FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 12, N° 3, 2014, pp. 253 - 264
DOI: 10.2298/FUACE1403253M

ANALYSIS OF METEOROLOGICAL AND AGRICULTURAL DROUGHTS IN SERBIA

UDC 551.577.3(497.11)=111 58.032(497.11)=111

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Abstract. *Drought represents a combined heat-precipitation extreme and has become an increasingly frequent phenomenon in recent years. In order to access the entire analysis of drought, it is necessary to include the analysis of several types of drought. In this paper, impacts of meteorological and agricultural drought were analyzed across the Standardized Precipitation Index (SPI) and Agricultural Rainfall Index (ARI) on the territory of Serbia for the period from 1980 to 2010. For both types of drought, year 2000 is notable as the year when most of the observed stations had the highest drought intensity. It was found that meteorological drought for year 2000 has a higher intensity in the central and southeastern parts of the country, as well as in the north. Of all the stations, the highest intensity of meteorological drought was observed at Loznica station in 1989. Agricultural drought in 2000 had the lowest intensity in western Serbia.*

Key words: *drought, meteorological drought, agricultural drought, Standardized Precipitation Index, Agricultural Rainfall Index, Serbia.*

1. INTRODUCTION

Drought is a part of natural climate changes, which occurs in all climate zones, but with no clear regularity. The complexity and specificity of drought is explained by the fact that there is no single definition of drought. With regard to the field of influence, droughts can be classified into four groups: meteorological, hydrological, agricultural and socio-economic drought (Wilhite and Glantz 1985). According to Wilhite and Glantz (1985), meteorological drought occurs at a reduced precipitation compared to the average precipitation for several years, and it is one of the major causes of drought; hydrological drought represents deficiencies in water supply from surface and underground water reserves; agricultural drought occurs when plants do n'ot have enough required water in the specified time. Otorepec (1980) claims that agricultural drought is caused by

Received December 28, 2014
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meteorological and hydrological drought because it connects the different characteristics of these droughts with their impact on agriculture.

To determine the intensity, duration and frequency of droughts, there is a large number of quantitative indicators i.e. indices of drought. According to the recommendations of the World Meteorological Organization (WMO), all national meteorological and hydrological services should use the Standardized Precipitation Index (SPI) (WMO 2012). By using the SPI index, it is possible to analyze drought through intervals of 1, 3, 6, 9, 12 and 24 months. In agricultural regions, SPI-3 can be more effective in determining the available moisture than other indices. Therefore, by observing this index in May, it is possible to determine the condition of soil moisture during the growth of cultures (WMO 2012). Although there is a large number of agricultural drought indices, a reliable determination of evapotranspiration is the most important item in the estimation of these indices. The development of agricultural indices propagates the fact that agricultural sector will be the primary user of the improved monitoring and early warning system when drought occurs (Wilhite 2010).

Many scientists in the world have dealt with the analysis of drought (Moreira et al. 2008, Khalil et al. 2011, Tabari et al. 2012, Hisdal et al. 2001). Wang et al. (2011) studied the impacts of climate change on meteorological, agricultural and hydrological drought in the central parts of Illinois, considering the historical data and future scenarios, through the following periods: 1991-2000 and 2091-2100, 1990-1999 and 2090-2099, 1980-1989 and 2090-2099. They concluded that the influences of meteorological drought have amplified in agricultural and hydrological droughts due to the increasing temperature and decrease in precipitation in the vegetative period. Duan and Mei (2014) compared the meteorological, hydrological and agricultural drought on the Huai River (China) for the period from 1961 to 2000 and from 2061 to 2100, and concluded that hydrological and agricultural drought represent a threat to the water resources management in the future.

Gocic and Trajkovic (2013, 2014a) analyzed the drought on the territory of Serbia, and divided Serbia into three regions on the basis of the identification of drought: northern and northeastern Serbia; western and southwestern Serbia; and the central, eastern, southern and southeastern Serbia.

In this paper, the meteorological and agricultural drought was analyzed on the territory of Serbia for the period from 1980 to 2010. The territory of Serbia is observed over 12 meteorological stations. Meteorological drought is analyzed with the help of the Standardized Precipitation Index (SPI), while agricultural drought is analyzed with the Agricultural Rainfall Index (ARI). The aim of this paper is to monitor and analyze droughts which cover various fields of influence in Serbia in the most detailed and expedient manner.

2. MATERIALS AND METHODS

2.1. Data collection and study area

The study area in this paper is Serbia, with an area of 88 407 km^2. Serbia is located in the central part of the Balkan Peninsula, and its climate is temperate continental, with a gradual transposition between the seasons of the year. The average temperature is 10.9 °C in the Serbia, and the average precipitation is 896 mm annually.

The data required for the drought indices calculation (precipitation, maximum and minimum air temperatures, sunshine hours, actual vapor pressure, wind speed at 2 m height) were taken from 12 meteorological stations, from meteorological yearbooks issued by the Republic Hydrometeorological Service of Serbia (RHMSS), for the period from 1980 to 2010. Table 1 shows the geographical characteristics of the stations that were observed in this study.

Table 1 Geographical characteristics of the meteorological stations observed in this study

Station name	Longitude (E)	Latitude (N)	Elevation (m a.s.l.)
Belgrade	20°28'	44°48'	132
Dimitrovgrad	22°45'	43°01'	450
Kragujevac	20°56'	44°02'	185
Kraljevo	20°42'	43°43'	215
Loznica	19°14'	44°33'	121
Negotin	22°33'	44°14'	42
Nis	21°54'	43°20'	204
Novi Sad	19°51'	45°20'	86
Palic	19°46'	46°06'	102
Sombor	19°05'	45°47'	87
Vranje	21°55'	42°33'	432
Zlatibor	19°43'	43°44'	1028

2.2. Standardized Precipitation Index

The Standardized Precipitation Index (SPI) was developed by McKee et al. (1993) to quantify the precipitation deficit. It can be used for multiple time scales (1, 3, 6, 12, 24, 48 months). This versatility allows the SPI to monitor short term water supplies, such as soil moisture, important for agricultural production, and long term water resources, such as ground water supplies, steamflow and reservoir levels. It depends only on precipitation.

Calculating the SPI for a certain time period at any place requires a long sequence of monthly data for the quantity of precipitation, at least 30 – annual sequence (Seiler et al. 2002).

When calculating the SPI, it is necessary to summarize the monthly values of precipitation for each year. It is based on the cumulative probability of some precipitation appearing at the observation station. Research has shown that precipitation is subject to the law of gamma distribution. One whole period of observation at one meteorological station is used for the purpose of determining the parameters of scaling and the forms of precipitation probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \tag{1}$$

where: α – form parameter, β – scale parameter, x – precipitation quantity and Γ (α) is gamma function defined as follows:

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y}\, dy \tag{2}$$

Parameters α and β are determined by the method of maximum probability for a multiyear data sequence, i.e.:

$$\alpha_{pro} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{3}$$

$$\mathrm{A} = ln(\bar{x}) - \frac{\sum_i^n ln(x_i)}{n} \quad (4)$$

$$\beta_{pro} = \frac{\bar{x}}{\alpha_{pro}} \quad (5)$$

where: $\bar{x}$ – mean value of precipitation quantity, n – precipitation measurement number, x_i – quantity of precipitation in a sequence of data.

The obtained parameters are further applied to the determination of a cumulative probability of certain precipitation for a specific time period on a temporal scale of all the observed precipitation. The cumulative probability can be presented with the following statement:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta_{pro}^{\alpha_{pro}}\Gamma(\alpha_{pro})}\int_0^x x^{\alpha_{pro}-1} e^{-\frac{x}{\beta_{pro}}} dx \quad (6)$$

Since the gamma function has not been defined for x = 0, and the precipitation may amount to zero, the cumulative probability becomes:

$$H(x) = q + (1-q)G(x) \quad (7)$$

where: q denotes probability that the quantity of precipitation equals zero, which is calculated as:

$$q = \frac{m}{n} \quad (8)$$

where: m is a number that signifies how many times the precipitation was zero in a temporal sequence of data, and n is precipitation observation number in a sequence of data.

The SPI calculation is performed on the basis of the following equation (Bordi et al. 2001, Khadr et al. 2009, Lloyd-Hughes and Saunders 2002):

$$SPI = \begin{cases} -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), & 0 < H(\mathrm{x}) \leq 0.5 \\ +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), & 0.5 < H(x) \leq 1.0 \end{cases} \quad (9)$$

where t is determined as

$$t = \begin{cases} \sqrt{ln\frac{1}{(H(x))^2}}, & 0 < H(\mathrm{x}) \leq 0.5 \\ \sqrt{ln\frac{1}{(1-H(x))^2}}, & 0.5 < H(x) \leq 1.0 \end{cases} \quad (10)$$

and c_0, c_1, c_2, d_1, d_2 and d_3 are coefficients whose values are:
c_0 = 2.515517, c_1 = 0.802853, c_2 = 0.01032
8, d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308.

McKee et al. (1993) have proposed a classification system to define drought intensities resulting from the SPI value (Table 2).

Table 2 Drought classification based on the SPI value

SPI value	Drought class
SPI ≥ 2.0	Extremely wet
1.5 ≤ SPI < 2.0	Very wet
1.0 ≤ SPI < 1.5	Moderately wet
-1.0 ≤ SPI < 1.0	Near normal
-1.5 ≤ SPI < -1.0	Moderate drought
-2.0 ≤ SPI < -1.5	Severe drought
SPI < -2.0	Extreme drought

2.3. Agricultural Rainfall Index

The Agricultural Rainfall Index (ARI) is used for the identification of agricultural drought and represents a reliable indicator of monthly water balance (Sayari et al. 2013, Ghazalli 1987). ARI is calculated on a monthly level as the ratio of monthly rainfall (P) and monthly reference evapotranspiration (ET_0):

$$ARI = \frac{P}{ET_0} \tag{11}$$

where: P is monthly rainfall and ET_0 is monthly reference evapotranspiration.

Calculation of the ET_0 was performed based on the Penman-Monteith equation, (Allen et al. 1998):

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \frac{900}{T+273} \cdot U_2 \cdot VPD}{\Delta + \gamma \cdot (1 + 0.34 \cdot U_2)} \tag{12}$$

where: ET_0 – reference evapotranspiration (mm day^{-1}); Δ - slope of the saturation vapor pressure function (kPa °C^{-1}); R_n – net radiation (MJ m^{-2} day^{-1}); G – soil heat flux density (MJ m^{-2} day^{-1}); γ – psychometric constant (kPa °C^{-1}); T – mean air temperature (°C); U_2 – average 24 h wind speed at 2 m height (m s^{-1}) and VPD – vapor pressure deficit (kPa).

If the values of the *ARI* index are less than 40, there is drought in the observed month. The suitable conditions for vegetation occur if the values of index between 40 and 200. The ARI index values which exceeded 200 indicate a wet period, i.e. wet months (Sayari et al. 2013, Ghazalli 1987).

3. Results and Discussion

3.1. Spatio-temporal distribution of ET_0 and P

The spatial distribution of the average annual values of ET_0 is shown in Fig. 1. Central and western parts of Serbia have an average annual value of ET_0 between 700 and 800 mm year^{-1}, while the northern and eastern parts of Serbia have ET_0 between 800 and 900 mm year^{-1}. The regions around Belgrade and the south of the country have the highest values of ET_0.

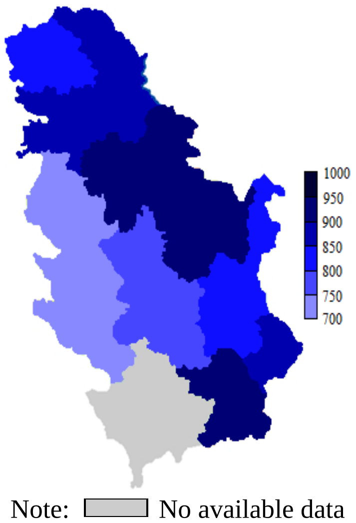

Fig. 1 Spatial distribution of average annual values of ET_0 for the period 1980-2010

The spatial distribution of the sum of the average monthly precipitation and maximum daily precipitation sum over the period 1980-2010 is shown in Fig. 2.

According to Fig. 2 a), the largest part of Serbia had average sums of monthly precipitation between 550 and 650 mm. The area along the valley of the South Morava to Vranje experienced precipitation of up to 650 mm during the year. A huge part of the west and southwest is the wettest region of Serbia. In the mountains, such as Zlatibor and Kopaonik, precipitation can reach 1000 mm a year.

Based on Fig. 2 b), Dimitrovgrad had a maximum daily sum of precipitation with the value of 123.3 mm over the period 1980-2010.

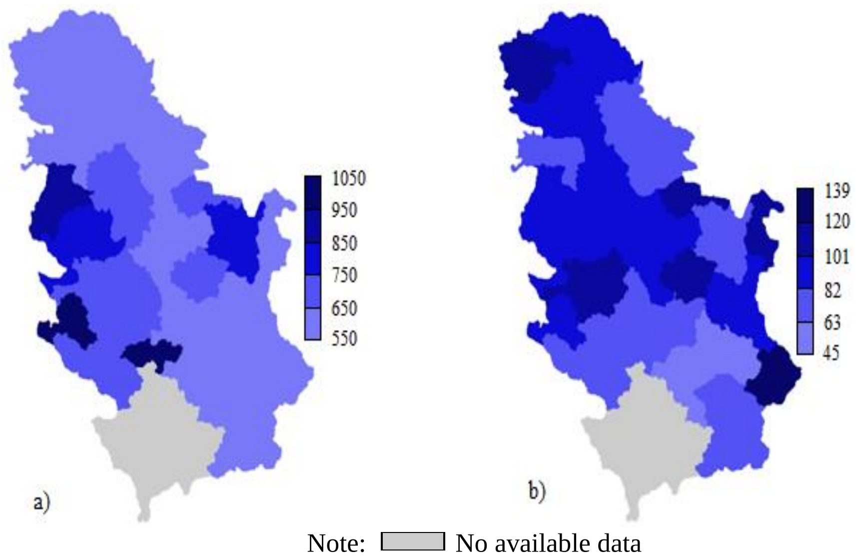

Fig. 2 Spatial distribution of a) the sum of the average monthly precipitation and b) the maximum daily precipitation sum during the period 1980-2010

From the stations that were analyzed in the paper, Fig. 3 shows the values for the ET_0 for three stations which Gocic and Trajkovic (2014b) showed to have the significant trends at $\alpha = 0.01$.

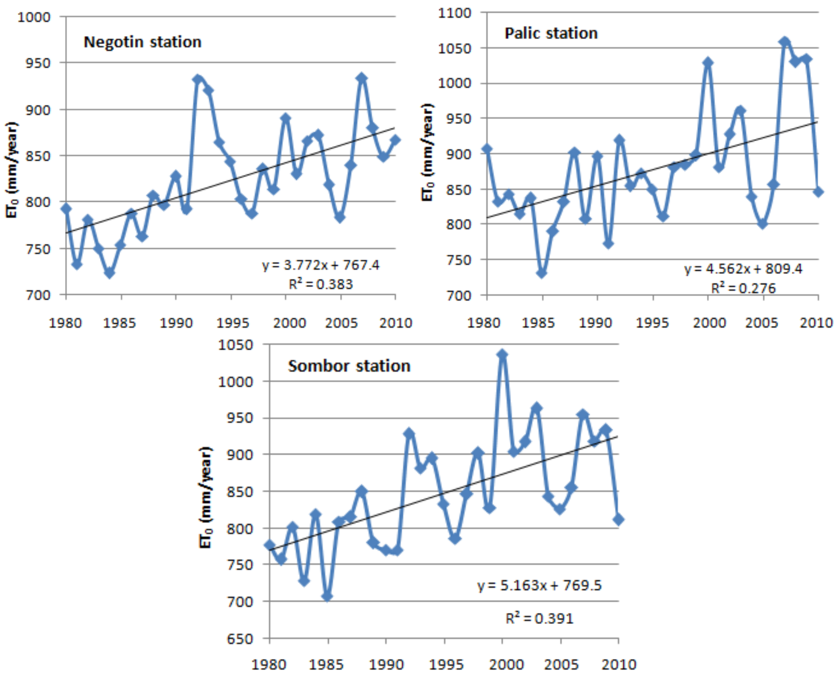

Fig. 3 Time series and linear trends of annual ET_0 at three stations

For all three meteorological stations, it is observed that the values of ET_0 grow throughout the observed period, which clearly shows the trend line. The highest values of ET_0 were recorded in 2007 for stations Negotin and Palic, while Sombor recorded the highest value in 2000. In 1985, the lowest values of ET_0 were recorded on Palic and Sombor, while the lowest value of ET_0 occurred in Negotin in 1984.

According to Gocic and Trajkovic (2013), the lowest values of the average annual precipitation were recorded at stations in Nis, Vranje and Palic for the period from 1980 to 2010. Fig. 4 shows the values of annual precipitation for the observed period for stations in Nis, Vranje and Palic.

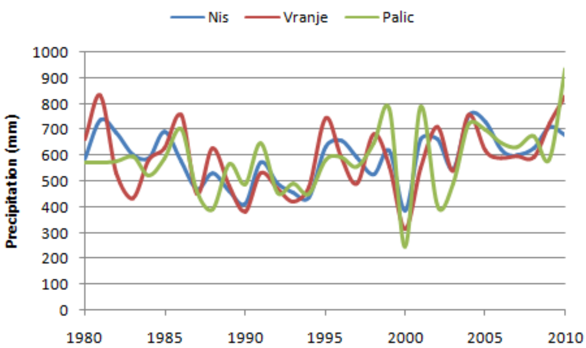

Fig. 4 Annual precipitation time series at three synoptic stations

Figure 4 shows that the values of annual precipitation for all three stations do not differ much from each other. The year 2000 was the year with the lowest precipitation for the observed three stations. The highest precipitation values in Nis were recorded in 2004, the ones for Vranje were in 1981, and the ones for Palic occurred in 2010.

3.2. Spatio-temporal distribution of SPI and ARI indices

3.2.1. Spatial distribution

The spatial distributions for the values of SPI-3 (1 June - 31 August) and ARI indices for year 2000 are shown in Fig. 5.

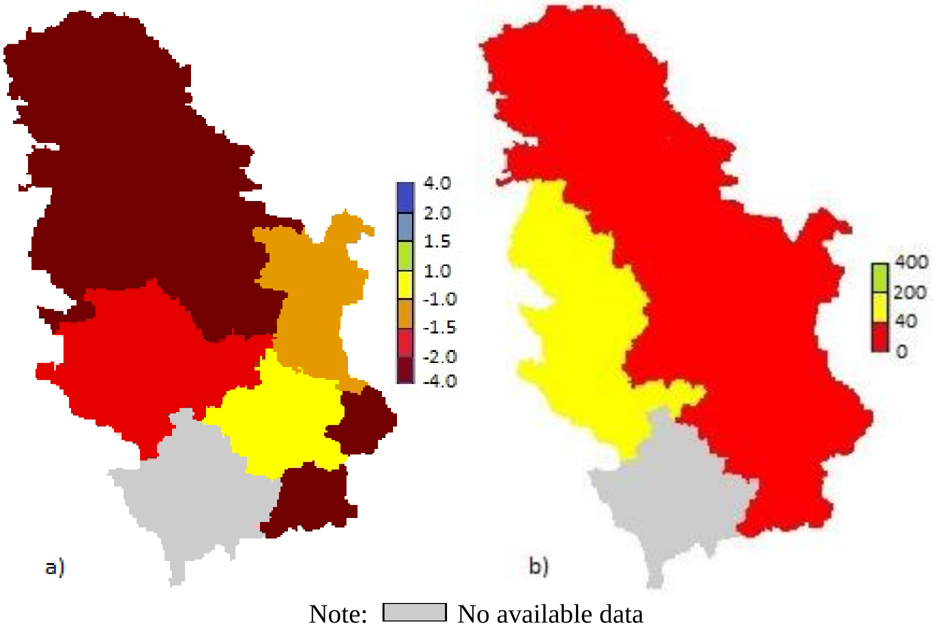

Fig. 5 Spatial distributions for year 2000 a) SPI-3 index and b) ARI index

The SPI-3 for year 2000 on the territory of Serbia shows that meteorological drought includes four states of drought: near normal, moderate, severe and extreme drought (Fig. 5 a). Extreme drought covers the northern, central and southeastern parts of the country, while the severe drought covers the western and central parts of Serbia. Moderate drought covers the eastern parts of Serbia and near normal drought includes southeastern parts of the country.

Fig. 5 b) shows the value of the ARI index, and it can be seen that, for year 2000, there were conditions suitable for vegetation in western Serbia, while the other parts of the country experienced drought.

3.2.2. Temporal distribution

The values of the SPI and ARI indices are grouped according to the regionalization of Serbia proposed by Gocic and Trajkovic (2014a). Fig. 6 shows the temporal distribution of the SPI-3 index.

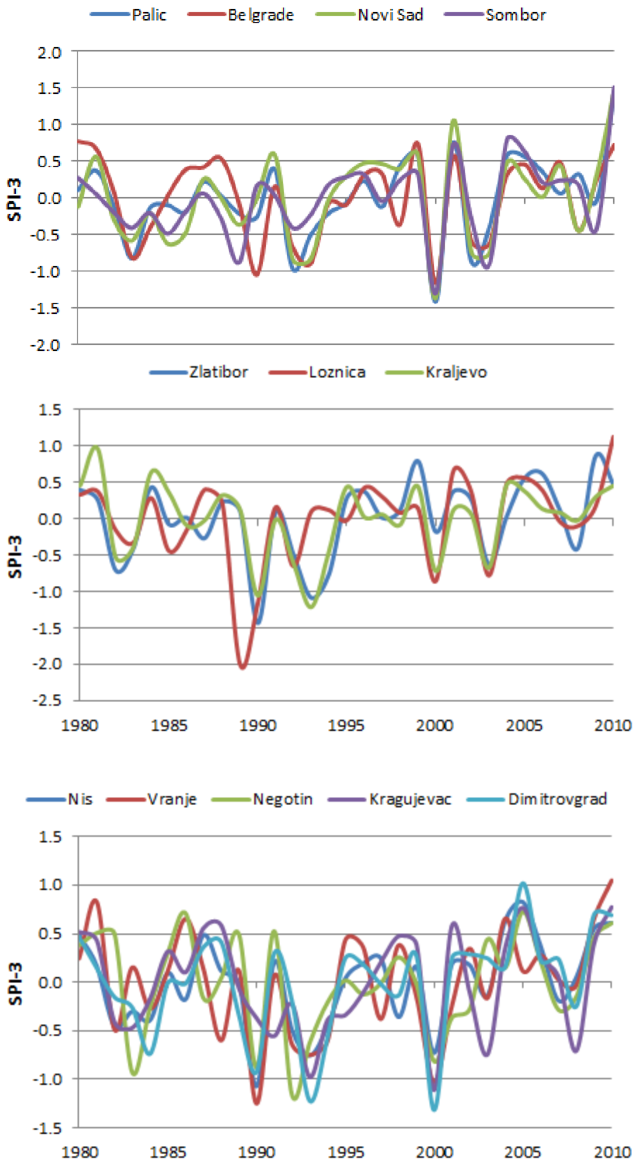

Fig. 6 Values for the SPI-3 index for the period from 1980 to 2010 on the territory of Serbia

In a region that includes the stations of Palic, Belgrade, Novi Sad and Sombor, the lowest values of the SPI-3 index were recorded in 2000 for all stations, where the drought can be characterized as moderate drought. For the stations in Zlatibor, Loznica and Kraljevo, the SPI-3 has the lowest value in Loznica, and that is -2 in 1989. For the region that includes the stations in Nis, Vranje, Negotin, Kragujevac and Dimitrovgrad, the most intense drought according to the SPI-3 index was in Dimitrovgrad, with a value of -1.3 in

2000. In this region, besides year 2000, droughts were prominent in 1993 in Dimitrovgrad, in 1992 in Negotin and in 1990 in Vranje.

The values of the ARI index for the period from 1980 to 2010 are shown in Fig. 7.

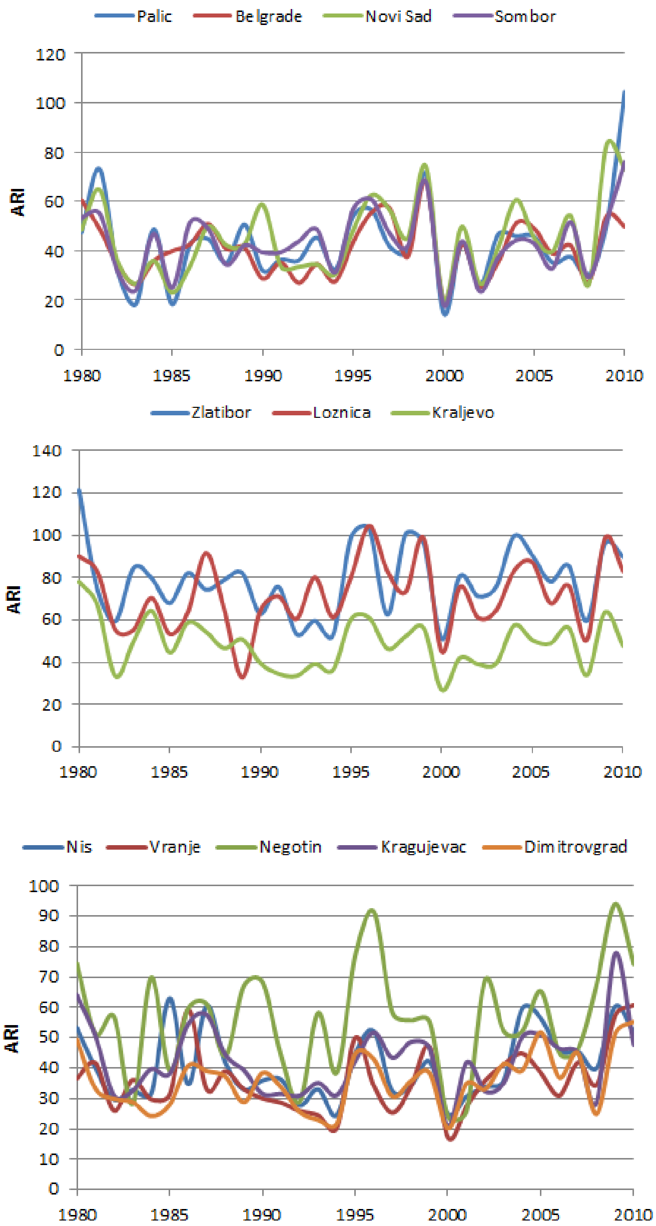

Fig. 7 The ARI index for the period from 1980 to 2010

For the region that includes the stations in Zlatibor, Loznica and Kraljevo, the lowest value of the ARI index was in Kraljevo in 2000. It can be noted that, of all the three stations, the ARI index has the lowest value for Kraljevo, during the whole observed period. The values of the ARI index for Zlatibor and Loznica show that there are suitable conditions for vegetation for the period from 1980 to 2010. As in the previous cases at the stations in Nis, Vranje, Negotin, Kragujevac and Dimitrovgrad, the largest agricultural drought occurred in year 2000, and the maximum value of the ARI index occurred in Vranje. The most suitable conditions for vegetation occurred in the area covered by the station in Negotin.

4. Conclusion

In order to analyse drought, it is necessary to thoroughly examine all its types over the longest possible time periods and ensure a detailed monitoring of the spatial distribution of drought.

In this paper, the meteorological and agricultural droughts were observed over the SPI-3 and ARI indices for the territory of Serbia for the period from 1980 to 2010. The analysis has shown that meteorological droughts are dominant, and that they are of a greater intensity compared to the humid intervals over the whole observed period. In northern Serbia, there are uniform occurrences of droughts and periods with suitable conditions for vegetation, while the rest of the country is dominated by periods with conditions suitable for vegetation. The highest intensity of agricultural droughts was recorded in year 2000.

The further research should include the impacts of meteorological, hydrological and agricultural droughts on the condition of the climate in Serbia, as well as their mutual influences.

Acknowledgement. *The research presented in the paper is funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia within scientific project no. TR37003.*

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ANALIZA METEOROLOŠKE I POLJOPRIVREDNE SUŠE U SRBIJI

Suše predstavljaju kombinovani toplotno–padavinski ekstrem ipostaju sve učestalije pojave poslednjih godina. Kako bi se celishodnije pristupilo analizi suša neophodno je obuhvatiti analizom nekoliko tipova suša. U radu su posmatrani uticaji meteorološke i poljoprivredne suše preko Standardized Precipitation Index (SPI) i Agricultural Rainfall Index (ARI) na teritoriji Srbije za period od 1980. do 2010. godine. Za oba tipa suša, izdvaja se 2000. godina kao godina kada je većina posmatranih stanica imala suše najveće jačine. Utvrđeno je da meteorološka suša za 2000. godinu ima veći intenzitet u centralnim i jugoistočnim delovima zemlje, kao i na severu. Od svih stanica meteorološka suša najvećeg intenziteta zabeležena je u Loznici 1989. godine. Poljoprivredna suša u 2000. godini imala je najmanju jačinu u zapadnoj Srbiji.

Ključne reči: *suša, meteorološka suša, poljoprivredna suša, standardizovani indeks padavina, poljoprivredni indeks padavina, Srbija.*