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Determination of the intensity of hydrological and climatological drought in the Južna Morava River sub-basin

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Abstract

The aim of this work is to determine the dependence of discharge on precipitation in the Južna Morava River sub-basin to the Korvingrad hydrological station. Data from the hydrological station Korvingrad and three meteorological stations Kuršumlija, Leskovac and Vranje were used for a period of 31 years (1991-2021). Streamflow Drought Index (SDI) and Standardized Precipitation Index (SPI) were used to determine hydrologically and meteorologically dry and wet periods. The results showed that it is possible to distinguish 5 hydrologically dry and 4 hydrologically wet periods. The mean annual and monthly values of SDI and SPI were most numerous in the mildly dry and mildly wet category. We can conclude that the precipitation at the synoptic stations greatly affects the flows of the Južna Morava at the Korvingrad hydrological station.

1. Introduction

Hydrological droughts belong to the group of natural disasters and according to the damage they cause, they can be compared to floods and earthquakes (Europea, 2007). They have significant economic, social and environmental impacts in regions around the world. Regions in Asia and Africa are often affected by droughts resulting in famine and loss of life (Europea, 2007; Reduction, 2007; DAT, 2011; Sheffeld and Wood, 2012; Van Loon and Van Lanen, 2012). Tallaksen and Van Lanen (2004) define drought as a sustained and regionally extensive period of below-average natural water availability. This phenomenon is repeated all over the world and its spatial and temporal characteristics vary from one region to another. Hydrological drought is a consequence of meteorological drought, lack of moisture in the soil and reduction in the level and volume of groundwater (Tallaksen and Van Lanen, 2004; Mishra and Singh, 2010). Meteorological droughts cannot be avoided, but they can be predicted and monitored in order to mitigate their effects. Drought assessment and monitoring is often done using drought indices (Vu-Thanh et al., 2014).

According to Giorgi (2006), Europe is the focal point of climate change. The positive trend of drought is more frequent in the region of Southern Europe and the Mediterranean area, which is a consequence of the increase in temperature (Briffa et al., 2009; Hoerling et al., 2012; Spinoni et al., 2015). Research by Spinoni et al. (2015) showed that in Southern Europe and the Carpathian region there was a decrease in precipitation and an increase in temperatures. Also, they came to the conclusion that the frequency of droughts in the Balkan Peninsula is related to the increase in air temperature. In addition to regions in Europe, regions around the world also face frequent occurrence of droughts that cause problems of water availability. This is a consequence of deteriorating water quality, increasing water demand and climatic variability of precipitation (Wood et al., 1997; Trenberth, 2001; Schewe et al., 2014; Mehran et al., 2015). Arid regions are most sensitive to climatic variability of precipitation which affects socioeconomic droughts (Cayan et al., 2008; Medellin-Azuara

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et al., 2008; Arab et al., 2010). Precipitation change in recent decades is assumed to be global (Hulme et al., 1998). Šegota and Filipčić (1996) point out that the variability of precipitation is affected by changes in global temperature and evaporation, which directly affects changes in river flow and the occurrence of hydrological droughts. Precipitation is often concentrated in extreme events during which a large amount of precipitation is discharged, while dry periods occur more often and last on average longer than wet periods (Iwashima and Yamamoto, 1993; Karl et al., 1995; Karl and Knight, 1998).

In recent decades, it has been established in Serbia that dry periods were more frequent than wet ones. Cold periods were more numerous in the second half of the 20th century. The change occurred in the last decade of the 20th century when the climate became warmer. Mean daily maximum and minimum temperatures recorded an increasing trend at most synoptic stations (Malinovic-Milicevic et al., 2014). Similar results were obtained by Gocić and Trajković (2013), whose results showed the existence of two hydrologically dry periods. The first hydrological drought lasted from 1987 to 1994, while the second was shorter from 2000 to 2003. They point out that the occurrence of droughts in this period was largely due to rainfall. Tošić and Unkašević (2014) point out that dry periods lasted longer in the south of Serbia, while in the north their length decreased.

2. Study area

The research covered the Južna Morava River sub-basin up to the Korvingrad hydrological station (Figure 1). The main river of the sub-basin is Južna Morava, while its main tributaries are Banjska reka, Vrla, Vlasina, Veternica, Jablanica, Pusta reka and Toplica. Južna Morava River is formed by the merging of Binačka Morava and Preševska Moravica near Bujanovac (Pavlović, 2019). The sub-basin includes the territory of Southern Serbia and the northern slopes of Skopska Crna Gora in North Macedonia and its total area is 9,396 km^2 (Miletić, 2022). The territory of the sub-basin is a spatially wide area that includes the Western Zone of the Crowned Mountains and Valleys in the west, the Eastern Zone of the Crowned Mountains and Valleys in the east, and the Zone of Bouldery Mountains and Valleys in the central part, in the Južna Morava River Valley. The highest areas of the sub-basin are in the west and east, while the lowest are in the Južna Morava valley and basins.

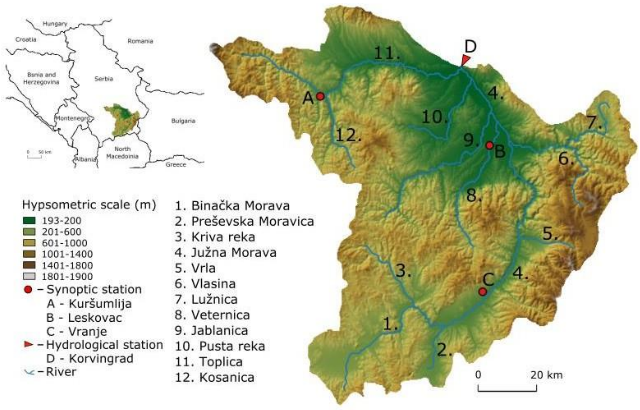

Figure 1. The territory of the Južna Morava sub-basin up to the Korvingrad hydrological station

According to Tomislav Rakićević (1980), the Južna Morava River sub-basin up to the Korvingrad hydrological station belongs to a moderate-continental climate and includes the Gnjilanski, Vranjski, Vlasinski, Niško-Leskovački and Kopaonički climatic regions. Areas that belong to the Kopaonik climate region have the highest amount of precipitation on an annual level, from 800 mm to 1200 mm. The Vlasina climate region is characterized by an average annual rainfall of 800-1000 mm. Niško-Leskovački climatic region is the driest and warmest in the sub-basin. Since the beginning of measurements, the average annual amount of precipitation at the meteorological station in Prokuplje is 529 mm, Niš 555 mm, Aleksinac 580 mm and Leskovac 587 mm. It is also the warmest in Serbia and the region with the longest growing season (more than 260 days a year) (Pavlović, 2019)

3. Materials and methods

The Streamflow Drought Index (SDI) was determined for the flows at the Korvingrad hydrological station, while the Standardized Precipitation Index (SPI) was determined for the precipitation at the Kuršumlija, Leskovac and Vranje synoptic stations. SDI is used to monitor and analyze hydrological droughts. It is calculated for each reference period of the k and i-th hydrological year (Nalbantis and Tsakiris, 2009; Tabari et al., 2013; Myronidis et al., 2018; Jahangir and Yarahmadi, 2020, Đokić et al., 2022). SDI is calculated using the following formula:

$$SDI_{(i,k)}=\frac{V_{(i,k)}-\bar{V}_k}{S_k}, \quad i=1,2,3\ldots;\ k=1,2,3\ldots$$

Where $V_{i,k}$ is the flow for the i-th hydrological year and the k-th reference period (for October, for November, December,..., for September), $\bar{V}_k$ is the mean value and

Sk is the standard deviation of the monthly and annual flows reference period k.

In the paper, SDI values are calculated for months and cumulative flows for the period October-September. In this way, it is possible to compare individual monthly flows in a hydrological year during the research period. The values of SDI in certain periods can show the occurrence of hydrological drought or high flow (Tabari et al., 2013; Đokić et al., 2022).

SDI can have different values and can therefore be classified into several classes. In their works, Hong et al. (2015) and Đokić et al. (2022) classified SDI into 8 categories shown in Table 1.

Table 1. Standardized Flow Index (SDI) Categories

SDI value	Category
SDI ≥ 2.0	Extremely wet
1.5 ≤ SDI < 2.0	Severely wet
1.0 ≤ SDI < 1.5	Moderately wet
0.0 ≤ SDI < 1.0	Mildly wet
-1.0 ≤ SDI < 0.0	Mild drought
-1.5 ≤ SDI < -1.0	Moderate drought
-2.0 ≤ SDI < -1.5	Severe drought
SDI ≤ -2.0	Extreme drought

A Standardized Precipitation Index (SPI) was developed to identify meteorological drought (McKee et al., 1993). Using SPI, it is possible to analyze the occurrence of drought in a certain time interval and compare the results with the values of other regions in the world (Ducić et al., 2014; Karabulut, 2015; Malakiya and Suryanarayana, 2016). Ducić et al. (2014) point out that drought has its confirmation only if it occurs continuously in the series when SPI values are lower than -1. The drought period ends when the value becomes positive.

The SPI is calculated for average monthly and annual precipitation in the same way as the SDI, using the following formula:

$$SPI_{i,k}=\frac{X_{i,k}-\bar{X}_k}{S_k}, i=1,2,3,\ldots;k=1,2,3,\ldots$$

Where Xi,k is the amount of precipitation for the i-th hydrological year and the k-th reference period, $\bar{X}_k$ is the mean value and Sk is the standard deviation of monthly and annual precipitation for the reference period. In the paper, SPI values were calculated for individual monthly periods and the period from October to September. By calculating SPI, it is possible to determine in addition to dry and wet periods in the analyzed period (Đokić et al., 2022). The SPI classification is shown in Table 2 as described and applied by Zhang et al. (2009), Karabulut (2015), Jang (2018) and Đokić et al. (2022).

Table 2. Standardized Precipitation Index (SPI) Categories

SPI value	Category
SPI ≥ 2.0	Extremely wet
1.5 ≤ SPI < 2.0	Severely wet
1.0 ≤ SPI < 1.5	Moderately wet
0.0 ≤ SPI < 1.0	Mildly wet
-1.0 ≤ SPI < 0.0	Mild drought
-1.5 ≤ SPI < -1.0	Moderate drought
-2.0 ≤ SPI < -1.5	Severe drought
SPI ≤ -2.0	Extreme drought

The paper analyzed data from the Korvingrad hydrological station located on the Južna Morava. The hydrological station is located at an altitude of 188.09 m a.s.l. and is 105.7 km away from the confluence (place of origin of Velika Morava) (Hydrological yearbooks, 1991-2021). Measurements at the station have been recorded continuously since 1922. In this paper, the data published in the hydrological yearbooks of the Republic Hydrometeorological Institute of Serbia for a period of 31 years (Hydrological yearbooks, 1991-2021) were processed. Periods of hydrological years starting on October 1 and ending on September 30 of the following year were analyzed. The data includes mean monthly and annual flows.

The paper analyzed meteorological data from three synoptic (main) stations in the sub-basin: Kuršumlija, Leskovac and Vranje. The weather station Kuršumlija is located at an altitude of 362 m a.s.l, Leskovac at 230 m a.s.l, and Vranje at 432 m a.s.l. The data that were used are published in the meteorological yearbooks of the Republic Hydrometeorological Institute of Serbia for a period of 31 years (Meteorological yearbooks, 1991-2021). The data refer to average monthly and annual precipitation amounts.

4. Results and discussion

4.1. The identification of the Ibar River pollutants

For the mentioned period, the average annual air temperature in Kuršumlija was 10.76°C, in Leskovac 11.58°C and in Vranje 11.61°C. The hottest month in Kuršumlija and Leskovac was July, while August was the hottest month in Vranje. The coldest month at all synoptic stations was January. The average annual rainfall in Kuršumlija was 670 mm, Leskovac 661 mm and Vranje 606 mm. The highest average monthly precipitation at all synoptic stations was in May (Kuršumlija 72 mm, Leskovac 69 mm and Vranje 63 mm), while the lowest was recorded in August (Kuršumlija 46 mm, Leskovac 45 mm and Vranje 42 mm).

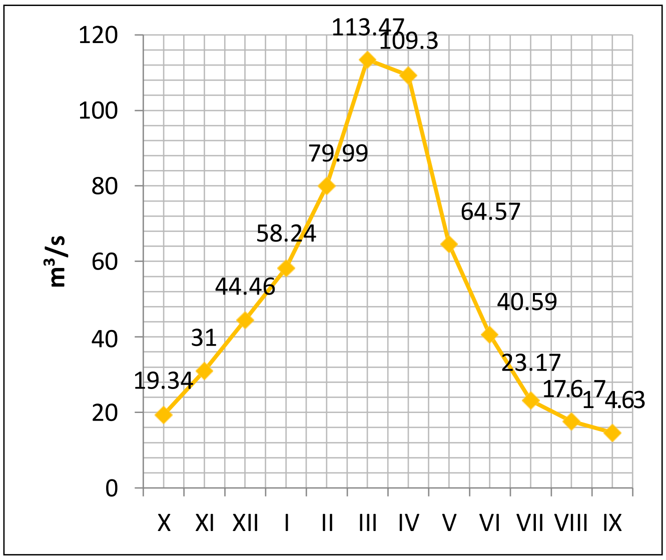

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Figure 2. Average monthly discharge (m³/s) at the Korvingrad hydrological station in the period from 1991 to 2021

Average discharge of the Južna Morava River at the Korvingrad hydrological station in the period 1991-2021. was 51.37 m^3. The value of specific runoff in the same period was 5.47 $l/s/km^2$. The highest value of average monthly flows, which is 113.47 m^3 was recorded in March. The lowest value of average monthly flows was recorded in September. The value of the average monthly flows in April is lower by 4.17 m^3 compared to the flows in March. The value is 7.76 times lower than that in March and amounts to 14.63 m^3 (Figure 2). High flow values at the end of winter and beginning of spring can be explained by the melting of snow in the higher parts of the sub-basin. The higher flows in April and May are also influenced by precipitation, because this is the period that coincides with the second hydrological maximum of precipitation.

The highest average monthly rainfalls at the synoptic stations Kuršumlija, Leskovac and Vranje were recorded in May. The value recorded at the synoptic station Kuršumlija was 70.1 mm, Leskovac 67.58 mm and Vranje 61.71 mm (Figure 3). It is the period of the second maximum rainfall that lasts from spring to early summer. At the synoptic station Kuršumlija, the period of the second maximum is longer compared to the synoptic stations Leskovac and Vranje. The second highest average monthly rainfall was recorded in July at 68.8 mm. The average monthly rainfall in July can be characterized as the second peak of the second rainfall maximum.

A smaller amount of precipitation is recorded in the period of the first maximum of precipitation. The first peak of precipitation begins in September and lasts until December. The highest amounts of precipitation at the synoptic stations Leskovac and Vranje are recorded in October. The value at the weather station Leskovac is 60.75 mm, while in Vranje it is 60.22 mm. The highest amount of precipitation in the period of the first peak of precipitation at the synoptic station Kuršumlija was recorded in December and is 58.27 mm (Figure 3).

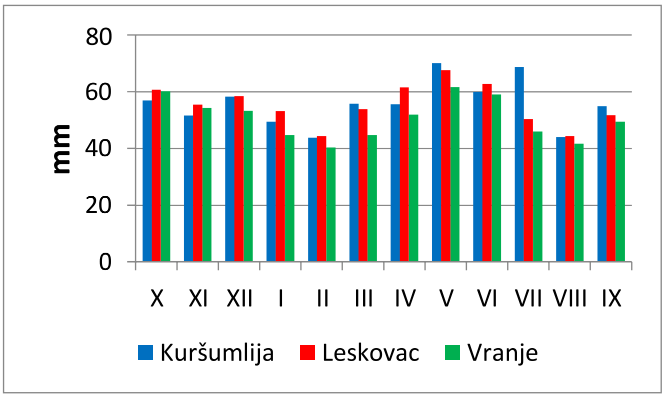

Figure 3. Average monthly amounts of precipitation (mm) at synoptic stations Kuršumlija, Leskovac and Vranje in the period from 1991 to 2021

The first precipitation minimum at all synoptic stations is during winter. It comes to the fore in February. The amount of precipitation at the synoptic station Kuršumlija is 43.82 mm, Leskovac 44.39 mm and Vranje 40.4 mm. The second minimum of precipitation is in August, when the lowest amounts of precipitation were recorded at all synoptic stations.

The higher amount of precipitation recorded at the synoptic stations at the end of spring and at the beginning of summer does not coincide with the highest flows at the Korvingrad hydrological station. This can be explained by higher temperatures contributing to higher evaporation. This period coincides with the growing season in which plants use additional water for their metabolic processes. The value of the flow of the Južna Morava does not come to the fore in the period of the first maximum of precipitation. This can be explained by the long dry period that precedes it (end of summer and beginning of autumn), the soil is in a moisture deficit as well as the vegetation, which needs water for metabolic processes. In the period of the highest flows, the amount of precipitation at all synoptic stations is low, which can be explained by still relatively low temperatures, low evaporation and plant hibernation.

The SDI values on a monthly and annual level is shown in Table 3. Shades of blue show monthly and annual discharge values above the average, while shades of red show flow values below the average. The SDI values of annual flows represented hydrological years and often varied during the research period (1991-2021). In the analyzed period, there were a total of 18 years with below-average flows, while above-average flows were recorded only during 12 years. In this period, one extremely watery year (2014/2015) was recorded. In total, there were two years of heavy water (2009/2010 and 2017/2018) and two years of moderate water (2004/2005 and 2005/2006). A total of 7 were mild water years. No extremely dry years were recorded, while the hydrological year 1993/1994. year was characterized as very dry. The hydrological years 1992/1993, 2000/2001 and 2006/2007 were moderately dry. The most numerous were mildly dry years, which totaled 14, i.e. 46.7% (Table 3). In the period from 1991/1992. until 1994/1995. in 2008, the average

Table 3. Monthly and annual SDI values for the Korvingrad hydrological station (1991-2021)

Hyd. Year	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
1991/1992	-0.46	-0.32	-0.70	-0.67	-0.73	-0.76	0.48	-0.66	-0.24	0.64	-0.52	-0.92	-0.67
1992/1993	-0.79	-0.34	-0.49	-0.51	-1.02	-0.34	-0.49	-1.06	-1.87	-1.60	-1.40	-1.43	-1.07
1993/1994	-1.25	-0.87	-0.88	-0.75	-1.06	-1.06	-1.35	-1.11	-1.46	-1.18	-1.29	-1.29	-1.60
1994/1995	-0.93	-0.93	-1.16	-0.78	-0.67	-0.97	0.24	0.28	-0.85	-0.56	-0.29	0.31	-0.84
1995/1996	-0.27	0.72	1.40	0.42	0.39	-0.07	1.39	0.42	-0.55	-1.00	-0.29	1.85	0.67
1996/1997	0.32	0.19	0.98	0.75	-0.82	-0.52	1.63	0.62	0.97	0.29	0.86	0.17	0.50
1997/1998	0.09	-0.15	-0.05	-0.48	0.57	-0.37	-0.82	-0.46	-0.27	-0.10	-0.76	0.23	-0.39
1998/1999	1.33	0.38	0.65	0.75	1.00	0.47	0.30	0.21	0.69	1.90	0.58	0.26	0.91
1999/2000	-0.01	-0.10	0.00	-0.56	0.14	-0.03	-0.49	-0.72	-1.22	-0.91	-0.85	-0.54	-0.46
2000/2001	-0.70	-0.88	-1.06	-1.03	-1.27	-1.12	0.09	-0.53	-1.00	-0.56	-0.76	-0.31	-1.21
2001/2002	-0.74	-0.67	-0.96	-0.82	-0.89	-0.87	-0.81	-0.27	1.65	-0.57	1.92	1.42	-0.82
2002/2003	3.60	0.25	0.67	3.09	0.49	-0.58	-0.06	-0.59	-0.74	-0.51	-0.42	-0.48	0.54
2003/2004	0.09	-0.51	-0.78	0.04	0.18	0.18	-0.57	-0.19	0.93	-0.01	0.22	0.08	-0.11
2004/2005	0.13	0.91	0.68	-0.07	0.96	0.99	0.09	1.34	1.33	0.66	1.60	0.80	1.07
2005/2006	0.75	-0.08	0.54	0.35	0.77	1.88	0.80	0.40	1.01	0.43	0.78	0.79	1.27
2006/2007	0.26	-0.27	-0.67	-0.55	-0.51	-0.74	-1.25	-0.60	-0.63	-1.12	-0.91	-0.71	-1.02
2007/2008	-0.14	2.36	0.57	-0.19	-0.79	-0.37	-0.78	-0.79	-1.09	-0.69	-0.88	0.54	-0.44
2008/2009	-0.55	-0.82	-0.11	0.22	-0.17	0.79	0.33	-0.54	-0.23	1.80	0.04	-0.39	0.19
2009/2010	-0.40	0.93	0.86	0.59	2.36	1.26	1.95	0.90	0.61	1.79	0.58	-0.10	1.83
2010/2011	-0.01	0.53	2.39	-0.40	-0.68	-0.70	-1.26	-0.64	-0.94	-0.83	-0.92	-1.08	-0.61
2011/2012	-1.00	-1.00	-1.01	-0.76	-0.53	-0.02	0.30	1.71	1.15	-0.44	-0.54	-0.73	-0.19
2012/2013	-1.07	-1.06	-0.95	-0.75	-0.44	-0.46	-0.62	-1.02	-0.50	-0.18	-0.61	-0.46	-0.98
2013/2014	-0.48	-0.76	-0.83	-0.91	-1.30	-1.10	1.01	3.67	0.44	0.55	1.41	3.54	-0.03
2014/2015	2.17	1.86	1.93	2.49	2.79	1.95	2.29	0.77	0.17	-0.34	-0.47	-0.76	2.68
2015/2016	0.92	0.01	-0.37	0.45	0.21	1.14	-0.97	0.72	-0.45	-0.18	-0.25	-0.22	0.32
2016/2017	0.19	2.98	-0.35	-0.28	0.41	-0.35	-0.87	0.02	0.03	-0.53	-0.43	-0.33	-0.08
2017/2018	0.06	-0.46	1.87	-0.17	0.85	2.81	1.01	-0.50	-0.43	2.53	2.01	0.14	1.53
2018/2019	-0.53	-0.66	-0.69	-0.49	-0.25	-0.79	-1.25	-0.60	1.06	-0.48	-0.55	-0.76	-0.90
2019/2020	-0.62	-0.83	-0.84	-0.85	-0.90	-0.37	-0.73	-0.63	2.26	0.78	2.16	0.36	-0.63
2020/2021	0.07	-0.42	-0.65	1.88	0.89	0.10	0.43	-0.15	0.16	0.43	-0.03	0.04	0.53

*The intensity of red and blue colors shows the category of dry and wet periods (Darker shades of red color belong to the extreme drought category, while darker shades of blue color belong to the extreme water category. Lighter shades of color represent moderately dry and moderately wet periods) annual SDI value was negative. In their work Gocic and Trajkovic (2013) in the period 1980-2010 established the existence of two dry periods, which coincides with the obtained results. The first period lasted until 1994. This period was followed by the period from 1995/1996 until 1998/1999 when the SDI values at the annual level were positive. The exception was 1997/199 when the SDI value was negative and this particular year belongs to the mildly dry category. In the period from 1999/2000 until 2001/2002 the SDI value was negative. It came to the fore in 2000/2001 hydrological year that belongs to the moderately dry category. This is precisely the period that coincides with the drought period in the study by Gocic and Trajkovic (2013). Flow values above the average were recorded in the period 2002/2003 until 2005/2006 which is confirmed by the SDI values. The exception was the hydrological year 2003/2004 years when the SDI values was negative. After 2005/2006 a year belonging to the moderately wet category was followed by a moderately dry year (2006/2007). In the period from 2010/2011 until 2013/2014 years of SDI values had negative values. Similar results were obtained by Urošev et al. (2016). In their research, they determined that in the South Morava basin, the longest hydrological droughts lasted from 1991 to 1994, as well as from 2011 to 2013. This period was followed

Table 4. Monthly and annual SPI values at the synoptic station Kuršumlija (1991-2021)

Hyd. Year	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
1991/1992	0.05	-0.69	-0.51	-0.94	-0.77	-1.02	0.83	-0.85	1.11	-1.25	-0.56	-0.80	-1.46
1992/1993	0.44	0.93	-1.52	-0.85	-0.88	0.31	-0.78	-1.65	-0.53	-1.53	-0.24	-0.23	-1.65
1993/1994	-0.67	0.01	0.36	0.31	-1.30	-1.28	-0.14	-1.41	0.85	0.88	-0.79	0.31	-0.73
1994/1995	-0.89	-1.12	-0.98	1.37	-0.24	0.20	-0.22	-0.39	-0.97	0.73	0.79	0.88	-0.10
1995/1996	-1.45	0.77	0.53	-0.43	0.22	-0.19	0.02	0.94	-1.64	-1.14	-0.48	3.63	0.24
1996/1997	-0.76	-0.39	0.88	-0.93	-0.78	-0.59	0.18	0.27	-1.21	0.47	0.50	-0.63	-0.93
1997/1998	1.60	-0.64	-0.11	-0.85	0.91	0.09	-0.91	0.26	-0.21	0.77	1.30	1.69	1.03
1998/1999	1.36	0.46	-0.94	-0.29	1.69	-1.06	0.44	0.70	1.31	0.11	-0.55	-0.42	0.63
1999/2000	-0.36	0.07	1.02	-0.40	-0.29	-0.77	-0.68	-0.59	-0.45	-0.31	-0.94	0.68	-0.92
2000/2001	-1.10	-1.07	-0.75	-0.62	1.13	-0.45	2.62	-1.08	0.27	-0.27	-0.41	0.74	-0.36
2001/2002	-1.52	-0.58	-0.39	-0.66	-0.65	-0.53	0.33	-0.06	-0.19	0.10	2.58	0.11	-0.31
2002/2003	-0.05	-0.48	0.19	0.85	-1.24	-1.43	0.00	-0.07	-1.40	-0.52	-0.78	-0.11	-1.27
2003/2004	1.81	-0.13	-0.41	0.26	-0.01	-0.01	-0.36	-1.08	0.34	0.71	-0.22	-0.05	0.32
2004/2005	0.13	1.66	0.09	0.26	0.64	0.39	-0.05	0.98	0.33	-0.39	1.98	-0.27	1.73
2005/2006	-0.57	-0.70	0.30	-0.55	0.39	0.84	0.63	-0.92	1.43	-0.66	1.81	-0.94	0.34
2006/2007	0.13	-0.53	-0.25	-0.48	-0.01	-0.48	-1.07	1.69	-1.10	-1.56	-0.06	0.09	-1.09
2007/2008	1.57	2.83	-0.85	-0.56	-1.69	0.41	-0.52	-0.85	-0.45	0.43	0.05	-0.03	0.37
2008/2009	-0.88	-0.28	1.44	0.33	1.34	0.82	-1.03	-0.59	1.75	-0.26	0.26	-0.36	0.55
2009/2010	0.76	1.25	0.68	-0.20	2.44	0.15	1.16	0.03	0.59	-1.47	-0.85	-0.62	0.96
2010/2011	0.57	0.32	1.20	-0.61	-0.43	-0.88	-1.02	-0.87	-0.23	-0.09	-1.04	-0.99	-1.25
2011/2012	0.00	-1.50	0.31	1.12	0.17	-1.06	-0.15	2.22	-1.27	1.54	-1.08	-1.08	-0.48
2012/2013	-0.57	-1.01	0.57	-0.12	1.18	0.36	-0.82	0.62	-0.69	0.31	-0.90	-0.51	-0.79
2013/2014	-0.05	0.02	-1.21	-0.60	-1.67	-0.31	3.33	1.95	0.05	1.38	0.07	1.88	1.54
2014/2015	-0.16	-0.24	1.06	0.39	0.03	2.28	0.10	-0.99	-0.31	-1.49	0.24	0.07	0.43
2015/2016	1.43	0.20	-1.88	0.72	0.28	1.20	-1.00	0.07	0.01	2.45	-0.37	0.12	0.84
2016/2017	0.57	2.09	-1.51	-0.21	-0.29	-0.45	0.19	0.51	-1.32	-0.61	-0.60	-0.12	-0.39
2017/2018	1.48	0.47	2.66	-0.13	0.53	2.36	0.41	0.78	0.76	1.32	0.02	-0.92	2.60
2018/2019	-1.48	0.05	0.67	0.61	-0.76	-1.40	-0.62	1.07	1.84	0.71	-0.60	-0.78	-0.31
2019/2020	-1.39	-0.38	-0.19	-0.91	0.94	1.35	-0.40	0.07	1.59	-0.08	1.88	-0.60	0.38
2020/2021	-0.04	-1.39	-0.47	4.10	-0.87	1.16	-0.45	-0.74	-0.27	-0.27	-1.02	-0.73	0.08

by a period when SDI values were positive (from 2014/2015 to 2017/2018). The exception was 2016/2017 years when the SDI values was negative. After 2017/2018 the year belonging to the very dry category was followed by two mildly dry years (2018/2019 and 2019/2020). The last hydrological year in the analyzed period (2020/2021) belongs to the mild water category (Table 3).

The SDI values on a monthly basis were as variable as the mean annual values. At the beginning of the analyzed period, from the hydrological 1991/1992 until 1994/1995 year, the values were positive only during five months (in April and July 1992, as well as in April, May and September 1995). The value of the flow in those months belonged to the mild water category. The longest period of negative average monthly SDI values was 32 months, from August 1992 to March 1995. In this period, the SDI value characterized as moderately dry for 14 months. June and July 1993 were very dry. In the period from the hydrological year 1995/1996 to 1998/1999, there were more months in which the SDI value at the monthly level had positive values. The longest period in which flows were above average lasted 13 months, from September 1998 to September 1999. The highest SDI value was recorded in July 1999. The monthly value belongs to the category of severely wet. The period from the hydrological 1999/2000 until 2002/2003 is the period in which the

Table 5. Monthly and annual SPI values at the Leskovac weather station (1991-2021)

Hyd. Year	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
1991/1992	0.05	-0.69	-0.51	-0.94	-0.77	-1.02	0.83	-0.85	1.11	-1.25	-0.56	-0.80	-1.46
1992/1993	0.44	0.93	-1.52	-0.85	-0.88	0.31	-0.78	-1.65	-0.53	-1.53	-0.24	-0.23	-1.65
1993/1994	-0.67	0.01	0.36	0.31	-1.30	-1.28	-0.14	-1.41	0.85	0.88	-0.79	0.31	-0.73
1994/1995	-0.89	-1.12	-0.98	1.37	-0.24	0.20	-0.22	-0.39	-0.97	0.73	0.79	0.88	-0.10
1995/1996	-1.45	0.77	0.53	-0.43	0.22	-0.19	0.02	0.94	-1.64	-1.14	-0.48	3.63	0.24
1996/1997	-0.76	-0.39	0.88	-0.93	-0.78	-0.59	0.18	0.27	-1.21	0.47	0.50	-0.63	-0.93
1997/1998	1.60	-0.64	-0.11	-0.85	0.91	0.09	-0.91	0.26	-0.21	0.77	1.30	1.69	1.03
1998/1999	1.36	0.46	-0.94	-0.29	1.69	-1.06	0.44	0.70	1.31	0.11	-0.55	-0.42	0.63
1999/2000	-0.36	0.07	1.02	-0.40	-0.29	-0.77	-0.68	-0.59	-0.45	-0.31	-0.94	0.68	-0.92
2000/2001	-1.10	-1.07	-0.75	-0.62	1.13	-0.45	2.62	-1.08	0.27	-0.27	-0.41	0.74	-0.36
2001/2002	-1.52	-0.58	-0.39	-0.66	-0.65	-0.53	0.33	-0.06	-0.19	0.10	2.58	0.11	-0.31
2002/2003	-0.05	-0.48	0.19	0.85	-1.24	-1.43	0.00	-0.07	-1.40	-0.52	-0.78	-0.11	-1.27
2003/2004	1.81	-0.13	-0.41	0.26	-0.01	-0.01	-0.36	-1.08	0.34	0.71	-0.22	-0.05	0.32
2004/2005	0.13	1.66	0.09	0.26	0.64	0.39	-0.05	0.98	0.33	-0.39	1.98	-0.27	1.73
2005/2006	-0.57	-0.70	0.30	-0.55	0.39	0.84	0.63	-0.92	1.43	-0.66	1.81	-0.94	0.34
2006/2007	0.13	-0.53	-0.25	-0.48	-0.01	-0.48	-1.07	1.69	-1.10	-1.56	-0.06	0.09	-1.09
2007/2008	1.57	2.83	-0.85	-0.56	-1.69	0.41	-0.52	-0.85	-0.45	0.43	0.05	-0.03	0.37
2008/2009	-0.88	-0.28	1.44	0.33	1.34	0.82	-1.03	-0.59	1.75	-0.26	0.26	-0.36	0.55
2009/2010	0.76	1.25	0.68	-0.20	2.44	0.15	1.16	0.03	0.59	-1.47	-0.85	-0.62	0.96
2010/2011	0.57	0.32	1.20	-0.61	-0.43	-0.88	-1.02	-0.87	-0.23	-0.09	-1.04	-0.99	-1.25
2011/2012	0.00	-1.50	0.31	1.12	0.17	-1.06	-0.15	2.22	-1.27	1.54	-1.08	-1.08	-0.48
2012/2013	-0.57	-1.01	0.57	-0.12	1.18	0.36	-0.82	0.62	-0.69	0.31	-0.90	-0.51	-0.79
2013/2014	-0.05	0.02	-1.21	-0.60	-1.67	-0.31	3.33	1.95	0.05	1.38	0.07	1.88	1.54
2014/2015	-0.16	-0.24	1.06	0.39	0.03	2.28	0.10	-0.99	-0.31	-1.49	0.24	0.07	0.43
2015/2016	1.43	0.20	-1.88	0.72	0.28	1.20	-1.00	0.07	0.01	2.45	-0.37	0.12	0.84
2016/2017	0.57	2.09	-1.51	-0.21	-0.29	-0.45	0.19	0.51	-1.32	-0.61	-0.60	-0.12	-0.39
2017/2018	1.48	0.47	2.66	-0.13	0.53	2.36	0.41	0.78	0.76	1.32	0.02	-0.92	2.60
2018/2019	-1.48	0.05	0.67	0.61	-0.76	-1.40	-0.62	1.07	1.84	0.71	-0.60	-0.78	-0.31
2019/2020	-1.39	-0.38	-0.19	-0.91	0.94	1.35	-0.40	0.07	1.59	-0.08	1.88	-0.60	0.38
2020/2021	-0.04	-1.39	-0.47	4.10	-0.87	1.16	-0.45	-0.74	-0.27	-0.27	-1.02	-0.73	0.08

monthly flow values were below the average. The longest period of negative SDI values lasted 13 months, from May 2001 to May 2002. In the period from 2002/2003 until 2005/2006 the flows were above average. October 2002 and January 2003 are extremely wet months. In the period that followed until the hydrological year 2010/2011 years, the SDI value has often fluctuated. From January 2011 to March 2014, two dry periods can be observed. The first period lasted from January 2011 to March 2012, and the second from July 2012 to March 2014. In both periods, there were a total of 10 months that were moderately dry according to SDI values. In the period from April 2014 to June 2015, flows were below average, which is confirmed by the negative SDI values. In this period there were 6 extremely watery, 3 very watery, 2 moderately watery and 4 mildly watery months. The flows are in the period from 2018/2019 until 2020/2021 years often varied. The longest period with negative SDI values lasted 11 months, from July 2019 to May 2020 (Table 3). In the period from 2000-2021 years, droughts were frequent, but ccording to the number of months, they lasted shorter compared to the period from 1991-2000 years. Similar results were obtained by Urošev et al. (2016), who concluded that with the increase in the number of droughts, their duration decreased from 2000 to 2014. SPI values on an annual basis in the period from 1991/1992 until 2020/2021 years at the synoptic station Kuršumlija often varied. Annual precipitation was below

Table 6. Monthly and annual SPI values at the synoptic station Vranje (1991-2021)

Hyd. Year	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
1991/1992	-0.45	-0.44	-0.72	-1.22	-0.23	-0.90	0.95	-1.40	0.56	-0.34	-0.72	-1.16	-1.84
1992/1993	-0.02	0.58	-0.41	-0.97	-1.26	0.54	-0.60	0.13	-1.19	-1.01	-0.50	-0.61	-1.50
1993/1994	-0.32	-0.37	0.05	-0.08	-0.50	-1.22	0.54	-1.89	0.45	2.57	0.50	-0.57	-0.16
1994/1995	-0.61	-0.99	-1.09	0.72	-0.31	-0.17	0.30	0.77	-0.35	-0.12	1.32	0.85	0.12
1995/1996	-1.49	0.76	2.02	-0.30	-0.24	0.38	0.03	0.43	-1.73	-0.63	-0.38	3.08	0.49
1996/1997	-0.70	-0.46	0.13	-0.74	-0.79	-0.88	-0.17	-0.33	-0.65	0.18	0.49	-0.88	-1.42
1997/1998	0.77	-0.62	-0.35	-0.93	0.28	-0.15	-0.77	0.32	1.23	-0.08	-0.09	1.26	0.28
1998/1999	1.25	-0.04	-0.24	-0.30	0.90	-1.23	-0.13	-0.14	0.71	-0.79	-0.92	-0.44	-0.44
1999/2000	-0.20	0.59	0.34	-0.08	-0.58	-0.45	-0.54	-0.58	-1.28	-0.98	-1.15	-0.13	-1.49
2000/2001	-0.82	-1.20	-1.06	-0.78	0.29	-0.55	2.44	-1.24	0.50	0.62	-0.39	0.16	-0.69
2001/2002	-1.31	-0.59	-0.58	-0.86	-0.90	-0.40	0.75	1.02	-0.37	1.67	1.86	0.14	0.16
2002/2003	0.42	-0.74	0.26	1.96	-0.89	-1.32	-0.96	-0.67	-0.09	-0.53	-0.34	-0.71	-1.00
2003/2004	2.04	-0.83	-0.35	-0.13	0.16	0.68	-0.13	-0.65	0.88	1.33	1.61	0.08	1.55
2004/2005	-0.54	1.29	-0.33	0.05	-0.18	-0.66	-0.57	-0.77	-0.09	-0.53	2.90	-0.20	0.30
2005/2006	-0.37	-0.34	0.75	-0.57	-0.06	0.54	-0.24	-0.60	2.65	-0.83	0.81	-0.55	0.35
2006/2007	-0.28	-0.62	-0.88	0.03	0.07	0.08	-1.29	1.42	-0.66	-1.31	-0.35	0.09	-1.18
2007/2008	0.99	0.98	-0.62	-0.81	-1.69	0.71	-0.15	-0.13	-0.65	0.73	-0.27	1.81	0.55
2008/2009	-0.96	-0.55	1.38	0.66	-0.46	-0.23	-0.04	-0.13	1.56	-0.74	-0.13	-0.73	-0.19
2009/2010	0.95	2.06	0.25	-0.36	1.55	0.54	1.28	0.33	0.25	-0.86	-0.71	-0.30	1.45
2010/2011	1.63	2.23	1.47	-0.72	-0.98	-0.77	-1.26	-1.33	-1.24	0.79	-0.90	-0.21	-0.15
2011/2012	-0.37	-1.41	0.01	1.23	0.60	-1.00	0.27	1.80	-1.07	-0.48	-1.11	-0.24	-0.75
2012/2013	-0.32	-1.16	0.39	0.25	2.91	0.46	-0.54	1.22	-0.52	-0.05	-1.05	-0.33	-0.04
2013/2014	-0.49	0.28	-1.22	-0.32	-1.16	-0.17	3.44	2.16	0.97	1.44	-0.48	2.07	2.03
2014/2015	0.27	0.45	-0.04	0.62	1.56	1.58	-0.63	-0.97	-0.98	-1.22	0.12	0.88	0.42
2015/2016	2.20	0.60	-1.80	0.87	0.56	1.44	-0.87	0.58	-0.33	1.90	0.34	-0.54	1.63
2016/2017	1.16	1.96	-1.30	-0.81	0.52	-0.88	-0.10	1.24	-0.14	-1.05	-0.82	0.13	0.06
2017/2018	0.36	-0.49	2.82	-0.16	1.36	2.25	-0.43	0.64	-0.39	0.11	0.37	-1.41	1.25
2018/2019	-1.42	0.54	0.54	0.82	-1.07	-1.28	-0.31	0.19	0.92	0.19	-0.77	-0.85	-0.74
2019/2020	-1.35	-0.12	0.57	-0.61	0.80	2.21	-0.07	-0.54	1.46	-0.41	1.48	0.30	1.00
2020/2021	-0.01	-1.34	0.00	3.55	-0.29	0.86	-0.21	-0.90	-0.42	0.41	-0.72	-1.00	-0.06

average for 16 hydrological years. The most numerous are mildly dry years, of which there were 13 in total. In the period from 1991/1992 until 2002/2003 in total there were 9 mildly dry years. Mildly wet years have occurred more often since 2003/2004 years. The hydrological year 2009/2010 and 2017/2018 was extremely wet, while 2013/2014 was very wet year. The very dry years were 1992/1993 and 2011/2012. The only moderately dry year (2010/2011) followed an extremely wet year (Table 4).

The most numerous months in the analyzed period (1991-2021) belonged to the slightly wet and slightly dry categories. Negative monthly SPI values were more frequent in the period from 1991/1992 until 2002/2003 years. Positive SPI values are more frequent since 2007/2008 until 2020/2021 years. Extremely wet months are more common since 2004/2005 until the end of the analyzed period. The longest period in which the SPI had negative values lasted 9 months, from December 1992 to August 1993. The longest period in which SPI values were positive lasted 7 months, from February 2010 to August 2010. Annual SPI values at the Leskovac weather station (1991-2021) show that there were 15 wet and dry years each. The most numerous were mildly watery years with a total of 11, followed by slightly dry years with a total of 10 years. There were a total of 21 hydrological years (70% of the total number of hydrological years) with SPI values in the slightly dry and slightly wet category.

The hydrological year 2017/2018 was extremely watery year, while 2 were very wet (2004/2005 and 2013/2014) and one was moderately wet (1997/1998). There were 4 moderately dry ones, and only 1992/1993 was very dry. In the period from the hydrological 1991/1992 until 2002/2003 there are more months with negative SPI values (Table 5).

The annual SPI value at the synoptic station Vranje (1991-2021) does not match the values of SPI at the synoptic stations Kuršumlija and Leskovac. In total, there were 9 moderately wet and moderately dry years, while the number of moderately dry (5) and moderately wet (3) years is higher than in Kuršumlija and Leskovac. The hydrological year 1991/1992 was severely drought, while 2003/2004 and 2015/2016 were severely wet. 2013/2014 was extremely wet. In the period from 1991/1992 until 2008/2009 there are more months with a negative SPI value (Table 6).

SPI values of monthly and annual precipitation amounts at the Kuršumlija, Leskovac and Vranje synoptic stations can explain the SDI values of the mean monthly and annual flows of Južna Morava at the Korvingrad hydrological station. In the period when the monthly and annual SDI values were often negative, the SPI values at all synoptic stations were also negative. This period lasted from the hydrological year 1991/1992 until 2001/2002 years. During the short period of 1995/1996 until 1998/1999 years SDI values had positive values, while SPI values at all synoptic stations were often negative.

The discrepancy between the results can be explained by the occurrence of precipitation in the territory of the sub-basin where there are meteorological stations whose data were not processed in the paper. By analyzing SDI from 2002/2003 until 2020/2021 hydrological year, it is possible to distinguish several wet and dry periods. In periods when SDI average, it is possible to see that there were more months with below average precipitation.

Based on monthly and annual SDI values in the period from hydrological 1991/1992 until 2020/2021 year, it is possible to single out 5 dry and 4 wet periods that alternated cyclically (Table 3). They differed in duration (number of hydrological years) and intensity. The first dry period lasted from 1991/1992 until 1994/1995 years. It lasted the longest and was the driest period. The results obtained by Đokić et al., (2022) coincide with the dry period until 1995. From the hydrological 1995/1996 until 1998/1999 year, it is possible to observe the first wet period, in which 1997/1998 the year was moderately dry. The second dry period followed from the hydrological 1999/2000 and lasted until 2001/2002 years. During this period there were 6 moderately dry months. The second wet period that lasted 4 years, from 2002/2003 until 2005/2006 year, had one mildly dry year (2003/2004). From the hydrological 2006/2007 dry and wet periods lasted shorter, but monthly SDI values often had values lower than -1 and higher than 1. During the hydrological year 2006/2007 and 2007/2008 a shorter dry period followed. The dry period coincides with the results obtained by Akbari et al. (2015). They concluded that a dry period occurred simultaneously in Southern Iran and the Middle East. Hydrological 2008/2009 and 2009/2010 years had wetter periods, so it is possible to single out a third wet period. This was followed by a period in which flow values were below average. The dry period began in the hydrological year 2010/2011 and lasted until March 2014. The last wet period from April 2014 lasted until September 2018. This was the wettest period with 10 extremely wet, 4 very wet, 4 moderately wet and 16 slightly wet months recorded. The last dry period lasted from the hydrological year 2018/2019 until the hydrological year 2020/2021 years.

Table 7. Number of monthly and annual values of different classes of SDI for the Korvingrad hydrological station and values of different classes of SPI for synoptic stations Kuršumlija, Leskovac and Vranje in the period from hydrological 1991/1992 until 2020/2021 years

SDI values - Korvingrad	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
≥ 2 Extremely wet	2	2	1	2	2	1	1	1	1	1		
1.5 to 1.99 Severely wet	0	1	2	1	0	2	2	1				
1 to 1.49 Moderately wet	1	0	1	0	1	2						
0 to 0.99 Mildly wet	10	8	8	8	1							
0 to 0.99 Mild drought	14	17	15									
−1 to −1.49 Moderate drought	3											
−1.5 to − 1.99 Severe												
≤ −2 Ex												

SPI values - Kuršumlija	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
≥ 2 Extremely wet	1	2	1	2	1	2	2	1	1	1		
1.5 to 1.99 Severely wet	2	1	2	0	2	0	1	2				
1 to 1.49 Moderately wet	2	3	2	2	3	3						
0 to 0.99 Mildly wet	8	8	7	7								
0 to 0.99 Mild drought	12	12	15									
−1 to −1.49 Moderate drought	5											
−1.5 to − 1.99 Severe												
≤ −2 Ex												

SPI values - Leskovac	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
≥ 2 Extremely wet	0	2	1	1	1	2	2	1	0	1		
1.5 to 1.99 Severely wet	3	1	0	0	1	0	0	2				
1 to 1.49 Moderately wet	3	1	4	2	3	3						
0 to 0.99 Mildly wet	8	10	10	8								
0 to 0.99 Mild drought	11	11	11									
−1 to −1.49 Moderate drought	4											
−1.5 to − 1.99 Severe												
≤ −2 Ex												

SPI values - Vranje	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
≥ 2 Extremely wet	2	2	2	1	1	2	2	1	1	1	1	2	**1**
1.5 to 1.99 Severely wet	1	1	0	1	2	1	0	1	1	2	2	1	**2**
1 to 1.49 Moderately wet	2	1	2	1	1	1	1	4	2	2	2	1	**3**
0 to 0.99 Mildly wet	6	8	11	8	9	9	6	8	8	7	6	8	**9**
0 to 0.99 Mild drought	15	14	10	18	13	12	19	12	13	14	16	15	**9**
−1 to −1.49 Moderate drought	4	4	4	1	3	5	2	3	4	4	3	3	**4**
−1.5 to − 1.99 Severe drought	0	0	1	0	1	0	0	1	1	0	0	0	**2**
≤ −2 Extreme drought	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	30	30	30	30	30	30	30	30	30	30	30	30	**30**

In the analyzed period (1991-2021) out of a total of 360 months, negative SDI values were recorded during 212 months (58.9%). There were a total of 275 months whose SDI belonged to the categories of mild drought and mildly wet months. No extremely dry months were recorded, while there were a total of 17 extremely wet months (0.5%). The most numerous were mildly dry months, totaling 175 (48.6%). In total, there were 16 severe dry and 15 moderatele dry months. July is the month that had the most severe wet months (3). Two severe dry months were recorded in June and July (Table 7). During the research period, droughts often occurred during the summer. At the end of the 20th and the beginning of the 21st century, hydrological droughts also lasted during the winter, so their length increased.

Droughts were more pronounced during the winter months compared to the summer months, which coincides with the results of Urošev et al. (2016).

Annual SPI values were uniform at all synoptic stations. At the synoptic station Kuršumlija, there were a total of 14 hydrological years that had an amount of precipitation higher than the average, while at the synoptic stations Leskovac and Vranje, the number of years above and below the average is the same. At all synoptic stations, the amount of precipitation was around the average, so mild dry and mildly wet years dominated. In Kuršumlija, the number of hydrological years in the mildly dry category was 13. In Leskovac, there were 11 mildly wet years, while in Vranje the number of mild dry and mildly wet years was equal (9) (Table 7).

At all synoptic stations, negative SPI values are more numerous than positive ones. During 204 (56.7%) months in Kuršumlija, 199 (55.3%) months in Leskovac and 215 (59.7%) months in Vranje, precipitation was below average. At the synoptic station Vranje, 145 months had flows above the average. There were no extremely dry months at all synoptic stations. There were a total of 249 mildly wet and mildly dry months in Kuršumlija, 259 in Leskovac and 165 in Vranje. At all synoptic stations, the number of months decreases regularly from the mildly dry to extremely dry category. At the synoptic station Leskovac, the number of months from the mildly wet to extremely wet category decreases regularly, while the trend is different at the synoptic station Kuršumlija and Vranje. The number of severely wet months is the lowest at the Vranje (13) and Kuršumlija (14) synoptic stations, while the number of extremely wet months is 18 (Table 7).

5. Conclusion

The research results showed that some extremely and strongly hydrological wet years have dry periods. The dry periods lasted significantly shorter, so they did not directly affect the mean annual flows at the Korvingrad hydrological station. The same is repeated in hydrological years that are extremely and very dry. It is common to have one or more months with above average flows. High flow values during several months cannot affect the long-term increase in flow, which can be explained by the deficit of moisture in the soil. Part of the water is used by plants in the growing season for their metabolic processes and thereby additionally reduces the inflow of water into the river.

Hydrologically dry years are more numerous than watery years. Out of 17 hydrologically dry years, 14 are mildly dry. Flows during 21 hydrological years were around average values. Analysis of flow at the hydrological station Korvingrad and precipitation at synoptic stations Kuršumlija, Leskovac and Vranje showed the dependence of flow on precipitation. In most hydrological years, precipitation can explain most of the flow of Južna Morava. This leads us to the conclusion that precipitation is the most important factor affecting flows.

There were also periods when a higher amount of precipitation could not explain higher flows, which can be explained by the large area of the Južna Morava sub-basin and the occurrence of precipitation in the part of the sub-basin where there are no meteorological and precipitation stations. The discrepancy can also be explained by the occurrence of precipitation at meteorological and precipitation stations whose data were not processed in the paper. On the other hand, due to the large area of the sub-catchment, it is possible for high flows to occur a few days after rainfall, so it is a common phenomenon that rainfall is discharged at the end of one month, and that it is registered through the flows at the beginning of the next month.

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