ANALYSIS OF HYDROLOGIC DROUGHT IN THE SOUTHEAST SERBIA FOR THE PERIOD 1961-2011

Mladen Milanović[1], Milan Gocić[2], Slaviša Trajković[3], Borislava Blagojević[4]

[1]MSc, University of Nis, Faculty of Civil Engineering and Architecture, mmsmladen@gmail.com
[2]MSc, University of Nis, Faculty of Civil Engineering and Architecture, mgocic@yahoo.com
[3]Prof. dr, University of Nis, Faculty of Civil Engineering and Architecture, slavisa@gaf.ni.ac.rs
[4]Dr, University of Nis, Faculty of Civil Engineering and Architecture, borislava.blagojevic@gaf.ni.ac.rs

Abstract

The lack of water from the atmosphere that circulates in the water cycle causes different types of drought. The drought that is of the utmost importance for water resources management is the hydrologic drought. To assess this type of drought more effectively, a number of indices have been developed. One of the simplest hydrologic drought indices to estimate is the Standardized Streamflow Index (SSFI).

In the initial study of the 3 months timescale SSFI, we obtained the SSFI-3 based on the runoff data from seventeen hydrologic stations in the Southeast Serbia for the period 1961-2011. The results show that the wet periods prevail from 1973 to 1979, and the dry periods from 1985 to 1996.

Because the SSFI is similar to the Streamflow Drought Index (SDI), we continue the research by enlarging the number of timescales, and comparing the SSFI and SDI results. We also use the results of the Mann-Kendall trend test from the previous research. The SSFI and SDI magnitudes are compared for the following timescales: 1, 3, 6, 9 and 12 months by two goodness-of-fit indicators.

The analysis of the results shows the insignificant differences in the hydrologic drought magnitude between the SDI and SSFI, match of the dry periods classified by both indices, and points out to the direction for the further research that should lead to the identification of the drought homogeneous regions.

Keywords: hydrologic drought, Standardized Streamflow Index, Streamflow Drought Index, the Južna Morava river basin

Introduction

The hydrological drought is a result of the deficiency in the precipitation for supplying surface and ground waters, which results in low water levels in rivers and a small influx to ground and surface water reserves and lakes. Although the lack of precipitation is a primary cause of hydrological drought, there are other factors that boost the intensity, duration and spatial distribution, including land use, land degradation and human interventions in the basin. Therefore, the most severe hydrological droughts do not always appear in the areas with the lowest precipitation (EEA, 2001).

The meteorological drought identification, classification and spatial monitoring by the meteorological drought indices have shown effective results over the past two decades. The most widely used drought indicator is Standardized Precipitation Index (SPI) (McKee et al., 1993).

The appearance of hydrological drought is usually phase-shifted, i.e. it appears with a lag compared to meteorological drought. Namely, it takes longer for the effect of precipitation deficiency to manifest itself on the elements of the hydrological system. These manifestations include a humidity content reduction in the soil, reduced flow in the rivers, and reduced surface and ground water storage. For this reason, the economic effects of hydrological drought of all spheres are noticeable after the ones caused by meteorological drought.

Due to many manifestations of precipitation deficiency on the runoff cycle, many hydrologic drought indices have been developed so far, taking in the account different hydrologic variables. The hydrologic drought indices that are the most similar to the SPI in the terms of a singe input data type and calculation procedure are the Standardized Streamflow Index (SSFI) and the Streamflow Drought Index (SDI) (Modarres, 2007; Hosseinzadeh Talaee et al., 2012; Nalbantis, 2008; Nalbantis and Tsakiris, 2009; Yang, 2010). The former is characterized by a simplified calculation procedure, while the latter uses the same estimation procedure as SPI.

This paper compares the SSFI and the SDI results at the timescales of 1, 3, 6, 9 and 12 months at seventeen hydrologic stations in the Južna Morava river basin. The study aims are: 1) to understand differences and similarities in the results, 2) to decide upon one index for hydrologic drought identification for operational purpose, and 3) to provide base for regional drought research.

Material and methods

Study area and collected data

The Južna Morava river is formed by the connection between the Binačka Morava and the Preševska Moravica rivers. The basin area is 15,469 km^2. The most significant tributaries are the rivers Toplica and Nišava. The other tributaries are mostly torrential rivers. There are several gorges and plains along the Južna Morava river flow. The plains are mostly used for agriculture, and the rural population of the Southeast Serbia is predominantly agricultural. The development perspective for the region is the agricultural production, since it plays a significant part in the overall foreign trade, with 21% share in total exports (Jevtić et al., 2011). In order to provide for stable water supply to increase agricultural yields, a number of irrigation systems are planned.

The surface water observation network in the Južna Morava river basin comprises of 38 active stations, six of which are on the Južna Morava river, while the others are on the tributaries (Figure 1). The research is performed on the mean monthly runoff data issued by the Republic Hydro-meteorological Service of Serbia for the period 1961-2011.

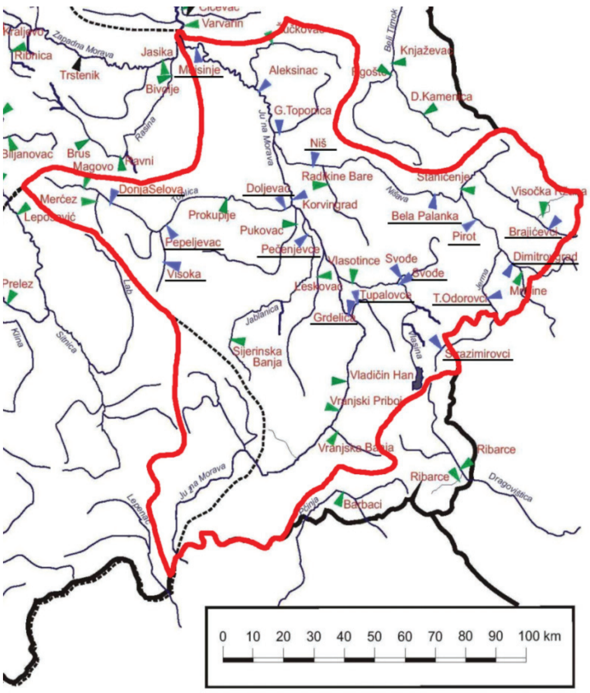


Figure 1: The basin of the Južna Morava river with the hydrological station (HS) network (Blagojević et al., 2013). The runoff data is processed for the underlined HS

Methodology

Two hydrological drought indices are analyzed in the paper. The Standardized Streamflow Index (SSFI) (Modarres, 2007) of a given period is estimated from the following equation

$$SSFI_{i,k} = \frac{V_{i,k} - \overline{V}_k}{S_k}$$

where $\overline{V}_k$ = mean streamflow, S_k– standard deviation and

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,j} \quad , \; i = 1, 2, \ldots, \quad j = 1, 2, \ldots, 12, \quad k = 1, 2, 3, 4$$

$V_{i,k}$ – cummulative streamflow, $Q_{i,j}$ – monthly streamflow

The SDI (Streamflow Drought Index) (Nalbantis and Tsakiris, 2009) is estimated according to the same methodology as SPI (McKee et al., 1993) using two parameter gamma distribution. The reference period for distribution parameters is 1961-2005.

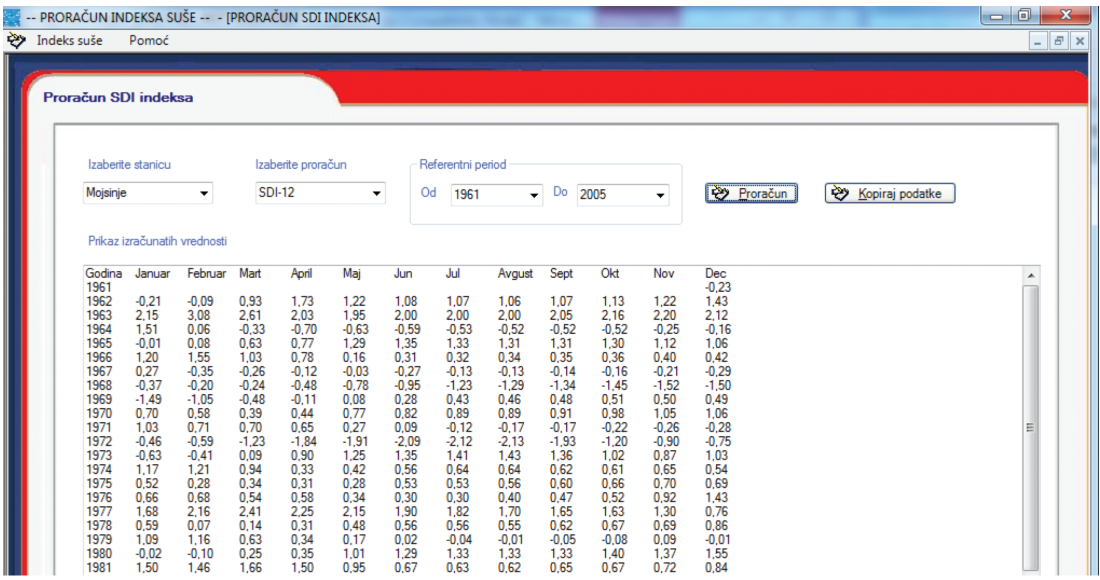
In order to evaluate differences between the SSFI and SDI, SSFI was considered modeled value and SDI observed. Two goodness-of-fit indicators were applied (Krause et al., 2005; Harmel et al., 2010): the Nash-Sutcliffe Coefficient of Efficiency (E) and the Index of Agreement (d).

Results and discussion

The SSFI and SDI at different timescales were calculated for 1961 to 2011 period, while 1961 to 2005 period was used as the reference period for distribution parameter estimates for SDI.

The SSFI and SDI values are considered for all HS regardless of the trend test results. Trend detection is performed by the Mann–Kendall non-parameter test at the 0.95 confidence level (Blagojević et al., 2013). The HS that do not have trend in the processed mean monthly runoff series are: Korvingrad, Grdelica, Tupalovce, Trnski Odorovci, Stazimirovci, Doljevac, Pepeljevac, Visoka and Donja Selova.

The values of the SSFI and SDI index were obtained with the application of software shown in Figure 2 (Blagojevic et al., 2013).



Godina	Januar	Februar	Mart	April	Maj	Jun	Jul	Avgust	Sept	Okt	Nov	Dec
1961												-0,23
1962	-0,21	-0,09	0,93	1,73	1,22	1,08	1,07	1,06	1,07	1,13	1,22	1,43
1963	2,15	3,08	2,61	2,03	1,95	2,00	2,00	2,00	2,05	2,16	2,20	2,12
1964	1,51	0,06	-0,33	-0,70	-0,63	-0,59	-0,53	-0,52	-0,52	-0,52	-0,25	-0,16
1965	-0,01	0,08	0,63	0,77	1,29	1,35	1,33	1,31	1,31	1,30	1,12	1,06
1966	1,20	1,55	1,03	0,78	0,16	0,31	0,32	0,34	0,35	0,36	0,40	0,42
1967	0,27	-0,35	-0,26	-0,12	-0,03	-0,27	-0,13	-0,13	-0,14	-0,16	-0,21	-0,29
1968	-0,37	-0,20	-0,24	-0,48	-0,78	-0,95	-1,23	-1,29	-1,34	-1,45	-1,52	-1,50
1969	-1,49	-1,05	-0,48	-0,11	0,08	0,28	0,43	0,46	0,48	0,51	0,50	0,49
1970	0,70	0,58	0,39	0,44	0,77	0,82	0,89	0,89	0,91	0,98	1,05	1,06
1971	1,03	0,71	0,70	0,65	0,27	0,09	-0,12	-0,17	-0,17	-0,22	-0,26	-0,28
1972	-0,46	-0,59	-1,23	-1,84	-1,91	-2,09	-2,12	-2,13	-1,93	-1,20	-0,90	-0,75
1973	-0,63	-0,41	0,09	0,90	1,25	1,35	1,41	1,43	1,36	1,02	0,87	1,03
1974	1,17	1,21	0,94	0,33	0,42	0,56	0,64	0,64	0,62	0,61	0,65	0,54
1975	0,52	0,28	0,34	0,31	0,28	0,53	0,53	0,56	0,60	0,66	0,70	0,69
1976	0,66	0,68	0,54	0,58	0,34	0,30	0,30	0,40	0,47	0,52	0,92	1,43
1977	1,68	2,16	2,41	2,25	2,15	1,90	1,82	1,70	1,65	1,63	1,30	0,76
1978	0,59	0,07	0,14	0,31	0,48	0,56	0,56	0,55	0,62	0,67	0,69	0,86
1979	1,09	1,16	0,63	0,34	0,17	0,02	-0,04	-0,01	-0,05	-0,08	0,09	-0,01
1980	-0,02	-0,10	0,25	0,35	1,01	1,29	1,33	1,33	1,33	1,40	1,37	1,55
1981	1,50	1,46	1,66	1,50	0,95	0,67	0,63	0,62	0,65	0,67	0,72	0,84

Figure 2: The screenshot of the software application for the calculation of the SSFI and SDI index

The drought intensity classification is the same for both indices (Nalbantis, 2008; Hosseinzadeh Talaee et al., 2012) (Table 1).

Table 1. Qualitative and quantitative classes of hydrologic drought intensity

Description	SSFI, SDI
Mild drought	-1.0 ≤ SSFI,SDI < 0.0
Moderate drought	-1.5 ≤ SSFI,SDI < -1.0
Severe drought	-2.0 ≤ SSFI,SDI ≤ -1.5
Extreme drought	SSFI,SDI < -2.0

The values of the SSFI and SDI index are estimated for 1, 3, 6, 9 and 12 months timescale. The results are shown for the SSFI 3 and SDI 3 at HS Mojsinje, Donja Selova and Dimitrovgrad in the graphic form (Figure 3). The three months timescale is selected for presentation of results and discussion, due to its suitability for the SDI prediction based on the SPI in the previous research (Blagojević et al., 2013).

HS Mojsinje is the most upstream HS in the studied basin (15,390 km^2). According to the results for 3 months timescale (Figure 3) the droughts prevail in the period from 1987 to 1995. The SDI 3 has greater values than the SSFI 3 in 1968, 1972, 1993 - 1995, and 2001, which represent the periods of extreme drought. The highest obtained SDI 3 value of -2.47 is in 2001, while according to SSFI 3 the most extreme drought occurred in 1972 (SSFI 3= -2.29).

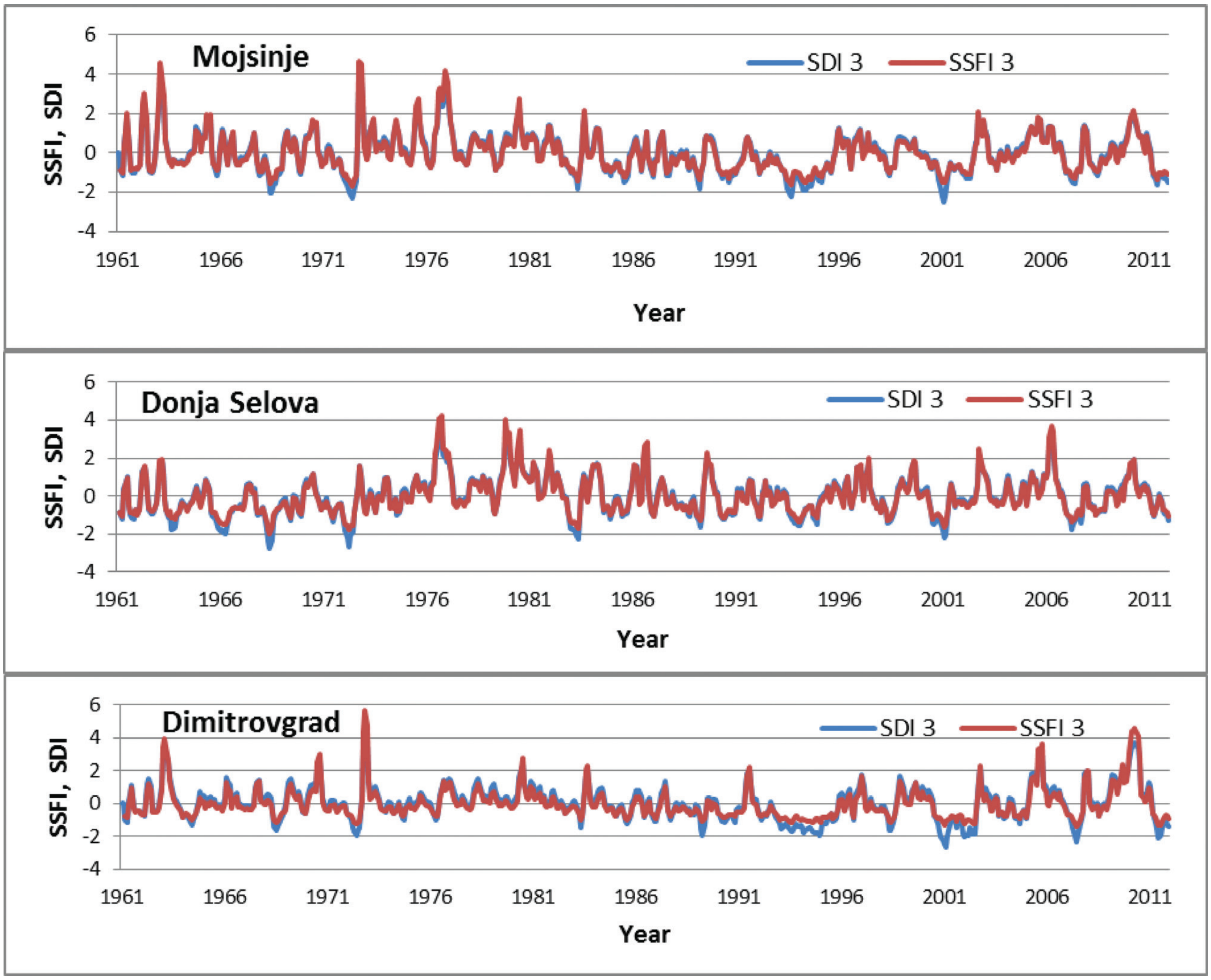


Figure 3: SSFI 3 and SDI 3 in the period 1961-2011 at selected HSs in the Južna Morava river basin

At the HS Donja Selova, according to the SDI 3, the extreme dry periods occurred in 1968, 1972, 1983 and 2001, the 1968 drought being the most extreme of all, estimated by the value of -2.62. According to the SSFI 3 the most extreme drought has the value of -1.79 obtained for 1972.

According to the SSFI 3 and SDI 3 at HS Dimitrovgrad, the severe drought periods occurred in 1968, 1972, 1983, 1989, 1991 - 1995, 2000 - 2002, 2007 and 2011. The extreme drought was recorded in 2001, 2007 and 2011. The SDI 3 in 2001 was -2.64 representing the most extreme drought, while according to SSFI it occurred in 2007 and equaled -1.36. This HS is the one with trend identified in the series of mean monthly runoff.

Table 2 shows the values of the goodness-of-fit indicators (E, and d), obtained for the SSFI and SDI for the timescales 1, 3, 6, 9 and 12 months, in the period 1961 - 2011. Indicators are shown for three HS: Mojsinje (covers the largest area of the basin), Donja Selova (due to the future dam location) and Dimitrovgrad (due to the poorest results).

Table 3 shows the values of two goodness-of-fit indicators for the isolated periods of all drought periods according to the SDI index values.

Table 2. Goodness-of-fit indicators between SSFI and SDI for HSs Mojsinje, Donja Selova and Dimitrovgrad

Indicators	Time series	Mojsinje	Donja Selova	Dimitrovgrad
E	1	0.94	0.94	0.89
	3	0.95	0.96	0.90
	6	0.96	0.97	0.91
	9	0.97	0.97	0.91
	12	0.98	0.98	0.91
d	1	0.98	0.99	0.97
	3	0.99	0.99	0.97
	6	0.99	0.99	0.97
	9	0.99	0.99	0.97
	12	0.99	0.99	0.97

Table 3. Goodness-of-fit indicators between SSFI and SDI for HSs Mojsinje, Donja Selova and Dimitrovgrad in the hydrologic drought periods according to SDI values

Indicators	Time series	Mojsinje	Donja Selova	Dimitrovgrad
t	1	0.78	0.81	0.59
	3	0.85	0.87	0.65
	6	0.89	0.90	0.70
	9	0.91	0.91	0.71
	12	0.93	0.93	0.73
t	1	0.92	0.93	0.82
	3	0.95	0.95	0.84
	6	0.96	0.96	0.87
	9	0.97	0.97	0.88
	12	0.98	0.98	0.89

Based on the obtained values of selected goodness-of-fit indicators shown in table 2, the results are qualitatively rated very good ($E > 0.75$) meaning that SDI and SSFI correspond to each other in the processed period 1961-2011. However, the results are slightly poorer when the drought periods are isolated, concatenated and compared (Table 3). The HS that holds the poorest result in goodness of fit indicators for SSFI and SDI for the studied basin is HS Dimitrovgrad. Still, these results are good (E>0.65) and satisfactory (E>0.5) for different timescales.

The drought periods identified by the SSFI and SDI correspond to each other very well. The differences are found in the cases of extreme droughts regarding the estimated values. The differences decrease with the increase of timescale.

Conclusion

Two indices of hydrologic drought were calculated for the area of Southeast Serbia represented by the Južna Morava river basin. The results show the most prominent drought periods in 1968, 1972, 1983, 1991 - 1995 and in 2001. The comparative analysis of the SSFI and SDI index shows that, during the extreme dry periods, SDI is more sensitive than the SSFI. According to the E and d values, SSFI and SDI match very well.

Although the SSFI calculation is not complex, and as such, it is preferable for operational purposes, the decision upon one index for hydrologic drought identification cannot be made yet. For further research, the other probability distributions should be considered for SDI estimation, and the indices should be compared and analyzed. Nalbantis (2008) and Shukla and Wood (2008) concluded that it is better to apply a log-normal distribution for the calculation of the SDI index, while Yang (2010) applied both the log-normal and gamma distribution and observed that the accuracy of the calculation depends on the timescale.

With the available data and obtained results, the base for the regional drought research is provided. In order to be able to continue the drought studies in the sphere of the ungauged basins, drought homogeneous regions should be identified.

The significance of this research lays in an attempt to identify both reliable and appropriate hydrologic drought index for operational purpose i.e. the hydroinformation system for drought warning in the Southeast Serbia.

Acknowledgements

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