Drought and its impact on the yields of field crops in the area of Nišava district

Jelena Živković[1], Marija M. Dimić[1]

[1]*University of Niš, Faculty of Science and Mathematics, Department of Geography, Višegradska 33, 18000 Niš, Serbia*

Abstract: Drought is a sub-type of climate related natural disasters. Unlike many natural disasters, drought is not a sudden phenomenon. It develops slowly, rarely causes rapid and dynamic losses in human lives. However, because of the appearance of hunger caused by it, as well as because of its direct effects, the consequences are sometimes very serious. The greater part of the territory of Nišava District (Dobrič, the valleys of Niš and Aleksinac) belongs to the areas most affected by drought in Serbia. This paper will analyze the impact of drought on yields of prevailing field crops in Nišava District, in the period 2006-2013.

Key words: drought, yields, field crops, Nišava district

1. Introduction

Along with the technological progress of mankind, which is manifested by an increase in the level of environmental degradation, the quantity and frequency of natural disasters also increases. In the first decades of 20th century, only a few dozen of natural disasters were registered in one year, although there are no records for some years. In the last two decades of the 20th century, the number of natural disasters has increased to over 200 per year. Only in 2010, EM-DAT, registered 373 natural disasters (Lukić et al, 2013). The increase in the frequency of natural disasters can be linked to future climate scenario. According to it, by 2100, the expected increase in air temperature is in the range of 1.1 and 6.4^{o}C on a global scale. And the expected increase of the sea level is between 18 and 59cm (Komac et al, 2013).

There are many differences in the definition and classification of natural disasters. It is difficult to provide generally accepted definition of what natural disasters really are, except when they are clearly identified. Definitions of natural disasters generally tend to cover all physical causes of their appearance. However, they are not always the result of the action of natural processes on the environment only, but often the result of the interaction process between the natural and anthropogenic systems (Lukic et al, 2013).

According to CRED (Center for Research on the Epidemiology of Disasters), natural disaster is any sudden and unpredictable situation or event that causes great destruction, property damage and human suffering, in situations where there are problems caused by it, beyond the capabilities of local communities to solve them, therefore there is a need for external intervention. The most appropriate definitions and categorization of natural disasters are the ones that have been made according to the physical causes of their appearance (geophysical, meteorological, hydrological, climatological, biological and astronomical). There are also those definitions that are based on quantitative indicators (the number of victims, the property insurance, the extent of necessary assistance) and others. Two organizations, Center for Research on the Epidemiology of Disasters (CRED), with its international database on disasters (EM-DAT), and insurance company, Munich Reinsurance Company (Munich RE), which is a database NatCatSERVICE, have striven for years to present a standardized definition that will be adopted at the global level, and in order to avoid terminological disharmony and to create a uniform classification. In 2007, CRED and Munich RE, reached an agreement on the classification of natural disasters, in order to provide the conditions of its most effective application for the purpose of monitoring, registration, prevention and operational goals in critical situations (Lukić et al, 2013).

In the Republic of Serbia, disasters are treated through two pieces of legislation: The Law on emergency situations in the Republic of Serbia and The National strategy for protection and rescue in emergency situations from 2011. In the Law on emergency situations, there is no definition of natural disasters, but instead the following terms were used: disasters, emergency situations and elementary disasters. Elementary disaster in this Act is defined as an event of hydrological, geological or biological origin, caused by action of natural forces such as earthquakes, floods, flash floods, storms, heavy rain, atmospheric discharges, hail, drought, landslide or mudslide, snow drifts and avalanches, extreme temperatures, ice accumulation on the watercourse, epidemic of infectious diseases, epidemics of animal diseases, the emergence of pests and other natural phenomena of major proportions, that may endanger the health and lives of people or cause severe damage.

The classification and definition are not in accordance with CRED and Munich RE. In the mentioned legal act of the Republic of Serbia, there are no types of climate disasters (although drought is mentioned as its subtype), hydrological and meteorological disasters are classified into one group. Invalid hierarchical classification, as well as large deviations compared to ones by CRED and Munich RE, hamper monitoring, registration and evaluation of the effects of natural disasters in Serbia.

Natural disasters make a negative impact on many economic activities (agriculture, energy, water management, construction, transportation, tourism and others). One of the sector that is 'vulnerable' when this phenomenon occurs is agriculture.

Drought is a natural disaster that is characterized by the deficit of rainfall, as well as by the lack of moisture in soil, which is necessary for normal growth and development of plants. In the meteorological service of the Republic of Serbia, drought is considered as a "steady stream of more then ten days, in which recorded daily rainfall is equal to or lower than 0.1mm". As such phenomenon, it causes losses in crop production in areas in which it occurs. Detailed methodological overview of the effects of drought in agricultural production can only be done when comparing the production effects of cultivated crops in natural conditions and irrigation conditions (Šimunić et al, 2007). This paper analyzes the impact of the drought, established on the basis of one indicator - the SPI index, on the yields of certain field crops in Nišava District. According to data from the Republic Hydrometeorological Service of Serbia, which conducts drought monitoring, based on SPI index, the value of this index established for the period, can be used as an indicator of agricultural drought. The administrative territorial unit, Nišava District, was chosen due to availability of statistics on crops production. The aim of this paper is to establish the relevance of the impact of drought on the yield movements of certain field crops in Nišava district in the period 2006-2013.

2. The concept and definition of drought

The very name 'drought' has different meanings depending on the people, their background and interests. Many scientists have different perceptions of drought. Walker (1998) believes the drought is a rare occurrence, while Sharma (1998) believes that droughts is frequent on the

Earth (Jankovic, 2009). There is a difference between aridity and drought. While aridity as a phenomenon means that there is a constant shortage of rainfall in a region, compared to the necessary values, drought is a short-term deviation of precipitation and air temperature from normal values, for the given area and time of year. Legislation in Serbia does not distinguish clearly between natural disasters such as drought and aridity as a long-term drought indicator (Lukić et al, 2013).

Drought is a complex natural phenomenon whose definition requires the inclusion of the climate elements (the amount of slopes, air temperature, air pressure, wind speed, etc.), as well as hydrological factors (the level of surface and groundwater), soil (the type of soil), biological factors (presence and type of land cover), geographical and other factors. Therefore, they established numerous simplified definitions of drought, as well as its division into: atmospheric, hydrological, land and agricultural drought.

The definition of drought depends on regional differences and needs, but also on the perspective this phenomenon is observed from. Regardless of the needs of defining the drought, it is necessary to include deviation of the actual relationship between rainfall and evapotranspiration in the area, from the normal value of this relationship in a multi-year period. The definitions of drought can be divided into: conceptual and operational. Conceptual definition generally explains the concept of drought, while operational definition needs to offer easier identification of the beginning and the end of drought as well was its and intensity.

Drought caused by natural climate changes that lead to a lack of rainfall in a period, is recognized as the *meteorological drought*. The lack of rainfall through the hydrological circle, in combination with high evaporation losses can lead to land infertility and that represents *agricultural drought*. Lowering the water level of navigable rivers, as well as draining underground aquifers, represents a *hydrological drought*. Precipitation deposited as snow and freezing rivers cause *winter drought* (Tallaksen & Hisdal, 1997).

3. Geographical position of Nišava District

Nišava District extends approximately between 43º10' and 43º40' north latitude and 21º30' and 22º10' east longitude. Accordingly, as the entire territory of Serbia, Nišava District stretches in the middle of the northern temperate zone. According to the Regulation on the Nomenclature of

Territorial Units, Nišava District belongs to the Region of Southern and Eastern Serbia, as one of nine NUTS3 territories ("RS Official Gazete", No.109/09 & 45/10). Territory of Nišava District covers following administrative units: the City of Niš and its municipalities (Medijana, Pantelej, Crveni Krst, Palilula and Niška Banja) as well as, the municipalities of Aleksinac, Doljevac, Merošina, Ražanj, Gadžin Han and Svrljig. The total area of Nišava district is 2.728 square kilometers. In 2012. there were 374.371 residents living in this area (Municipalities and Regions in the Republic of Serbia, 2013). The territory is located between Pomoravlje and Zaječar District in the north and north-east, Pirot District in the east, Jablanica and Toplica District in the south and south-west and Rasina District in the west.

Regional position and geographical position of the study area are complex and diverse. Observed territory includes a number of smaller physical geographic regions. The most dominant recess in the land relief is valley of Niš and Aleksinac, which is surrounded by mountains of medium height. Zaplanje (in the basin of Kutinska River) and Svrljiška valley (in the basin of Svrljiški Timok), are also significant, as well as Dobrič, which extends in the lower part of Toplica basin.

The City of Niš as well as municipalities of Aleksinac and Ražanj belong to South Morava Valley. The municipalities of Doljevac and Merošina are in Dobrič (Toplica), Gadžin Han is in Zaplanje, while Svrljig municipality is in the south part of Carpatho-Balkan region. Therefore, the territory of Nišava District includes several geographic micro-regions of Eastern and Southern Serbia.

Spatial distribution of administrative units within the Nišava district, indicates the complexity of the physical and regional geographic position of the area.

According to Rakićević, in terms of drought, the territory of Serbia can be divided into four areas:

- *Dry areas* (areas most affected by drought): valley of Niš, Leskovac, Bela Palanka, Aleksinac, Vranje and Gnjilane, Dobrič, plateau of Kosovo, Metohija, area of Negotin, northeastern part of Bačka and northern Banat.
- *Moderately dry areas*: Srem, western and southern Bačka, southern Banat, Mačva, Podunavlje, valley of Great and Western Morava and most of Šumadija.

- *Moderately moist areas*: Podrinje, the foothills of Valjevo mountain range, mountain areas till the 1000m altitude in western and southeastern Serbia, as well as Carpatho-Balkan mountains in Eastern Serbia.
- *Very humid areas*: the highest mountain regions of Serbia, represented by: Šara mountain, Prokletije, high mountains of Stari Vlah, Kopaonik, Stara planina and Vlasina region.

This division was based on the analysis of the most important parameters which determine duration, frequency and intensity of drought. These are: annual precipitation, pluviometric regime, temperature and humidity in the vegetation period and the lack of moisture in the soil (Dragićević & Filipović, 2009).

Figure 1. Administrative Districts of Serbia with Nišava District (www.nis.okrug.gov.rs)
Regional distribution of drought in Serbia

Based on Figure 2, it can be concluded that most of the Nišava District belongs to the areas which are most affected by drought. These are the areas within a yearly isohyets of 600mm.

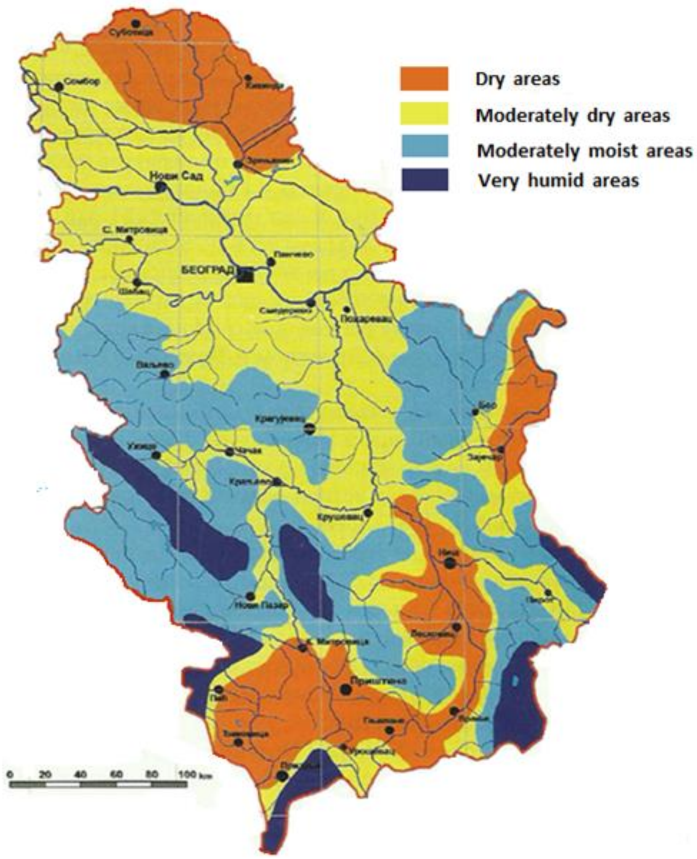


Figure 2. The regional distribution of drought in Serbia (Rakićević, 1988)

4. Indexes of drought

There are several indexes that show how the amount of rainfall and its distribution in the reporting period deviate from the average rainfall for at least thirty years, for the given time unit. Neither the one of them is superior to others, and most experts use different indexes to define the research results. The most commonly used indexes are:

- *De Marton Index* which establishes a link between rainfall, temperature and humidity of some areas (Ducić & Anđelković, 2004). Whereas vegetation depends on the amount of rainfall and air temperature, De Marton introduced this concept to demonstrate the connection between these two elements and the type of landscape in terms of moisture of vegetation.

- *Palmer Drought Severity Index* (PDSI) is based on the principle of balance between the need and the supply of the land with moisture. For determining the intensity of droughts, PDSI uses data on temperatures and precipitation. This index is more efficient in determining the long-term drought, but it is unsuitable for short-term synoptic forecasts (Dragićević & Filipović, 2009).
- *Percentage deviation* (Percentil) is calculated as the ratio of actual and normal (average for at least 30 years) precipitation amounts in the observed time period, multiplied by 100%. It is determined for any time unit, the vegetation period, hydrological years and others (Janković, 2009).
- *Standardized Precipitation Index* (SPI) is based on a calculation of the probability of precipitation for the selected time period. In addition to being able to calculate probability of precipitation for different time periods, this index can provide early warning of drought and help in assessing the intensity of the drought.

5. Standardized Precipitation Index – SPI index

The Standardized Precipitation Index (SPI) is a tool which was developed primarily for defining and monitoring drought. It allows an analyst to determine the rarity of a drought at a given time scale (temporal resolution) of interests for any rainfall station with historic data. It can also be used to determine the periods of anomalously wet events.

Standardized Precipitation Index is very applicable indicator of humidity conditions. Its calculation requires only data on the amount of rainfall. Standardized Precipitation Index is, in fact, the amount of rainfall recorded during a period of time represented by the value of the random variable that has standardized normal distribution of probabilities.

The notion that rainfall has different influence on the underground water level, the moisture content in the soil, as well as on water courses, has prompted Mc Kee, Doesken and Kleist to develop standardized precipitation index in 1993. This index is designed with the idea to quantify the precipitation deficit for different time periods (Redmond, 2002). Selection of the time period at the same time reflects the period in which the impact of drought on the availability of moisture can be noticed in different aquatic resources. Namely, the moisture content in soil is changed during the shorter period of time (due to appearance of anomalies in the precipitation regime), than in the surface and the groundwater, which react only to the long-term rainfall anomalies. For these reasons, SPI index calculation by Mc Kee and associates, was initially for a period of 3.6.12.24 and 48 months.

Calculation of SPI index for any location is based on the report on the long-term rainfall for the selected period. Positive SPI values indicate greater than average precipitation, and negative less than average precipitation.

In 1993, Mc Kee, Doesken and Kleist defined the criteria for the occurrence of drought for any period of time. The case of drought happens at any time when the SPI is continuously negative and reaches an intensity of -1.0 or less. This event ends when the SPI becomes positive.

Therefore, each case of drought has a duration that is defined from the beginning to the end. Also, it has intensity for each month in which drought is repeated. Positive sum of SPI indexes for all months with the case of drought, could be called "the size of the drought".

Monitoring moisture conditions carried out by the Republic Hydrometeorological Service of Serbia within the Department of Agrometeorology, includes the determination of SPI values on the basis of the amount of rainfall recorded in the previous 30, 60 and 90 days. Beside these, SPI values are also calculated for previous 1, 2, 3, 4, 5, 6, 9, 12 and 24 months. SPI values, established for longer periods of time, indicate the prevailing characteristics of moisture conditions during the vegetation season, the calendar year and so on.

Table 1. Humidity conditions and the value of SPI index (Hydrometeorological Institute of Serbia, Agro Climate)

Insignia	Humidity conditions	SPI values
ED	Exceptional drought	SPI≤-2.326
EXD	Extreme drought	-2.326<SPI≤-1.645
SD	Severe drought	-1.645<SPI≤-1.282
MD	Moderate drought	-1.282<SPI≤-0.935
D	Drought	-0.935<SPI≤-0.524
N	Normal humidity terms	-0.524<SPI<+0.524
SIH	Slightly increased humidity	+0.524≤SPI<+0.935
MIH	Moderately increased humidity	+0.935≤SPI<+1.282
VW	Very wet	+1.282≤SPI<+1.645
EXW	Extremely wet	+1.645≤SPI<+2.326
EW	Exceptionally wet	SPI≥+2.326

6. Materials and methods

Data on the production of field crops in Nišava District are taken from the website of the Republic Institute for Statistics of Serbia (www.stat.gov.rs). Field crops covered by the survey are: maize, wheat, rye, barley, oats, triticale and sunflower. In addition to data on the total yield of the observed cultures in tones, the analysis also shows the average yield in kilograms per hectare, as well as sown areas with field crops in hectares. SPI index values and data on the production of field crops were monitored from 2006. to 2013.

Table 2. Total production of field crops in the area of Nišava District (www.stat.gov.rs)

Year		maize	wheat	rye	barley	oats	tritica-le	sun-flower
2006.	Sown area (ha)	31891	22189	251	2668	1583	1069	7
	Average yield (kg/ha)	3658	2709	1924	2201	1698	2973	1714
	Total yield (t)	42794	31261	483	5871	2688	3140	12
2007.	Sown area (ha)	30392	22369	185	2572	1561	1297	7
	Average yield (kg/ha)	1208	1888	1276	1767	1401	2275	1000
	Total yield (t)	37381	42235	236	4545	2187	2951	7
2008.	Sown area (ha)	31620	20173	179	2688	1595	1285	105
	Average yield (kg/ha)	3879	3818	2330	3060	2320	3949	1524
	Total yield (t)	122639	77025	417	8226	3700	5074	160
2009.	Sown area (ha)	30400	21262	153	2436	1652	1505	8
	Average yield (kg/ha)	4051	3090	1889	2560	1944	3176	1875
	Total yield (t)	123159	65688	289	6236	3212	4780	15
2010.	Sown area (ha)	30500	20328	134	2285	1632	1647	4
	Average yield (kg/ha)	4100	2900	2100	2400	1800	3200	1000
	Total yield (t)	125814	59805	279	5523	2877	5298	4
2011.	Sown area (ha)	29703	20406	144	2334	1405	1580	5
	Average yield (kg/ha)	2900	3000	2300	2700	1900	3100	2000
	Total yield (t)	86110	61830	331	6221	2615	4926	10
2012.	Sown area (ha)	30312	19945	130	2279	1387	1453	5
	Average yield (kg/ha)	1900	2900	2000	2400	1600	3100	2000
	Total yield (t)	57720	58619	267	5509	2264	4543	10
2013.	Sown area (ha)	30333	20325	128	2325	1387	1682	6
	Average yield (kg/ha)	-	3595	2233	2884	2054	3751	-
	Total yield (t)	-	73145	268	6668	2761	6309	-

Data on SPI values are taken from the Republic Hydrometeorological Service of Serbia website (www.rhmz.gov.rs). They refer to the SPI calculated for six-month period. The study focused on two annual periods: the growing season, which runs from April to September, and the fall-winter period, which runs from October to March.

Table 3. Humidity conditions in Nišava District for the vegetation period (April-September), (Hydrometeorological Institute of Serbia, Agro Climate

Year	Vegetation period
2007.	Moderate drought (Severe drought in the valley of Niš)
2008.	Normal humidity conditions
2009.	Normal humidity conditions
2010.	Normal humidity conditions
2011.	Severe drought
2012.	Normal humidity conditions
2013.	Severe drought

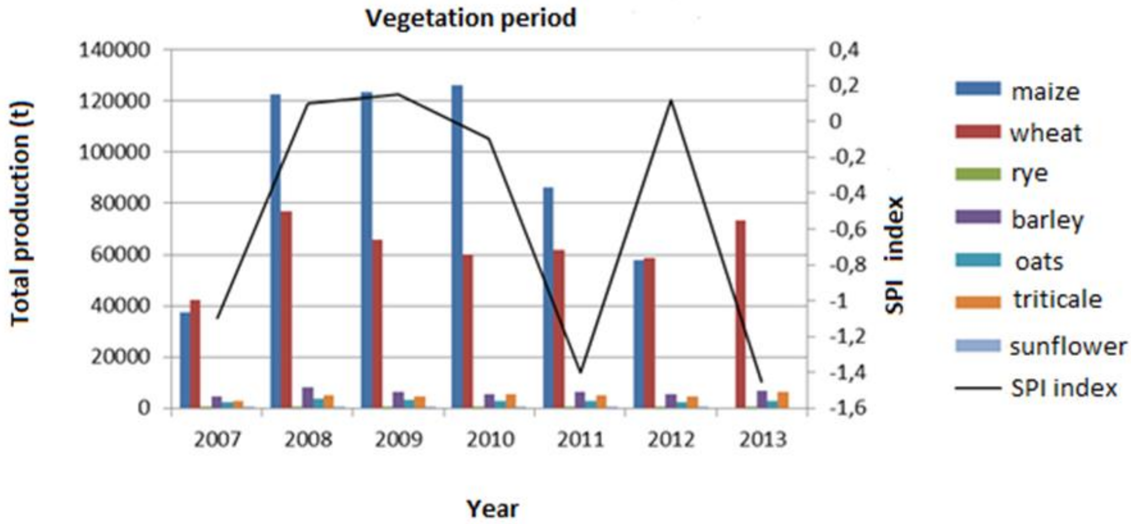
Table 4. Humidity conditions in Nišava District for the autumn-winter period (October-March) Hydrometeorological Institute of Serbia, Agro Climate

Year	Autumn-winter
2006/2007.	Drought
2007/2008.	Very wet
2008/2009.	Slightly increased humidity
2009/2010.	Exceptionally wet
2010/2011.	Normal humidity conditions
2011/2012.	Normal humidity conditions
2012/2013.	Moderately increased humidity

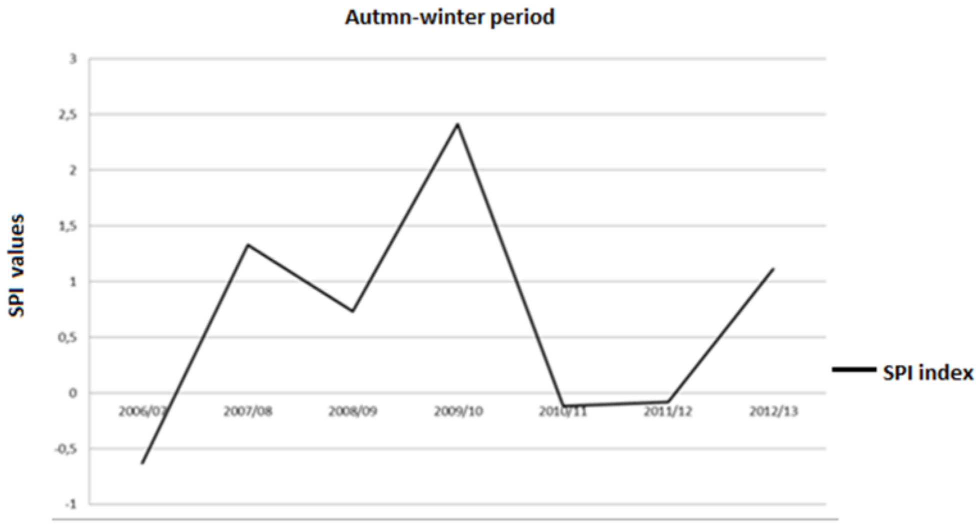
7. Research results

Data analysis indicates that in the years with the phenomenon of severe drought (2007, 2011, 2013) yield of field crops reduced. This phenomenon is most evident in the case of maize.

In 2007, in which phenomenon of moderate drought was registered (but in the valley of Niš severe drought was registered), yield of maize decreased by 70%, compared to 2010. (normally wet), which is also the most productive year in the period from 2006. to 2013. In that year, there was a high correlation between the SPI index and the yields of maize. In 2011, yield of maize was 31.6% lower then in 2010. However, in 2012, which had a normal moisture conditions, yield of maize was 54% lower then in the most productive 2010. Therefore, in this year, the reduction of maize yield was not conditioned by drought.



Graph 1. The ratio of the total production of certain crops and SPI index in Nišava District



Graph 2. The value of SPI for the autumn-winter period (2006-2013)

In the case of wheat, the results indicate that the yield less varied in the period from 2006. to 2013. Yield of wheat in 2011. and 2013. (which had a drought in the vegetation period) are even higher than in 2010. and 2012. (normal humidity conditions during the vegetation period). In this case, there is no correlation between SPI index in the vegetation period and the yield of wheat. For yields of wheat humidity conditions during the autumn-winter period are more important. In the period from 2006. to 2013., drought in autumn-winter period only occurred during 2006/07, while in other periods, normally or moderately increased humidity conditions prevailed.

Given the fact that the area sown with maize and wheat in Nišava District, makes up almost 90% of the total area under the field crops, the share of other analyzed cultures, is not significant for monitoring the impact of the SPI index on the movement of yields.

8. Discussion

Based on the research results, it can be concluded that there is certain impact of drought (established on the basis of the SPI index) on the yields of crops in the area of Nišava District, during the observed period. The reduction of maize yields does not always coincide with a period of drought defined by the negative values of SPI index during the vegetation period - when this culture needs the maximum amount of moisture. When it comes to wheat yield movements, it is noted that yields have a lesser variation of value in the period from 2006. to 2013. In some years, when there was a drought during the growing period (2011 and 2013), wheat yields have achieved higher values than in the normal wet years (from April to September). However, in the fall-winter period (October-March), in the Nišava District (except for 2006/07), there was the absence of drought. For the wheat yield the amount of precipitation during the sowing period is of crucial importance, as well as period before sowing, which is usually in September or October. Given that fact, in the case of wheat a correlation between the SPI index and the yield can also be established. Other crops that are analyzed in this paper are not relevant for monitoring the impact of the SPI index on the movement of yields, because the percentage of participation of their respective plantations is slight, compared to the dominant cultures (maize and wheat).

In comparison to other economic activities, agricultural production is characterized by dependence on a large number of natural factors, especially on soil, as well as on yearly climate conditions and on localities. In the fight against uncontrollable natural conditions, of mitigating the effects of adverse weather conditions should be take into account. In Serbia, drought is present almost every year in certain regions, with a greater or lesser intensity and it represents a limiting factor for high yields. According to some studies, with the use of agricultural procedures of small grains, the effect of "poor year" can be improved from 10 to 25%. Therefore, in order to reduce the risk of drought, appropriate measures of protection against drought should be taken (monitoring and early warning, risk assessment and mitigation of consequences).

References

Alley, W.,M. (1984): The Palmer Drought Severity Index: limitations and assumptions. Journal of Climate and Applied Meteorology, 23:1100-1109

Edwards, D., McKee T. (1997): Characteristics od 20th century drought in the United States at multiple time scales. Climatology Report 97-2.

Palmer, W.C. (1968): Keeping track of crop moisture conditions, nationwide: The new crop moisture index.Wetherwise 21: 156-161)

Redmond, K.T. (2002): The depiction of drought. Bulletin of the American Meteorological Society. 83, 1143-1147

Božić, M., Nikolić G., Milošev D. (2009): Suša i strategija navodnjavanja. Institut za vodoprivredu „Jaroslav Černi“

Volodin, A.,(1946): Velike i sušne pojave u prirodi, Prosveta. Beograd

Gavrilović, Lj. (2007): Prirodne nepogode kao faktor ugrožavanja životne sredine. Prvi kongres srpskih geografa. Zbornik radova. Beograd

Dragićević, S., Filipović, D. (2009): Prirodni uslovi i nepogode u planiranju i zaštiti prostora. Geografski fakultet Univerziteta u Beogradu.

Ducić, V., Anđelković, G. (2004): Klimatologija. Praktikum za geografe. Geografski fakultet Univerziteta u Beogradu

Maksimović, N.,A. (1946): Kako nastaju suše i možemo li se boriti protiv njih?, Beograd

Radenković, B. (1951): Borba protiv suša. Zadružna knjiga. Beograd

Šimunić, I., Husnjak, S., Tomić, F. (2007): Utjecaj suše na smanjenje prinosa poljoprivrednih kultura. Agronomski glasnik. Zagreb

Lukić, T., Gavrilov, B.,M, Marković, B.,S, M, Komac,B.,Z, Mlađan, D., Đorđević, J., Milanović, M., Vasiljević, A., Đ, Vujičić, D., Kuzmanović, B., M, Prentović, R. (2013): Classification of the natural disasters between the legislation and application: experience of the Republic of Serbia. Acta Geographica Slovenica, 53-1, DOI: 10.3986/AGS53301.

Komac, B., Zoran, M., Gavrilov, B.,M, Marković, B., S. (2013): Natural Hazards – some introductory thoughts. Acta Geographica Slovenica, 53-1, DOI: 10.3986/AGS53300.