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THE IMPORTANCE OF THE KNOWLEDGE OF THE EFFECTS OF MOISTURE CONDITIONS ON THE FREQUENCY AND INTENSITY OF FOREST FIRES

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Abstract: The spatial and temporal variability of forest fire occurrence can only be understood in the context of moisture conditions. This paper compares moisture conditions during the growing season on the territory of northeastern Serbia with the dynamics of forest fires. The data recorded at two main weather stations, which cover the majority of northeastern Serbia - Negotin and Zaječar, were compared. Moisture values were estimated on the basis of the Standardized Precipitation Index for the growing season (SPI-6) and Davis`s Optimum Summer Weather Index (I). The data analysis for the period 2009–2015 indicates that moisture conditions correlate with forest fire occurrence and intensity on the territory of northeastern Serbia. The degree of forest fire risks affected by moisture conditions in the growing season is the highest during the periods of droughts. The exceptionally wet period in 2014 resulted in the smallest number of fires. In addition, the analysis of Davis`s Optimum Summer Weather Index (I) revealed a positive correlation with the forest fire activity on the territory of northeastern Serbia. The increased values of the index (I) were observed in 2012 and 2015 leading to an increased risk of forest fires. The decreased values (I) in 2014 correlated positively with the low number of forest fires in the summer months. The results were compared with current scientific results from Southeastern Europe and the wider region and they are applicable in the field of ecology and forestry.

Keywords: sustainable development, moisture conditions, forest fires, forestry, environment

1. INTRODUCTION

Forest fires are a common phenomenon in Serbia. They occur almost every year and present a limiting factor to sustainable forest management. Therefore, there is a growing need for adequate measures aimed at reducing the risk of fire and its harmful effects in the upcoming period. The climate parameters determine the initial and boundary conditions necessary for the prediction of forest fire ignition and spread. Understanding the long-term relationships between climate and fire regimes is thus essential for the sustainable management of the boreal forest in a changing climatic environment (Bergeron, Y. *et al.,* 1998). In addition

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to extensive environmental damage, forest fires significantly endanger forest productivity (Milenković, M. *et al*., 2017).

Moisture content is one of the most important factors that affect the flammability of plant materials and the risk of fire (Živanović, S., 2010). The concept of moisture conditions is the official term in agrometeorology and it is determined using several indicators (indices), based on which the occurrence of drought in a particular area is monitored over a certain period of time.The flammability of the vegetation cover depends on the amount of moisture contained in the flammable material, soil, and air, all of which are more or less influenced by the values and variations of climate elements. To cite the results obtained by the authors Dale, V.H. *et al*. (2001), `The frequency, size, intensity, periodicity, and type of fire depend on the weather and climate together with the structure and composition of the forest.", Radovanović, M., Pereira Gomes, J.F., 2008; point out that prolonged droughts, high temperatures, vegetation composition, terrain configuration, occurrence of lightning strikes, etc. are under certain conditions most likely to cause and regulate the conditions required for the development of forest fires. The trend of solar radiation on the surfaces under plant cover is one of very important factors that create conditions suitable for the occurrence of fires (Živanović, S., Vukin, M., 2017). The coincident drought and high temperature periods lead to the devitalization of tree trunks and desiccation of vegetation (Spasov, P., 2003; Allen, C.D. *et al*., 2010; Letić, Lj. *et al*., 2017; Krstić, M. *et al*., 2018), which contributes to the development of conditions favorable for fire ignition (Živanović, S., 2014; Živanović, S. *et al*., 2015). The risk of fire is lower during extremely wet periods (Dimitrakopoulos, A.P. *et al*., 2011; Ćurić. M., Živanović, S., 2013). Thus, forest fires tend to be concentrated during the dry summer period when the temperature is high, air humidity low and fuel moisture reduced (Piñol, J. *et al*., 1998; Dragićević, S. *et al*., 2011). Forest fire occurrence in Serbia varies from a period to a period and depends mainly on the weather conditions and fuel moisture content (Tabaković Tošić, M. *et al*., 2009; Živanović, S., 2017).

Moisture conditions of a particular period can be represented by means of a drought index. Numerous drought indices are used throughout the world today, but one of the most common indices is the SPI, i.e., the Standardized Precipitation Index (McKee, T.B. *et al*., 1993, 1995). The variability of climatic parameters in the summer months, when fire occurrence is increased, can be estimated using Davis`s Optimum Summer Weather Index (I). The aim of this research was to investigate the influence of moisture conditions on the risk of forest fire occurrence and thus to obtain new information required for further work on the prevention and control of forest fires.

2. MATERIAL AND METHODS

The territory of northeastern Serbia comprises the geographical area whose precipitation drains off into all five Timok rivers (Svrljiški, Trgoviški, Beli, and Crni Timok, which together comprise the lower or The Veliki Timok River) as well as the regions of Ključ and Poreč (Andjelković, A. *et al*., 2018). This area is separated from other areas by natural borders: the Danube in the north, the Balkan Mountains and the Veliki Timok river in the east (towards Bulgaria), the mountain ranges stretching from the Gramada and the Svrljig Mountains to Midžor in the south, and the northern parts of the Kučaj Mountains in the west

(Manojlović, P., 1986).

The data analyzed in this paper were obtained from surface meteorological measurements conducted at two main weather stations which cover most of northeastern Serbia - Negotin and Zaječar. The risk of vegetation fire was estimated based on the values of the Standardized Precipitation Index (SPI-6) and Davis`s Optimum Summer Weather Index (I).

The Standardized Precipitation Index is the amount of precipitation recorded over a time period and represented using the values of a random variable with a standard normal distribution of probabilities. This index depends on the probability density function of precipitation and the probability distribution function of precipitation. According to this method, the following categories of moisture conditions were derived.

Table 1 Categorization of moisture conditions by SPI (RHMSS, 2010)

Category of moisture conditions	SPI values
Exceptional drought	SPI ≤ -2.326
Extreme drought	-2.326 < SPI ≤ -1.645
Severe drought	-1.645 < SPI ≤ -1.282
Moderate drought	-1.282 < SPI ≤ -0.935
Minor drought	-0.935 < SPI ≤ -0.524
Near normal	-0.524 < SPI < +0.524
Slightly increased moisture	+0.524 ≤ SPI < +0.935
Moderately increased moisture	+0.935 ≤ SPI < +1.282
Considerably increased moisture	+1.282 ≤ SPI < +1.645
Extremely wet	+1.645 ≤SPI < +2.326
Exceptionally wet	SPI ≥ +2.326

The positive values of the SPI show that the amount of precipitation in a certain time period is higher than the median obtained from long-term precipitation records, while the negative values of the SPI show that the amount of precipitation in a certain time period is below the median.

The spatial and temporal variability of the climatic parameters was determined by the Davis`s Optimum Summer Weather Index (I). Davis`s Optimum Summer Weather Index (I) is based on three parameters: air temperature, insolation, and precipitation (Davis, 1968):

$$I = (18\ TL_{max} + 0.217\ S) - (0.276\ N) + 320 \quad (1)$$

Where

I - Davis`s Optimum Summer Weather Index,

TL_{max} - the mean monthly maximum air temperature in three summer months(°C),

S - the average daily insolation in three summer months (h) and

N - the amount of precipitation in three summer months (mm).

The dynamics of forest fire occurrence were estimated using a wide range of data for the time period between 2009 and 2015. The correlation between the dynamics of forest fire occurrence and moisture conditions was estimated on the basis of the statistical indicators of the number of fires and the values of the SPI and I. The study period was long enough to ensure the reliability of the analysis.

3. RESULTS AND DISCCUSION

3.1. General Characteristics of Moisture Conditions of the Study Area

The territory of Serbia is prone to changing moisture conditions, especially during the warm half of the year (Spasov, P., 2003). The Standardized Precipitation Index (SPI) is an applicable indicator of moisture conditions calculated using the data on the amount of precipitation (www.hidmet.gov.rs). The values of the SPI indicate the moisture accumulated in the surface soil which affects the possibility of vegetation fire occurrence. Drought can occur at any point when the values of the SPI are continuously negative and its intensity is below or equal to –1.0.

Figure 1 shows the estimate of moisture conditions in the growing season on the territory of northeastern Serbia based on the values of SPI-6 for September (www.hidmet.gov.rs). The map of SPI-6 (Figure 1), where moisture conditions are calculated based on the previous six months, distinguishes six categories of moisture conditions, from exceptionally wet to extremely dry conditions. According to the Standardized Precipitation Index (SPI-6), exceptionally wet conditions were recorded on the territory of northeastern Serbia in the growing season of 2014. The percentage of precipitation in the growing season of 2014 was two to three times above the average (www.hidmet.gov.rs). The most unfavorable moisture conditions, i.e., extreme drought, were recorded in this territory in 2011. It can also be observed that Zaječar was the only territory affected by extreme drought in the growing season of two calendar years, 2011 and 2013.

Moisture conditions are prone to change in the summer months, which most often has harmful effects on vegetation. The values of Davis`s Optimum Summer Weather Index (I) were considerably higher in 2012 (Table 2), which arose from the precipitation deficiency. The lowest values of this index can be observed for the year 2014 when there was a surplus of precipitation on the territory of northeastern Serbia. It is also worth noting that the values for 2014 are lower than the long-term annual mean (Table 2).

Table 2 Optimum Summer Weather Index for the periods 1961–1990 and 2009–2015

Weather station	Year							
	1961–1990	2009	2010	2011	2012	2013	2014	2015
Negotin φ 44°14N λ 22°33E 42 m.a.s.l.	776	796	825	828	895	840	756	845
Zaječar φ 43°53N λ 22°18E 144 m.a.s.l.	768	799	790	819	873	848	729	851

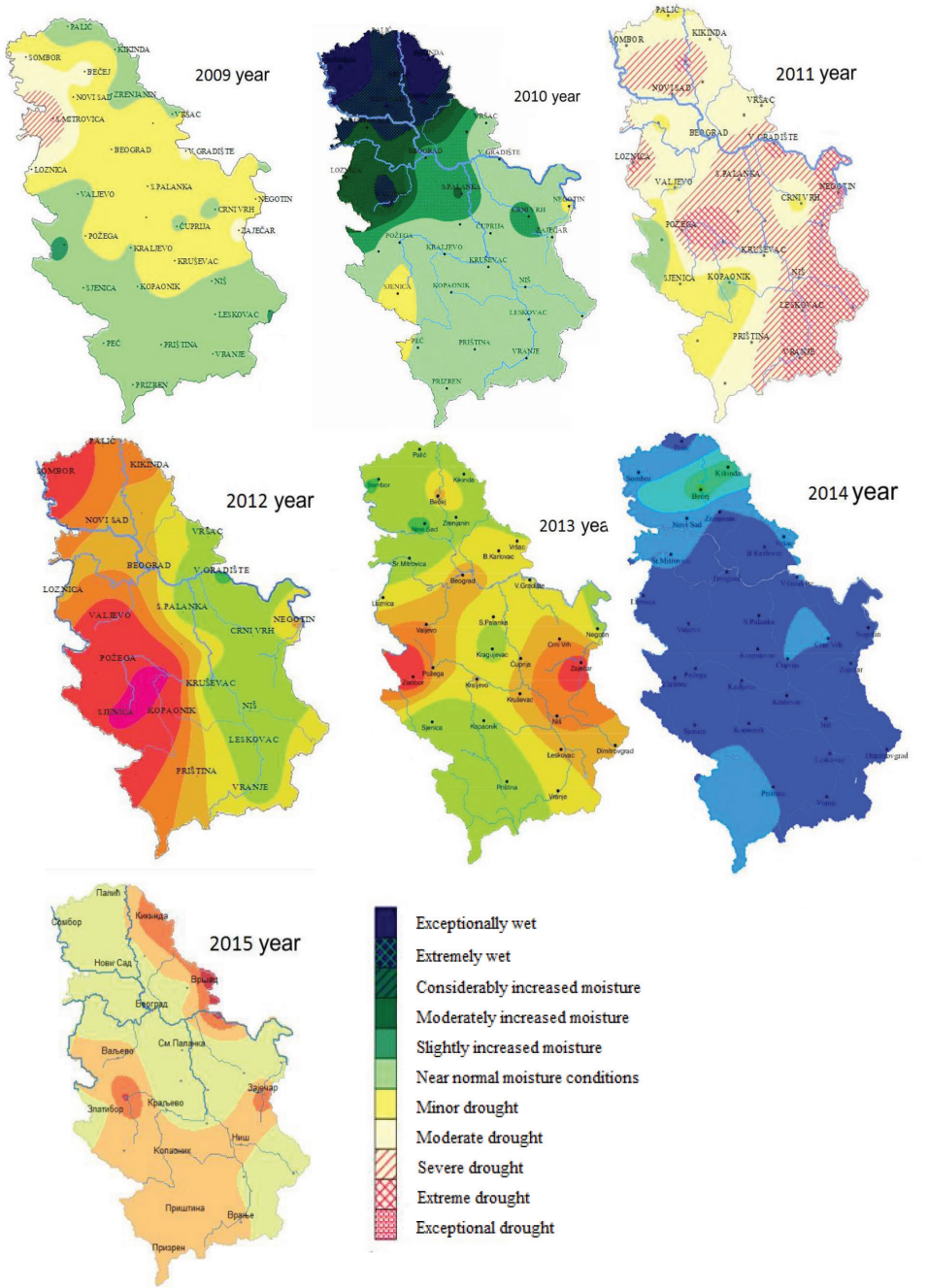

Figure 1 Moisture conditions in Serbia estimated on the basis of the Standardized Precipitation Index (SPI-6) for the growing season (1 Apr–30 Sep) 2009–2015 (Source: www.hidmet.gov.rs)

3.2. Dynamics of Fire Occurrence in the Study Area

Forests on the territory of northeastern Serbia are at risk of fire for the larger part of the year. Diagram 1 shows the dynamics of fire occurrence in the areas covered with forests and scrubs on the territory of northeastern Serbia for the period 2009–2015 (*Archives of the Ministry of Internal Affairs*). From this figure, it can be determined that the highest number of fires were registered in 2012 and 2015, whereas the lowest number of fires occurred in 2014. The vast majority of registered fires (90.4%) occurred in the areas covered in scrub.

The dynamics of fire occurrence correlate positively with the periods of low SPI values (Table 3). From Table 3, it can be observed that there are marked differences in the number of fires on a certain territory depending on moisture conditions: namely, the higher the difference in moisture conditions, the higher the difference in the number of fires. The majority of fires on this territory occurred when SPI-6 values were low. A remarkably low number of fires occurred when moisture conditions were exceptionally wet, as in 2014.

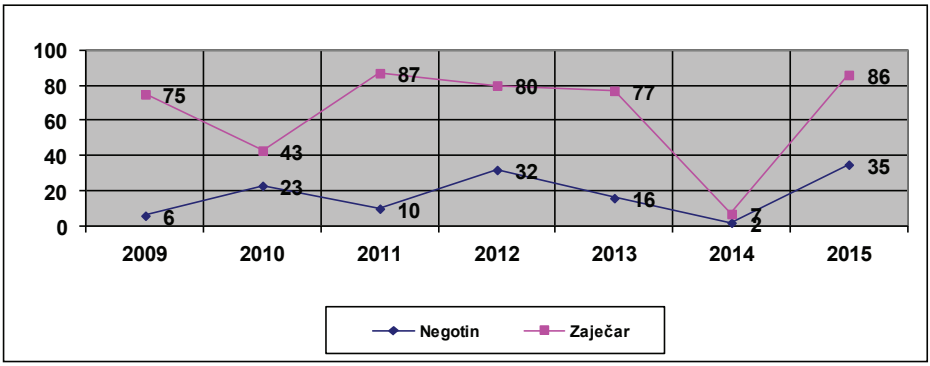

Diagram 1 The number of forest fires per growing season on the territory of northeastern Serbia (period 2009–2015)

Table 3 The number of forest fires in the growing season and moisture conditions

Year	Negotin		Zaječar	
	No. of fires	Moisture conditions (SPI-6)	No. of fires	Moisture conditions (SPI-6)
2009	6	Minor drought	75	Moderate drought
2010	23	Minor drought	43	Near normal conditions
2011	10	Exceptional drought	87	Extreme drought
2012	32	Moderate drought	80	Near normal conditions
2013	16	Near normal conditions	77	Extreme drought
2014	2	Exceptionally wet	7	Exceptionally wet
2015	35	Near normal conditions	86	Severe drought

The occurrence of fires in the summer months (June-July-August) is shown in Diagram 2. The highest number of fires in the study area was observed during 2012 and 2015 (Table 2), when Davis`s Optimum Summer Weather Index (I) had the highest values. The lowest number of fires occurred in 2014 when Davis`s Optimum Summer Weather Index (I) had the lowest values.

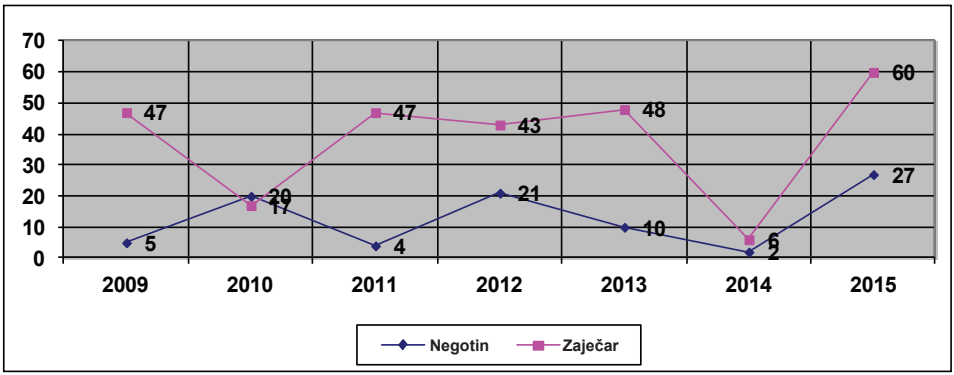

Diagram 2 The number of fires in the summer months (2009–2015)

The results obtained in this research confirm the observations (Westerling, A.L. *et al.* (2006); Won, M. S. *et al.* (2006, 2010); Živanović, S. (2010); Haire, S. (2009); Chandler, C. *et al.* (1983)) that the highest numbers of fires in nature correlate with the periods of high air temperature and low daily and monthly moisture content in the soil and fuel. Popov *et al.*, 2018; came to similar results in the research of extreme temperature trends in Bosnia and Herzegovina, concluding that extreme heat temperatures increased significantly, while cold temperature extremes showed a downward trend. It goes without saying that the dynamics of forest fire occurrence are also influenced by the distribution and amount of precipitation (Ćurić, M., Živanović, S., 2013) as well as the negligence and unawareness of people in or near a forest.

4. CONCLUSIONS

Monitoring of moisture conditions on a particular territory is becoming increasingly recognized as a useful tool for successful forest fire prediction and forest protection, i.e., forest planning and management in the conditions of climate change. Moisture conditions vary in time and space, which results in the fluctuations in the forest fire risk. Higher values of moisture content result in a reduced risk of fire, and vice versa. If the effects of moisture conditions on vegetation are used to estimate the risk of forest fire, its negative effects can be reduced to a minimum.

The paper presents the results of the study on moisture conditions during the growing season and the dynamics of forest fire occurrence in the area of northeastern Serbia, based on meteorological data of surface measurements at the main meteorological stations Zaječar and Negotin for the period 2009-2015. The data analyzed for the indicated period revealed the correlation of moisture

conditions with the occurrence and intensity of forest fires in the investigated area. It was concluded that the risk of forest fires is the highest the dry season, while the extremely wet period of 2014 led to the minimum number of fires. Moreover, 2012 and 2015 recorded an increase in the values of Davis`s Optimum Summer Weather Index (I), which resulted in an increase in the risk of forest fires.

The indicators of the moisture conditions obtained in this paper show that the highest forest fire risk is during the period with reduced levels of moisture. The results of this research provide the basis for adequate forest protection programs and public alerts on the areas of possible fire and the fire risk periods. All of the above contributes to more efficient operation in rescuing material goods and human lives and prevention of major environmental damage.

Extreme moisture conditions have already posed challenges to decision--makers, and numerous climate scenarios predict a further increase in their frequency in the future. It is in such variable weather conditions that forest fire protection will be of great importance for the mitigation of adverse effects of weather factors on the occurrence and development of forest fires.

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