Streamflow Drought Index modelling through Standard Precipitation Index assisted by service-oriented paradigm

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Abstract: The early drought warning is of a great importance for the management of water resources. In the sequence of drought processes, hydrologic drought occurs after meteorological drought. Service-Oriented Architecture (SOA) can improve representing hydrologic processes such as evapotranspiration, circulation of water in the atmosphere, plants, soil and unsaturated zone, as well as drought, by using independent Web services. To establish a relation between hydrologic and meteorological drought (i.e. runoff and precipitation), the Standardized Precipitation Index (SPI) and the Streamflow Drought Index (SDI) were used. The SPI and the SDI are the simplest drought indicators to obtain, in respect to data type and availability. The SPI is well known and widely used index that quantifies wet and dry periods in a given area. Similarly to the SPI, which is a probability index based only on precipitation, recently introduced SDI is calculated from long-term runoff data. In this paper, we investigate the relationship between SPI and SDI for 17 hydrologic stations in Serbia. The Mann-Kendall test was used to consider trends of precipitation monthly sums and mean monthly runoff over time. In our study, Web services are the tools for requesting time series, sharing hydrologic and meteorological data, estimating and monitoring SPI and SDI. The main goal of this paper is to study correlation between hydrologic and meteorological drought for application in regional drought monitoring.

Key words: Hydrologic drought, Meteorological drought, Standardized Precipitation Index, Streamflow Drought Index, Service-Oriented Architecture.

1. INTRODUCTION

The Ministry of Agriculture, Forestry and Water Resources of Serbia estimated the loss due to drought in 2007 in the agriculture only, to more than 45 billion RSD. In September 2009, the run-of-river hydroelectric plants worked with reduced capacity due to drought. The Electric Power Industry of Serbia intervened by increasing production of coal-fired electric plants. The need for reduction of the drought consequences is indisputable.

In this paper, we focus on exploring the relationship between hydrologic and meteorological drought from monthly data on precipitation sums and mean runoff, represented by the Standardized Precipitation Index (SPI) and the Streamflow Drought Index (SDI), respectively. The runoff at certain river cross-section represents a water resource available, and can be considered more useful for water resources planning and management compared to predicted precipitation at meteorological stations (MS).

The approach to detection of hydrologic drought independent from meteorological drought at one hydrologic station (HS) for Serbia exists, including sophisticated methods such as RUN and TIPS (Radić and Mihailović, 2006). However, there is a lack of regional hydrologic drought research for the territory of Serbia. As far as we know, this is the first hydrologic drought research based on SDI for any region of the country.

The existing worldwide results of regional or basin drought research include probability of an area of a certain extent to be covered by drought of a specific severity (severity–area–frequency curves) estimation for Denmark (Hisdala and Tallaksen, 2003), comparison of river discharges and reservoir storage to the different time scales of SPI in the mountainous Mediterranean basin (Vicente-Serrano and López-Moreno, 2005), and detection of long-term dry and wet periods through the monthly values of the SPI-24 averaged and the monthly values of the SDI-24 of the past and the near future (1961–2030) for the Xijiang River basin in China (Fischer et al., 2013).

There is not only a variety of drought indices, but different methodologies applied for estimating one index. The examples include estimation of SDI within calendar or hydrologic year, cumulative streamflow volume or runoff, four reference periods in one year and consequently four SDI per year or cumulative monthly values for each month, summing up monthly flow values at two gauge stations for volume calculation, etc. (Vicente -Serrano and López-Moreno, 2005; Nalbantis, 2008; Nalbantis and Tsakiris, 2009; Fischer et al., 2013).

In the Methodology section, we show the definition for drought indices adopted for this research, selected study area and available data, and the way we transfer precipitation data to hydrologic station (HS) basin, including the data trend test. We present reference periods used for parameter estimates for the SPI, SDI, and regression equation derivation. The Web services, a part of SOA, are represented as tools for requesting time series and estimating SPI and SDI values. The Results section contains the nonparametric trend test results, and the most important findings of correlation between SPI and SDI concerning the time lags, as well as regression models results measured by Nash-Sutcliffe efficiency index (NSE). At the beginning of final section, we discuss precision and accuracy of the SDI prediction, and bring the setbacks of the selected methodology and the improvements required for developing a simple prediction model for operational (real-time) use.

2. METHODOLOGY

The basic criterion for selection of methodologies is availability (accessibility) of both registered and real-time data in the observation stations network of the Republic Hydrometeorological Service of Serbia (RHMSS).

2.1 Study area

The Južna (South) Morava river basin is in the south of the Danube river basin (Fig. 1. a, b), the second largest European river. From macro-geological point of view, the Južna Morava connects Aegean basin with the Pannonian basin in Grdelica gorge (Borisavljević and Kostadinović, 2012). The Južna Morava is a cross-border, mountainous river basin with distinct gorges and valleys along the main course.

The Južna Morava river is 319 km long from its source at the union of the Binačka Morava and the Moravica rivers, to the union with the Zapadna (West) Morava river, thus creating the Velika (Great) Morava river. The most important left tributary to the Južna Morava is the Toplica, whereas the most important right tributary is the Nišava that rises in western Bulgaria; its valley provides an important transportation route from Belgrade via Sofia to Turkey. The Velika Morava and the Južna Morava together are a vital part of the Morava-Vardar (Axiós) corridor, the main road and rail route in Serbia. The Južna Morava river drainage area is 15,696 km^2 and its 85% is in Serbia (Fig. 1. b, c). The basin population is about 700,000. There are seven water reservoirs with the volume of more than 10 million m^3, four reservoirs with the volume less than 10 million m^3 and 35 small reservoirs with the purposes of water supply, energy production and flood defence (Borisavljević and Kostadinović, 2012).

The temperate-continental climate prevails in the Južna Morava river basin with minor local variations, such as Vlasina climatic area. It includes the Rhodopi mountain massif between the valley of the river Nišava in the north, the river Južna Morava in the west, the Bulgarian border in the east and FRY Macedonia in the south. Compared to the Carpathian-Balkan area there is somewhat lower precipitation, winters are more severe and last longer and summers are cooler. Climatic area of the Južna Morava river stretches along the course of the Južna Morava, including the valley of Toplica river, the Dobrička valley and the Bela Palanka valley. The lowest precipitation in Serbia is recorded in this area, shorter duration of snow cover, mild winters and very hot summers (Gocic and Trajkovic 2013a, 2013b).

The evaluation of the irrigation water quality indicator in the Južna Morava river basin upstream from the Toplica river confluence has shown that irrigation water quality was not limitation for sustainable rural development in the Južna Morava basin. The similar irrigation water quality is observed in other Serbian regions (Trajković, 2004). Consequently, irrigation water quantity remains an issue within water resources planning and management.

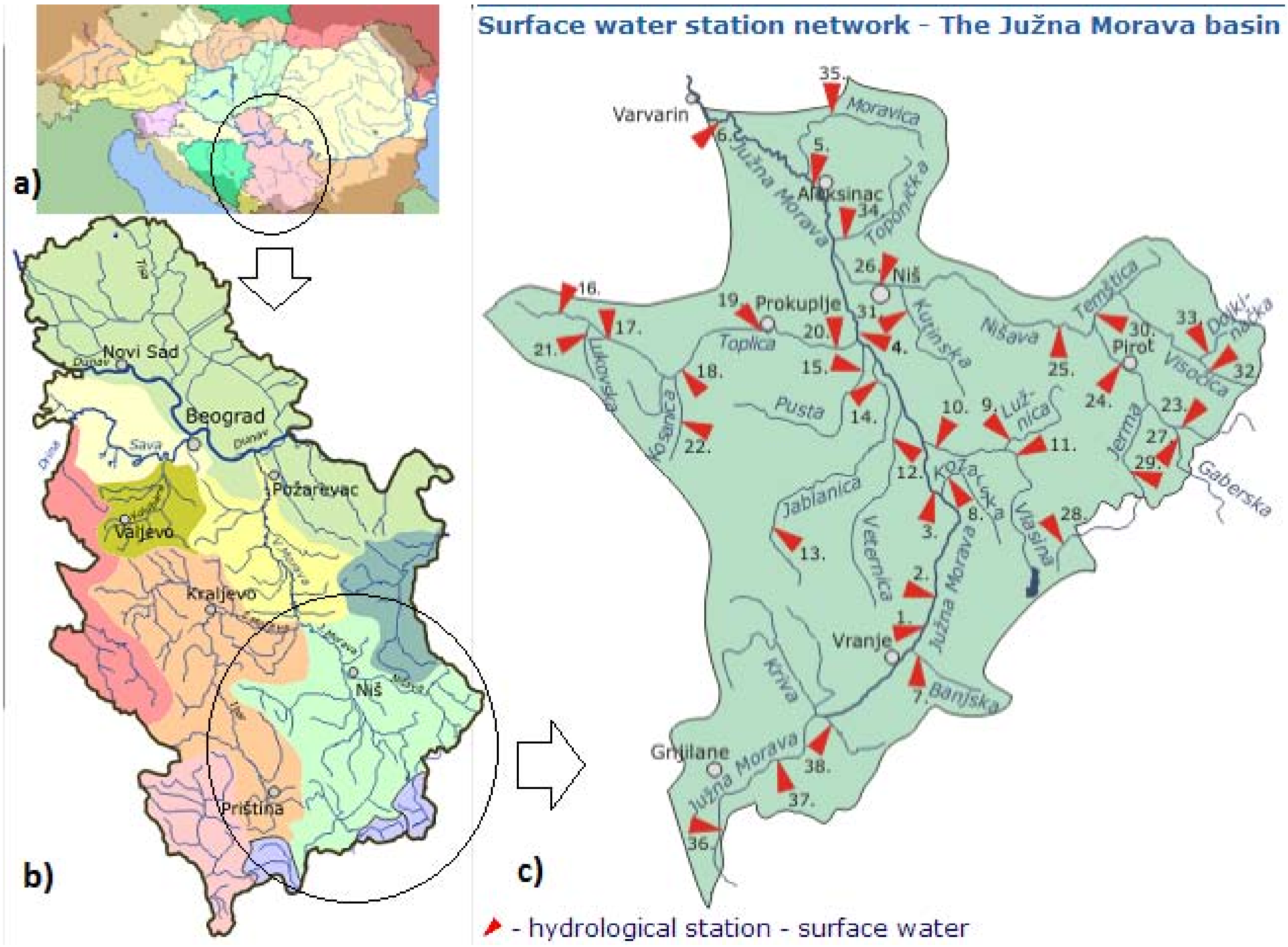


Fig. 1. a) The Danube river basin - the Republic of Serbia shown in the ellipse (source: http://commons.wikimedia.org/wiki/File:Bassin-du-Danube-blank-map.png), b) The RHMSS division of river basins in Serbia - the Južna Morava river basin shown in the ellipse, c) Layout of the RHMSS surface water station network of the Južna Morava river basin (source: http://www.hidmet.gov.rs/eng/hidrologija/povrsinske/index.php) .

2.2 Data

2.1.1 Hydrologic data

The surface water station network in the Južna Morava river basin comprises 38 HSs (Fig. 1. c). There are 14 HSs that are reporting stations. For these stations, up to 8 water related parameters are reported in near real-time, including water stage and river flow. However, river runoff records are not available before Hydrologic surface water yearbook is issued, which is usually in May/June of the following year.

In the period 1961-2011 there are 17 HSs out of 38 in the Južna Morava river basin without monthly runoff data gaps. We selected these 17 HSs for our research (Table 1.).

2.1.2 Meteorological data

Meteorological observation system of Serbia consists of 29 main meteorological stations (MSs). Four MSs are in the Južna Morava river basin (Niš, Dimitrovgrad, Leskovac and Vranje) and their ten days precipitation amounts (mm) are published regularly on the RHMSS Web site. Final verification of precipitation data shown for 10 days is due to 15th day of a month for the previous month.

There are also 5 standard MSs in the Južna Morava river basin (Prokuplje, Sokobanja, Babušnica, Pirot and Vlasotince) without monthly meteorological data gaps in the period 1961-2011. For our research, we selected the total of 9 MSs in the Južna Morava river basin.

In order to be able to compare runoff and precipitation data, i.e. the drought indices, we transfer the data from MS to HS. We use the Thissen polygon method on monthly records of precipitation. This is a common approach for modelling the spatial distribution of precipitation based on point observations. This interpolation method assigns weight at each MS in proportion to the HS catchment area that is closest to that MS. Precipitation value for each MS is multiplied by the area of each polygon cut from HS catchment area. All MS precipitation-area products for one HS are summed and divided by total basin area. The obtained value represents spatial precipitation data – at the HS for the processed month in our case.

Fig. 2. shows the Thissen polygons of 9 MSs constructed for the Južna Morava river basin. The MSs are represented by dots and HSs by triangles. The HSs considered for this research are underlined. The HS Pečenjevce catchment area divide is outlined to show the division of this HS area between MSs Prokuplje, Leskovac and Vranje for application of Thissen method.

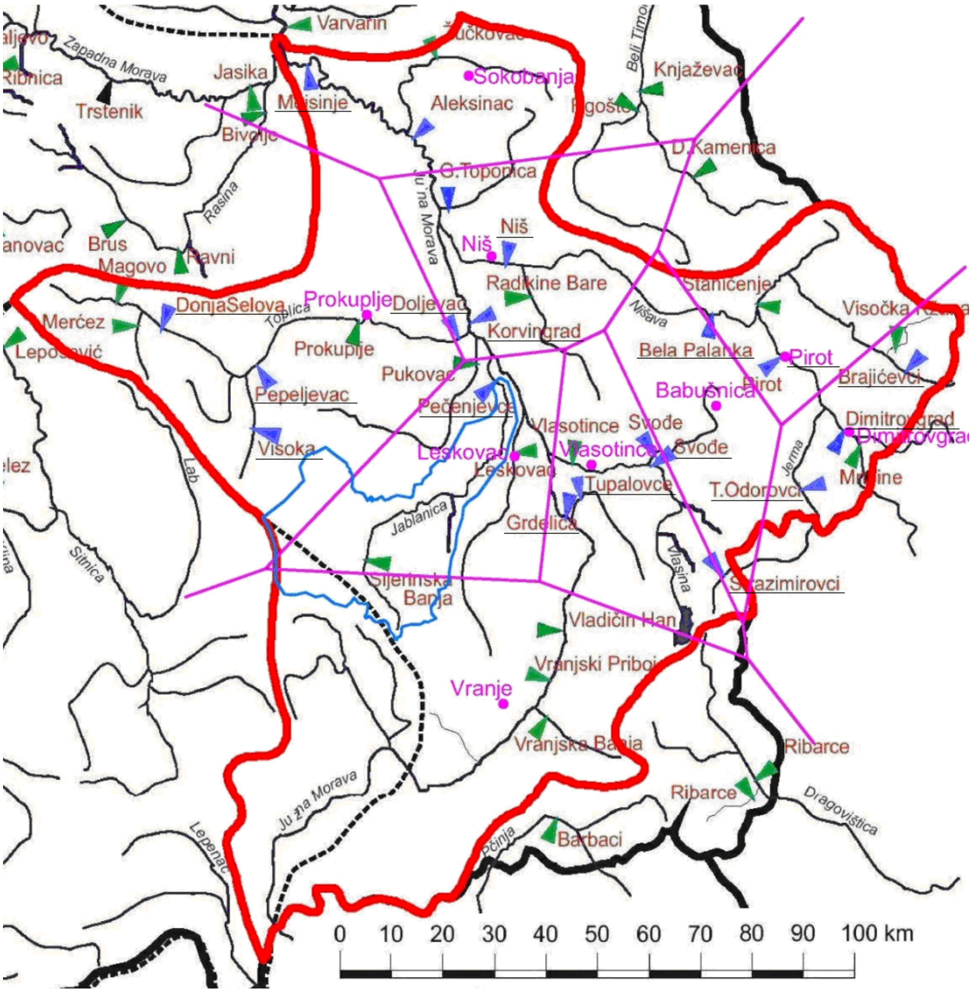


Fig. 2. The Thissen polygons constructed for the Južna Morava river basin.

2.1.3 Data test

The test applied for trend is the Mann-Kendall nonparametric test (Mann, 1945; Kendall 1975). For this purpose, software component for analyzing trend based on Web services was used (Gocic and Trajkovic, 2013c).

In this study, we run the test on the monthly average runoff data and monthly precipitation sums for each calendar month at the selected HSs in the period 1961-2011.

2.3 Standardized precipitation and discharge indices (SPI and SDI)

The SPI is a meteorological index (McKee et al., 1993) that quantifies the degree of meteorological drought using monthly precipitation sums. We calculate SPI for the monthly precipitation data sums and compute it by fitting the two-parameter gamma distribution to the frequency distribution of the precipitation summed to 1, 3, 6 and 12- month timescale. For the frequency distribution parameter estimates, we use the reference period 1961-2005. This is the methodology also adopted by RHMSS (Krajinović, 2010).

The streamflow drought index (SDI), or the standardized discharge index (Fischer et al., 2013) is calculated by the same approach to the SPI. The same timescale, distribution function (two-parameter gamma distribution), and reference period is applied on the monthly average runoff data.

We calculate the SPI and SDI for the 2006-2011 period to 1, 3, 6 and 12-month timescale with the frequency distribution parameter estimates from the reference period 1961-2005.

2.4 Correlation and regression

In order to study relationship between SPI and SDI in the Južna Morava river basin, we explore linear correlation in this paper. We use Pearson correlation coefficient R for the time lags of 0 to 12 months in the period 1961-2011.

As a forecast tool, we derive linear regression equations between SPI-1, 3, 6, and 12 with corresponding SDI, where SPI is predictor and SDI predictant. The regression equation parameter estimates are calculated by the least square method, using the reference period 1961-2005.

2.5 Service-Oriented Architecture

Service-Oriented Architecture (SOA) represents an architecture paradigm in which functionality is decomposed into distinct Web services (Erl, 2005). Web services are the services located in the specific location on the Internet that can be accessed via standard protocol (Booth et al., 2004). The key technologies used by Web services are Simple Object Access Protocol (SOAP), Web Services Description Language (WSDL) and Universal Description, Discovery and Integration (UDDI).

3. RESULTS

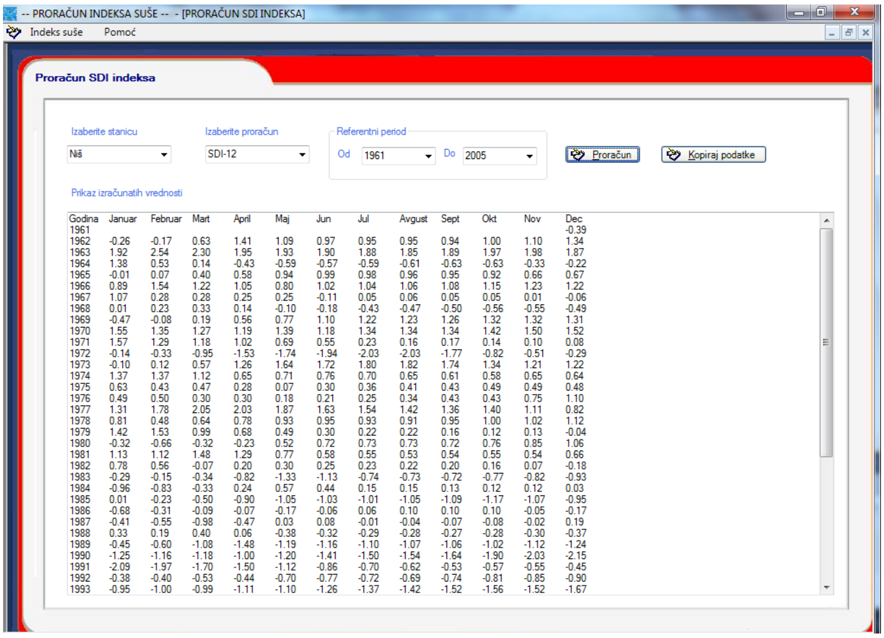
The Mann-Kendall nonparametric test results are shown in the Table 1. The HSs are grouped within sub-basins of the studied area.

Table 1. Number of calendar months with trend detected in the monthly precipitation and runoff time series by the means of Mann-Kendall test at the 0.95 confidence level.

Sub-Basin	Južna Morava						Nišava							Toplica			
HS	**Mojsinje**	Korvingrad	Grdelica	**Pečenjevce**	**Svodje (Vlasina)**	Tupalovce	**Niš**	**Bela Palanka**	**Pirot**	Trnski Odorovci	**Dimitrovgrad**	**Brajćevci**	Strazimirovci	Doljevac	Pepeljevac	Visoka	Donja Selova
Precipitation	1	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0
Runoff	0	0	0	1	1	0	1	3	4	0	0	1	0	0	0	0	0

At this stage of research, we do not remove trend from the input data series.

The SPI and SDI values are estimated by using Web services and the software represented in Fig. 3.



Izaberite stanicu: Niš
Izaberite proračun: SDI-12
Referentni period: Od 1961 Do 2005

Prikaz izračunatih vrednosti

Godina	Januar	Februar	Mart	April	Maj	Jun	Jul	Avgust	Sept	Okt	Nov	Dec
1961												-0.39
1962	-0.26	-0.17	0.63	1.41	1.09	0.97	0.95	0.95	0.94	1.00	1.10	1.34
1963	1.92	2.54	2.30	1.95	1.93	1.90	1.88	1.85	1.89	1.97	1.98	1.87
1964	1.38	0.53	0.14	-0.43	-0.59	-0.57	-0.59	-0.61	-0.63	-0.63	-0.33	-0.22
1965	-0.01	0.07	0.40	0.58	0.94	0.99	0.98	0.96	0.95	0.92	0.66	0.67
1966	0.89	1.54	1.22	1.05	0.80	1.02	1.04	1.06	1.08	1.15	1.23	1.22
1967	1.07	0.28	0.28	0.25	0.25	-0.11	0.05	0.06	0.05	0.05	0.01	-0.06
1968	0.01	0.23	0.33	0.14	-0.10	-0.18	-0.43	-0.47	-0.50	-0.56	-0.55	-0.49
1969	-0.47	-0.08	0.19	0.56	0.77	1.10	1.22	1.23	1.26	1.32	1.32	1.31
1970	1.55	1.35	1.27	1.19	1.39	1.18	1.34	1.34	1.34	1.42	1.50	1.52
1971	1.57	1.29	1.18	1.02	0.69	0.55	0.23	0.16	0.17	0.14	0.10	0.08
1972	-0.14	-0.33	-0.95	-1.53	-1.74	-1.94	-2.03	-2.03	-1.77	-0.82	-0.51	-0.29
1973	-0.10	0.12	0.57	1.26	1.64	1.72	1.80	1.82	1.74	1.34	1.21	1.22
1974	1.37	1.37	1.12	0.65	0.71	0.76	0.70	0.65	0.61	0.58	0.65	0.64
1975	0.63	0.43	0.47	0.28	0.07	0.30	0.36	0.41	0.43	0.49	0.49	0.48
1976	0.49	0.50	0.30	0.30	0.18	0.21	0.25	0.34	0.43	0.43	0.75	1.10
1977	1.31	1.78	2.05	2.03	1.87	1.63	1.54	1.42	1.36	1.40	1.11	0.82
1978	0.81	0.48	0.64	0.78	0.93	0.95	0.93	0.91	0.95	1.00	1.02	1.12
1979	1.42	1.53	0.99	0.68	0.49	0.30	0.22	0.22	0.16	0.12	0.13	-0.04
1980	-0.32	-0.66	-0.32	-0.23	0.52	0.72	0.73	0.73	0.72	0.76	0.85	1.06
1981	1.13	1.12	1.48	1.29	0.77	0.58	0.55	0.53	0.54	0.55	0.54	0.66
1982	0.78	0.56	-0.07	0.20	0.30	0.25	0.23	0.22	0.20	0.16	0.07	-0.18
1983	-0.29	-0.15	-0.34	-0.82	-1.33	-1.13	-0.74	-0.73	-0.72	-0.77	-0.82	-0.93
1984	-0.96	-0.83	-0.33	0.24	0.57	0.44	0.15	0.15	0.13	0.12	0.12	0.03
1985	0.01	-0.23	-0.50	-0.90	-1.05	-1.03	-1.01	-1.05	-1.09	-1.17	-1.07	-0.95
1986	-0.68	-0.31	-0.09	-0.07	-0.17	-0.06	0.06	0.10	0.10	0.10	-0.05	-0.17
1987	-0.41	-0.55	-0.98	-0.47	0.03	0.08	-0.01	-0.04	-0.07	-0.08	-0.02	0.19
1988	0.33	0.19	0.40	0.06	-0.38	-0.32	-0.29	-0.28	-0.27	-0.28	-0.30	-0.37
1989	-0.45	-0.60	-1.08	-1.48	-1.19	-1.16	-1.10	-1.07	-1.06	-1.02	-1.12	-1.24
1990	-1.25	-1.16	-1.18	-1.00	-1.20	-1.41	-1.50	-1.54	-1.64	-1.90	-2.03	-2.15
1991	-2.09	-1.97	-1.70	-1.50	-1.12	-0.86	-0.70	-0.62	-0.53	-0.57	-0.55	-0.45
1992	-0.38	-0.40	-0.53	-0.44	-0.70	-0.77	-0.72	-0.69	-0.74	-0.81	-0.85	-0.90
1993	-0.95	-1.00	-0.99	-1.11	-1.10	-1.26	-1.37	-1.42	-1.52	-1.56	-1.52	-1.67

Fig. 3. Screen printout of the application for SPI and SDI estimation.

3.1 Correlation

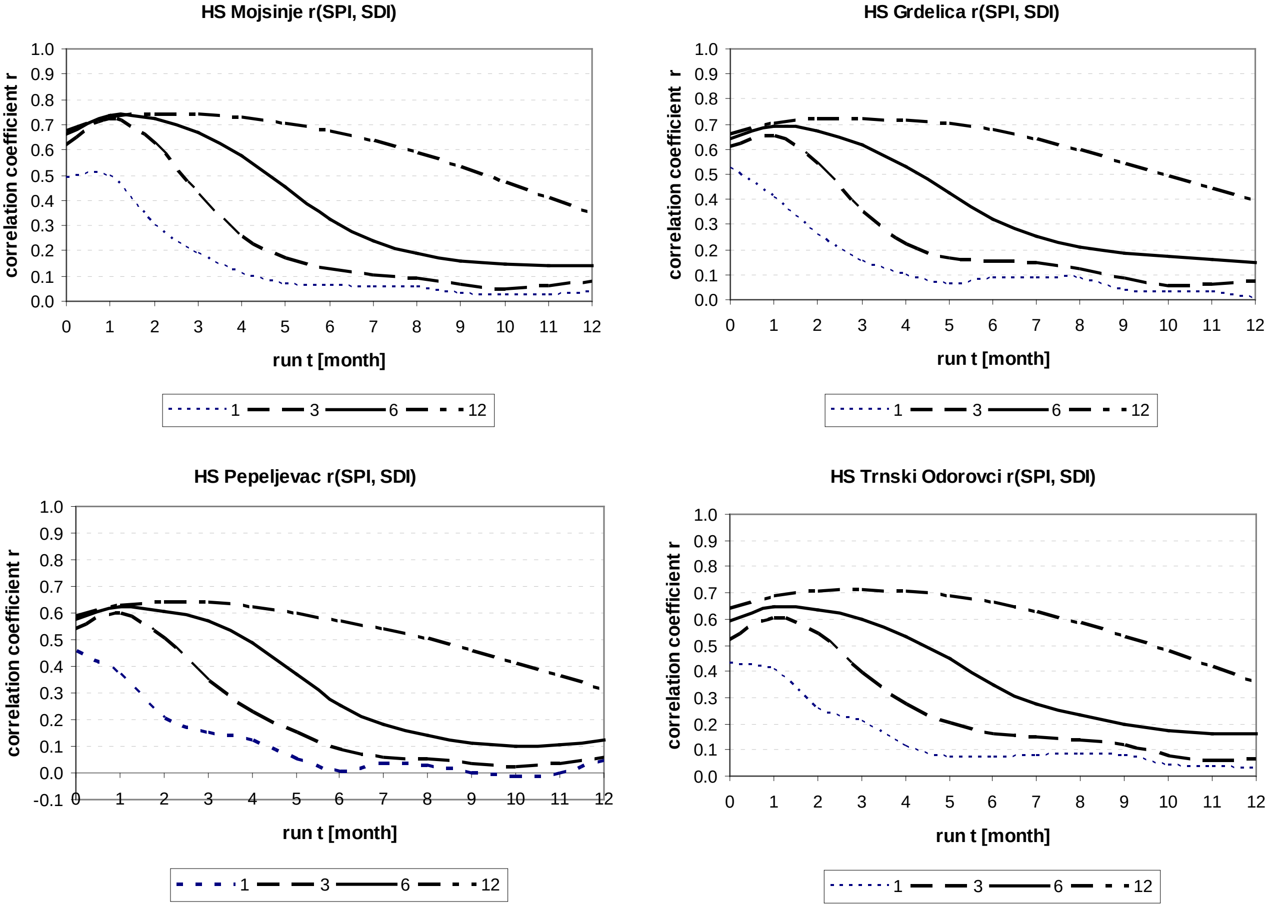


Fig. 4. Correlation coefficients between SPI and corresponding SDI obtained for 0-12 months time lags at four HSs in the Južna Morava river basin.

The change in linear correlation coefficients between SPI 1, 3, 6, and 12, and SDI 1, 3, 6, and 12, for the runs of 0 to 12 months is shown in Fig. 4. for 1961-2011.

The main diagonal entries in correlation matrices $r^{(t)}(x_i(k-t),y_j(k))$ where $x=SPI$, $y=SDI$, $i=j=1,3,6,12$, $t=0,1,2,\ldots,12$, $k=1,2,\ldots,624$, $k>i,j$ are shown in Table 2. for $i=j=3,6,12$.

Table 2. Correlation coefficients between observed SPI and SDI obtained for t [month] time lags in all of the sub-basins that exhibit moderately strong to strong correlation.

	HS Mojsinje			HS Korvingrad			HS Grdelica			**HS Pečenjevce**		
t	3	6	12	3	6	12	3	6	12	3	6	12
0	**0.621**	**0.662**	**0.677**	**0.613**	**0.640**	**0.661**	**0.613**	**0.639**	**0.660**	0.588	0.592	0.556
1	**0.726**	**0.736**	**0.727**	**0.685**	**0.704**	**0.710**	**0.657**	**0.690**	**0.703**	**0.626**	**0.630**	0.593
2	**0.628**	**0.726**	**0.742**	0.586	**0.696**	**0.729**	0.544	**0.672**	**0.719**	0.491	**0.601**	**0.601**
3	0.425	**0.670**	**0.741**	0.401	**0.651**	**0.734**	0.352	**0.617**	**0.724**	0.280	0.529	0.594
4	0.256	0.575	**0.727**	0.259	0.566	**0.725**	0.222	0.532	**0.718**	0.144	0.431	0.572
5	0.174	0.453	**0.704**	0.186	0.452	**0.706**	0.166	0.427	**0.703**	0.093	0.306	0.544
6	0.128	0.324	**0.675**	0.146	0.333	**0.681**	0.153	0.320	**0.680**	0.077	0.184	0.513
7	0.105	0.236	**0.636**	0.121	0.255	**0.646**	0.147	0.252	**0.644**	0.069	0.114	0.475
8	0.092	0.188	0.586	0.100	0.209	**0.603**	0.126	0.209	0.597	0.029	0.076	0.427

	HS Svodje (Vlasina)			**HS Niš**			**HS Bela Palanka**			**HS Pirot**		
t	3	6	12	3	6	12	3	6	12	3	6	12
0	0.515	0.548	**0.616**	0.598	**0.653**	**0.701**	0.598	**0.645**	**0.681**	0.495	0.542	**0.644**
1	0.579	**0.613**	**0.649**	**0.683**	**0.714**	**0.742**	**0.670**	**0.703**	**0.721**	0.589	**0.615**	**0.692**
2	0.500	**0.615**	**0.657**	0.596	**0.702**	**0.752**	0.583	**0.692**	**0.732**	0.534	**0.627**	**0.714**
3	0.360	0.591	**0.656**	0.405	**0.651**	**0.747**	0.404	**0.642**	**0.730**	0.391	**0.606**	**0.722**
4	0.259	0.525	**0.642**	0.266	0.571	**0.730**	0.270	0.563	**0.716**	0.280	0.556	**0.718**
5	0.201	0.425	**0.617**	0.203	0.466	**0.706**	0.209	0.461	**0.694**	0.236	0.483	**0.706**
6	0.144	0.303	0.582	0.161	0.340	**0.674**	0.167	0.340	**0.665**	0.209	0.389	**0.685**
7	0.097	0.219	0.541	0.131	0.256	**0.634**	0.134	0.255	**0.624**	0.192	0.320	**0.651**
8	0.058	0.164	0.494	0.105	0.205	0.586	0.101	0.201	0.577	0.166	0.276	**0.605**

	HS Trnski Odorovci			**HS Dimitrovgrad**			**HS Brajćevci**			HS Strazimirovci		
t	3	6	12	3	6	12	3	6	12	3	6	12
0	0.521	0.594	**0.640**	0.559	**0.605**	**0.600**	0.592	**0.625**	**0.649**	0.448	0.490	0.557
1	**0.604**	**0.647**	**0.687**	**0.637**	**0.658**	**0.637**	**0.645**	**0.668**	**0.686**	0.506	0.541	0.599
2	0.543	**0.638**	**0.707**	0.563	**0.644**	**0.645**	0.538	**0.643**	**0.695**	0.445	0.540	**0.621**
3	0.398	**0.600**	**0.713**	0.403	0.595	**0.637**	0.343	0.585	**0.689**	0.333	0.516	**0.634**
4	0.273	0.535	**0.705**	0.279	0.516	**0.618**	0.216	0.496	**0.670**	0.249	0.467	**0.637**
5	0.203	0.450	**0.688**	0.201	0.411	0.591	0.150	0.381	**0.642**	0.196	0.397	**0.631**
6	0.163	0.348	**0.665**	0.138	0.287	0.557	0.101	0.254	**0.610**	0.145	0.314	**0.616**
7	0.149	0.275	**0.629**	0.095	0.202	0.517	0.066	0.181	0.577	0.108	0.259	0.591
8	0.140	0.231	0.584	0.070	0.155	0.474	0.057	0.148	0.541	0.090	0.232	0.559

	HS Doljevac			HS Pepeljevac		
t	3	6	12	3	6	12
0	0.538	0.558	0.531	0.543	0.579	0.586
1	**0.614**	**0.616**	0.577	0.599	**0.623**	**0.628**
2	0.527	**0.610**	0.592	0.508	**0.609**	**0.640**
3	0.373	0.575	0.596	0.348	0.568	**0.641**
4	0.252	0.502	0.586	0.228	0.490	**0.626**

The values of correlation coefficients presented in Table 2. correspond to the illustration of correlation coefficient change with respect to runs of t month shown in Fig. 4. for four selected HSs that are underlined in Table 2.

The HSs in Table 2. are grouped within sub-basins of the studied area in the descending order according to the sub-basin area. The HSs with bolded titles correspond to findings of trend as in Table 1.

The HSs that are not shown in Table 2. (HS Pečenjevce, HS Tupalovce, HS Visoka and HS Selova) have weak linear correlation between SPI and SDI ($|r|<0.6$) or do not have it at all.

3.2 Regression models

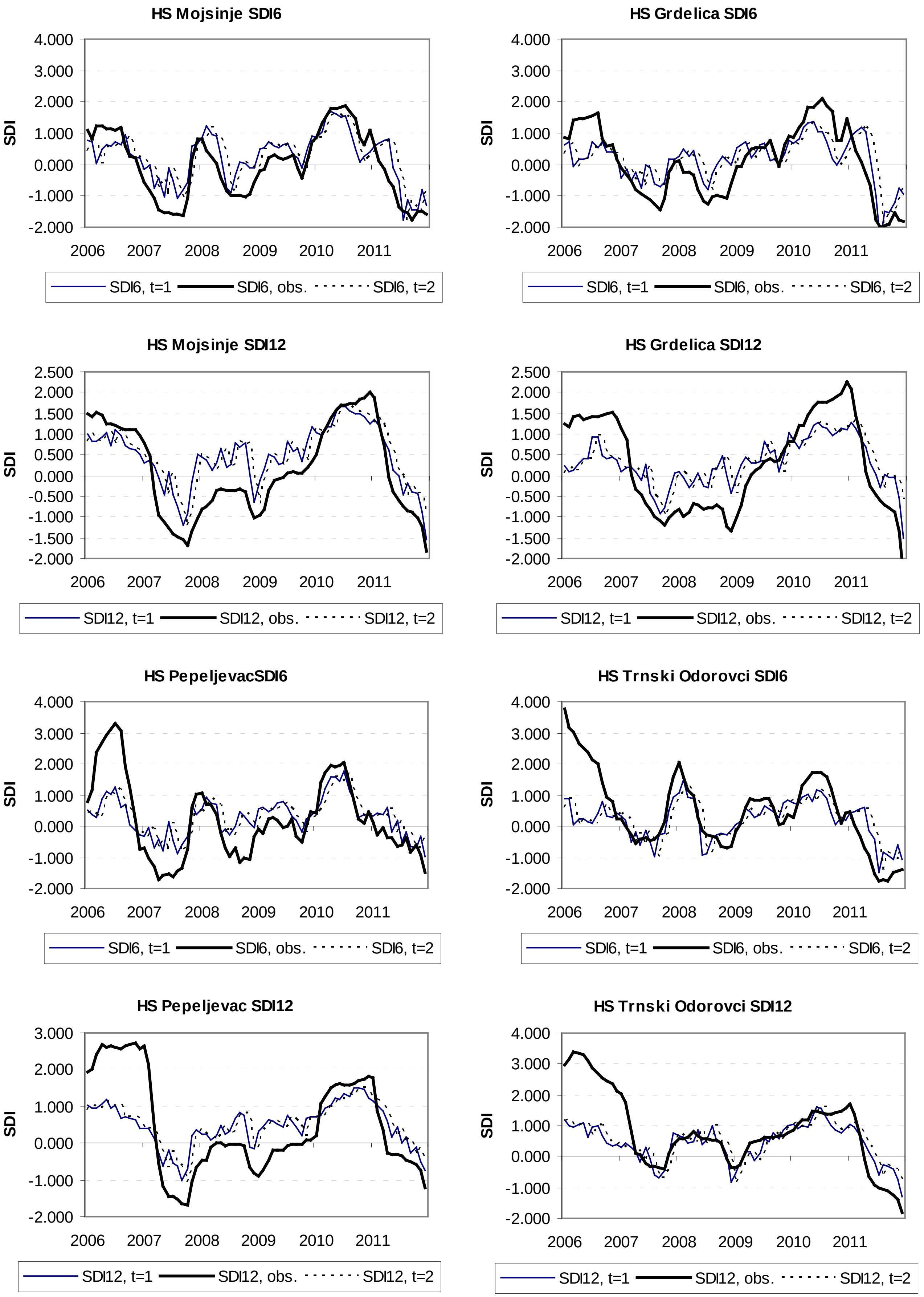


Fig. 5. Observed SDI6 and SDI12 and modeled values obtained by linear regression for 1 and 2 months time lag.

The modelled SDI6 and SDI12 values in the period 2006-2011 by the linear regression equations are shown in Fig. 5. for the same HSs selected for presentation in the Fig. 4.

Table 3. contains NSE obtained for observed (estimated) and modelled SDI time series with 1, 2 and 3 month lags. Satisfactory NSE values (>0.5) are bolded.

Table 3. Nash-Sutcliffe efficiency index (NSE) for linear regression models applied in 2006-2011 for 1, 2 and 3 months time lag. HS are classified in the upper and lower part of the table in regard to the trend test results. The upper part of the table is for the HS without detected trend.

		t=1				t=2			t=3	
A [km^2]	HS	SDI1	SDI3	SDI6	SDI12	SDI3	SDI6	SDI12	SDI6	SDI12
9,396	**Korvingrad**	0.252	**0.571**	**0.641**	**0.599**	0.372	**0.541**	**0.543**	0.391	0.463
3,782	**Grdelica**	0.189	0.494	**0.585**	**0.575**	0.318	**0.514**	**0.513**	0.396	0.454
2,052	**Doljevac**	0.188	0.459	**0.548**	**0.509**	0.373	**0.504**	**0.508**	0.416	0.477
986	**Pepeljevac**	0.210	0.461	**0.521**	0.461	0.362	0.466	0.470	0.366	0.449
557	Trnski Odorovci	0.164	0.374	0.404	0.391	0.248	0.354	0.388	0.270	0.362
370	Visoka	0.088	0.264	0.313	0.225	0.136	0.226	0.203	0.100	0.153
353	Donja Selova	0.190	0.408	0.471	0.437	0.287	0.411	0.438	0.331	0.419
98.1	Tupalovce	-0.123	-0.146	-0.348	-0.936	-0.278	-0.438	-0.995	-0.511	-1.023
95	Strazimirovci	0.158	0.252	0.339	0.082	0.158	0.242	-0.033	0.093	-0.170
15,390	**Mojsinje**	0.301	**0.635**	**0.672**	**0.629**	0.460	**0.589**	**0.595**	0.447	**0.528**
3,870	**Niš**	0.261	**0.591**	**0.623**	**0.644**	0.434	**0.559**	**0.630**	0.433	**0.577**
3,087	**Bela Palanka**	0.195	**0.553**	**0.653**	**0.674**	0.401	**0.564**	**0.647**	0.405	**0.570**
1,745	Pirot	-0.074	0.121	0.166	0.060	0.034	0.160	0.124	0.085	0.145
891	Pečenjevce	0.146	0.274	0.340	0.277	0.104	0.189	0.197	0.044	0.106
482	Dimitrovgrad	0.159	0.407	0.399	0.270	0.287	0.367	0.262	0.295	0.232
318	Svodje (Vlasina)	-0.185	-0.034	-0.020	-0.437	-0.134	-0.106	-0.528	-0.207	-0.601
227	Brajćevci	0.138	0.312	0.296	0.238	0.181	0.282	0.289	0.235	0.310

4. DISCUSSION AND CONCLUDING REMARKS

According to NSE values in Table 3. predictive power of selected linear regression model shows satisfactory results for large sub-basins in the studied area. The reason may be more accurate estimate of spatial distribution of precipitation based on point observations. Medium to smaller catchments (<1000 km^2) are more sensitive to local precipitation conditions. Due to coarse network of MS for this research, there were HSs with the same monthly precipitation data and consequently the same SPI (MS Dimitrovgrad- HS Brajćevci and HS Dimitrovgrad). In addition, these are state bordering sub-basins, and precipitation data from the other country is not available.

For future research, precipitation spatial distribution in HS basins should be improved. This could generate additional problem for real-time predictions, because precipitation data from the network of precipitation stations (PS) are not published in near real-time. In that way, 1 and 2 month lag for SDI prediction based on SPI is not possible. The best SDI modelling results are obtained for 1 and 2 month lag, and SDI6 and SD12 respectively (Table 3. and Fig. 5.).

In the validation period (2006-2011) shown in Fig. 5. for HSs with satisfactory model efficiency evaluated by NSE (Table 3.), it is evident that hydrologic drought onset is rarely matched, as well as drought intensity. It could be noted that modelled SDI time series show higher variability over observed series. This indicates that fitting a different, supposing 3 parameter theoretical probability distribution for SDI estimation, could lead to better results.

Finally, linear regression model should be changed for more appropriate one, still using SPI as input data, due to its real-time availability from the RHMSS on the territory of Serbia (Krajnović, 2010) in the case better solution can not be found. The input data that is going to be considered for future research is evapotranspiration (Gocić and Trajković, 2013c).

It should be noted that the implementation of SPI and SDI indices based on Web services can provide access information over the Internet. The implemented system is a multi-user mode with the possibility of easy upgrades.

The further research will be oriented into developing Web services for detection of drought trends in Serbia and comparative analyzing the drought indices based on precipitation and evapotranspiration. Besides, the Web services will be used as a tool for management of drought reduction measures.

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