered drought (according to SMI) is not indicated by the SPI, (Fig. 3 and Fig. 4).

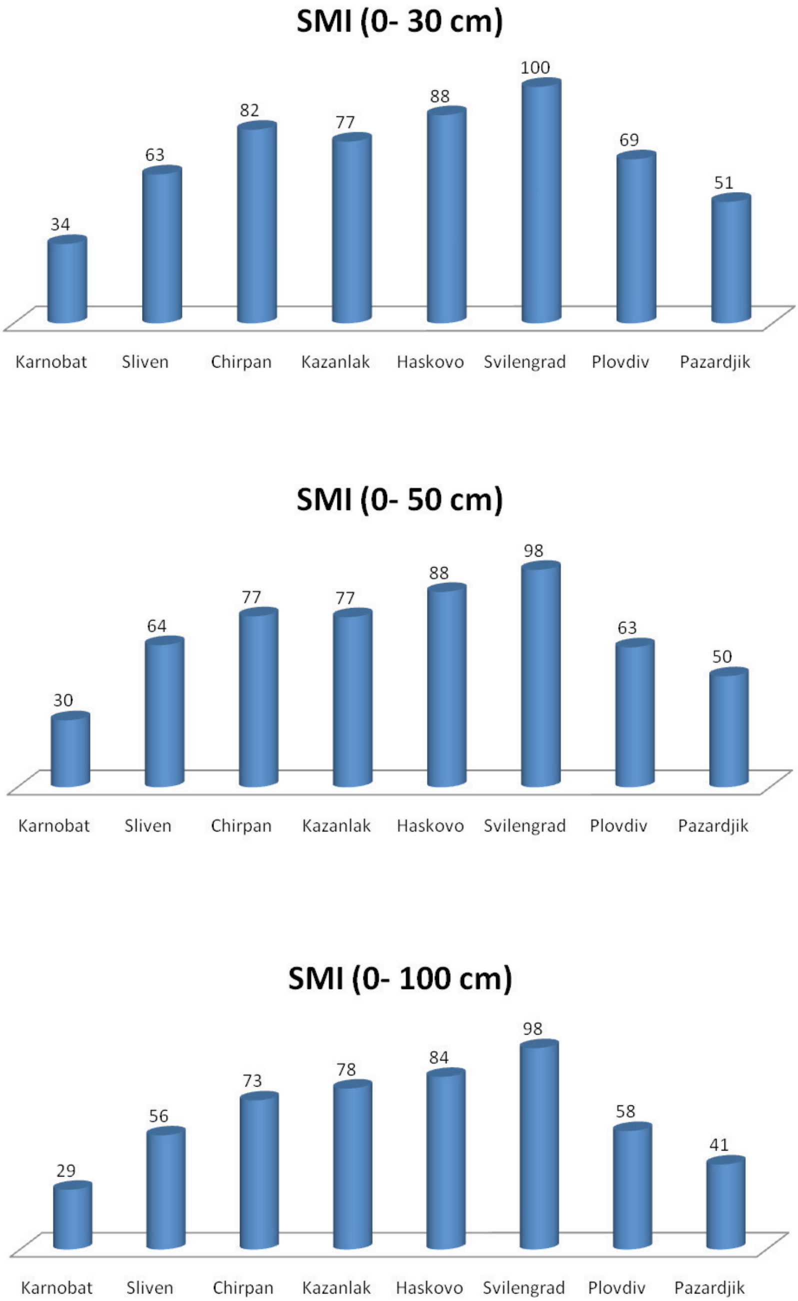


Fig. 4. Percentige of cases with increased drought (SMI) for three soil layers: a) 0-30 cm; b) 0-50 cm; c) 0-100 cm during the vegetation season

The distribution of the negative values of SPI reports atmospheric drought of varying intensity between 40 and 60% of the examined cases, evenly throughout the growth season, (Fig. 5). In each of the vegetation months, 50% of the ten-days periods have been reported as one of the degrees of extreme drought - extreme, severe, moderate and mild.

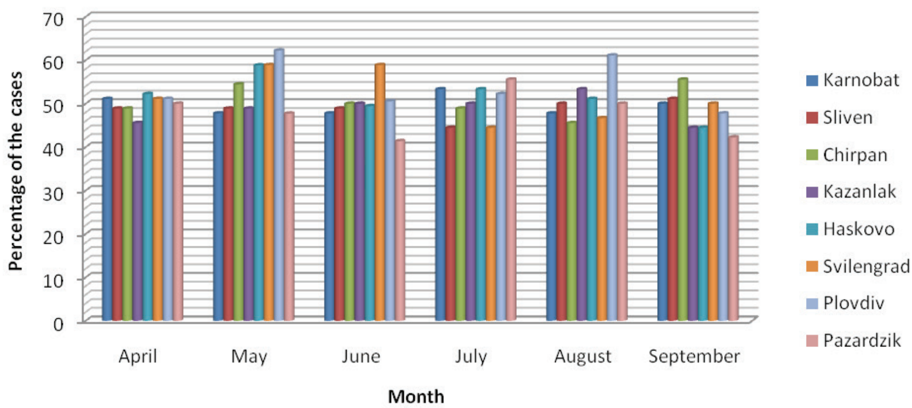


Fig. 5. Extreme, severe, moderate and mild drought distribution according to SPI during the vegetation season

Soil drought variations presented trough the numbers of cases according to SMI are much higher. The largest in the 0-30 cm layer is in April (3-100%) and in May (14%-100%) – (Fig. 6), with the lowest number of droughts in April (Karnobat, Chirpan, Pazardzhik under 5%). In June, July, August and September, more than 50% of the occurrence of soil drought is observed, with the exception of region of Karnobat. The high percentage of cases of autumn drought in Chirpan, Kazanlak, Haskovo, Svilengrad and Plovdiv is noticeable. In the deeper soil layers in April and May, soil drought is not a common event, with the exception of Kazanlak, Haskovo, Plovdiv and Svilengrad stations.

Only in April the cases of atmospheric drought exceed those with established soil drought. The soil water consumption in April is greatest, but at the beginning of the spring vegetation, soil water reserves usually reach to FC. This allows short droughts to be overcome without reaching moisture depletion below the optimum. The highest exceedance of the percentage of cases with soil drought is in August and September and at Svilengrad station, reaching 50%.

Different information is used to determine the two indices - rainfall SPI and soil humidity for SMI, which explains the insufficient relationship between them. Given that precipitation is the main resource for soil water supplies formation, we sought a correlation between the ranges of SPI and SMI for the three soil layers. Table 3 shows the correlation coefficients that indicate the absence of a significant relationship between the two indices.

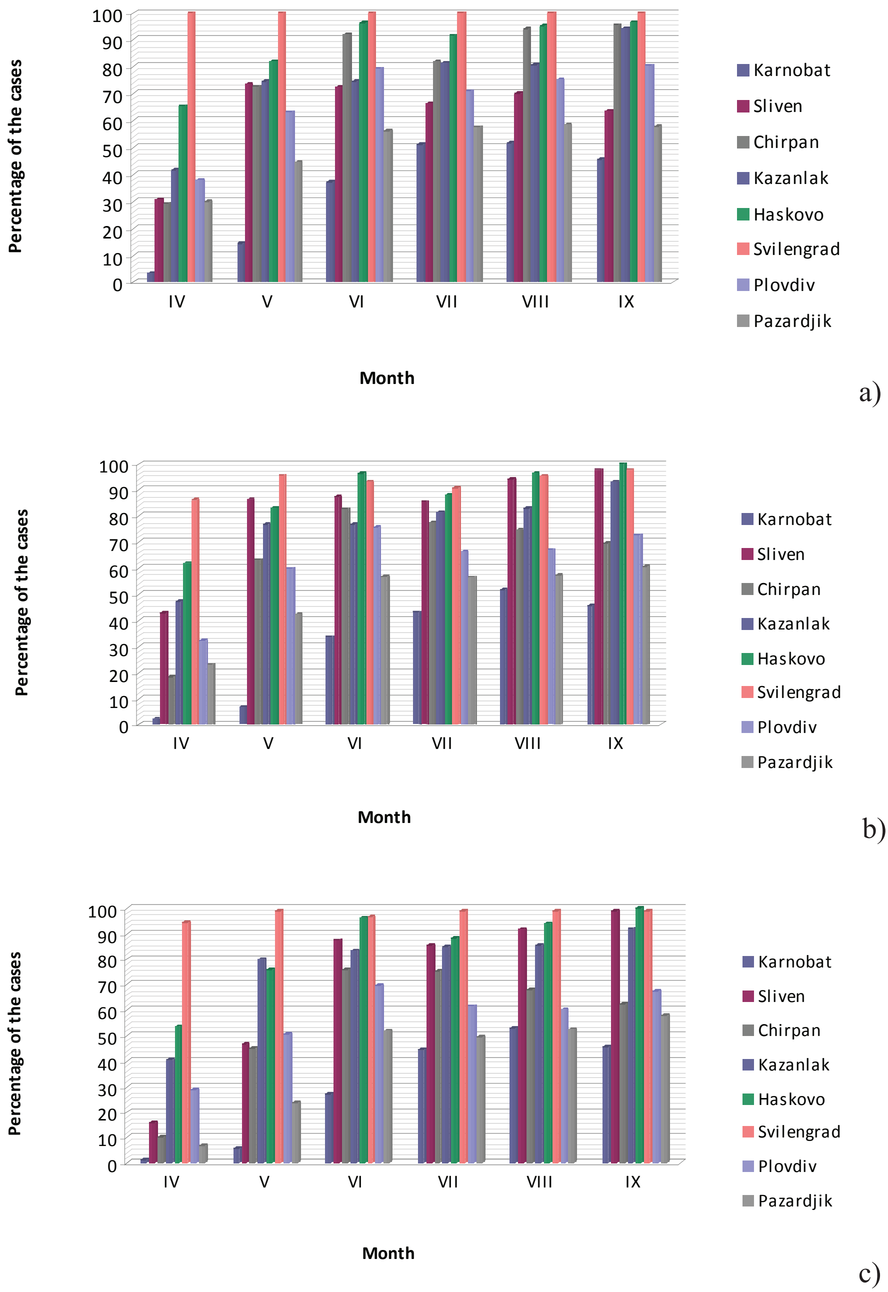
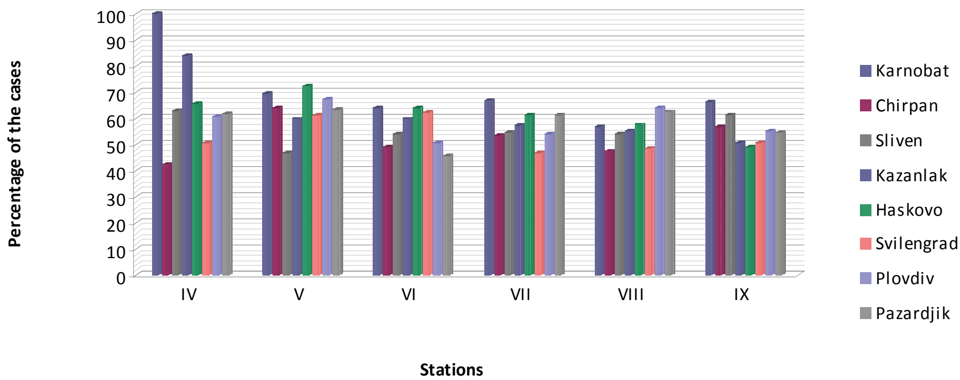
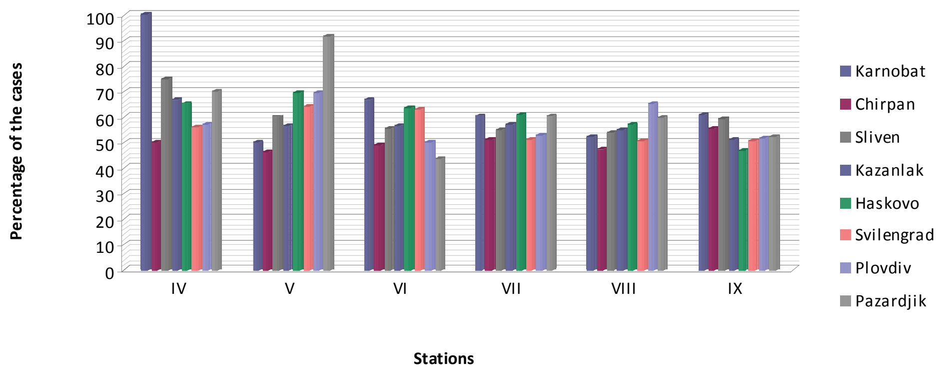


Fig. 6. Monthly distribution in (%) of cases with extreme, severe and high intense drought according SMI during the vegetation period in 3 soil layers: a) 0-30 cm; b) 0-50 cm; c) 0-100 cm



a)



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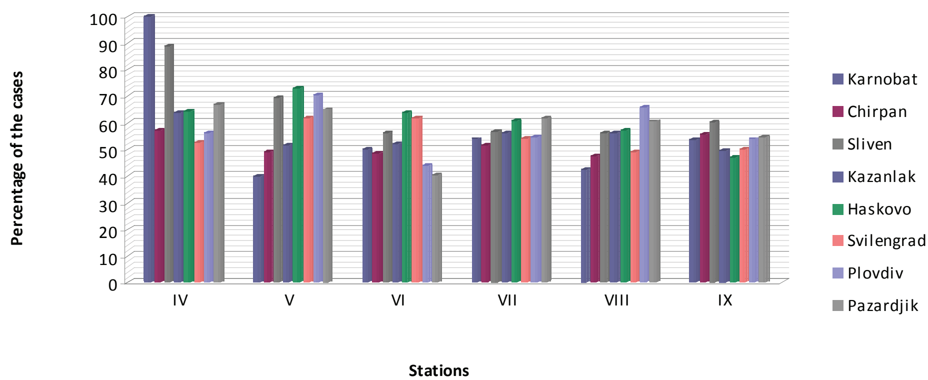

c)

Fig. 7. Coincidence of drought events:a) SPI and SMI 0-30 cm; b) SPI and SMI 0-50 cm; c) SPI and SMI 0-100 cm

Table 3 Correlation coefficient between SPI and SMI for 3 soil layers

Stations	0-30 cm	0-50 cm	0-100 cm
Karnobat	0.31	0.23	0.15
Sliven	0.22	0.29	0.24
Chirpan	0.15	0.11	0.07
Kazanlak	0.45	0.40	0.27
Haskovo	0.32	0.28	0.21
Svilengrad	0.25	0.26	0.20
Plovdiv	0.00	-0.01	-0.01
Pazardjik	0.04	0.04	0.01

The correlation between SPI and SMI-indicated droughts for the three layers by months during the vegetation period (Fig. 7) was analyzed. The highest coincidence rate is in April and May, but then, there are the least observed cases of soil drought. A higher incidence rate was observed in Karnobat, where the number of drought cases was the lowest. In 50-60% of the cases of soil drought, SPI values are negative, i.e. atmospheric drought is also reported. Conversely, in more than 40% of the SPI cases reported by the SMI does not indicate drought.

This result, as well as the low correlation coefficient between SPI and SMI, indicates that SPI alone can not be used to determine soil drought. For this purpose, it is necessary to use a quantitative indicator that takes into account the water deficit in the soil.

4. CONCLUSIONS

A parallel study of SPI and SMI over the period 1981-2010 was conducted. Summarizing the obtained results, following conclusions can be made:

1. During the period of investigation, the number of soil drought cases determined by the SMI value is significantly higher than that of atmospheric droughts according to the SPI value. That is because SPI gives an idea of precipitation deviation from the climate norm and does not take into account the losses of soil water by evaporation and transpiration;
2. The correlation between SPI and SMI during active vegetation period April – September is not significant;
3. It is found that both SPI and SMI indices are not always consistent. For example, when SMI indicates soil drought SPI does not always indicate atmospheric drought too;
4. SPI gives an inaccurate idea of soil drought. That is particularly true for the months of July and August. In relation to that, it is necessary to extend the study

on identification of an additional index connecting SPI and SMI in the case when the results of SPI deviate from that of SMI.

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