Serbian Journal of Geosciences **8 (2022)**

University of Niš, Faculty of Sciences and Mathematics

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Analysis of discharge fluctuation using modified Streamflow Drought Index (SDI) and Standardized Precipitation Index (SPI) in the upper Nišava River Basin

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Received 23.12.2022 · Accepted for publication 07.02.2023 · Published 15.02.2023

Keywords:

Streamflow Drought Index, Standardized Precipitation Index, Discharge, Nišava River Basin.

Abstract

This paper aims to determine discharge fluctuation in two sub-basins of the upstream area of the Nišava River Basin, and peculiarly to inspect high-discharge and low-discharge events. The influence of precipitation on discharge fluctuation was analyzed too. The data from two hydrological and one climatological station for 45 years (1964-2009) were used. Modified Streamflow Drought Index (SDI) and Standardized Precipitation Index (SPI) were used to determine hydrologically and meteorologically dry and wet periods. Results showed that in both sub-basins, hydrologically dry and wet periods can be distinguished, but most of the time river stream discharge was in the mild or moderate range. The study showed that two neighboring and similar rivers could have significant differences in discharge fluctuations and that modified standardized SDI and SPI are good indicators that can be used to compare hydrological conditions in different river basins.

1. Introduction

It is well known that water is necessary for life, and clean freshwater is used by humans for drinking and sanitation, for our industry, crops, and livestock. Globally, the availability of freshwater is limited, and in Serbia, groundwater, rivers and partly lakes are the main source of fresh water. Drought is a natural phenomenon that may affect many sectors of the environment and human life, and attract the attention of hydrologists, meteorologists, agricultural scientists, ecologists, and other scientists. Scientists generally divide droughts into the following categories: hydrological drought when water level decrease in river channels or reservoirs (Van Loon, 2015), meteorological drought when dry weather dominates the area awhile (Torelló-Sentelles and Franzke, 2022), agricultural drought when crops are threatened by dry weather (Liu et al., 2016), and socio-economic drought (Mehran et al., 2015; Liu et al., 2020) when water supply cannot fulfill the water demands (Van Loon and Van Halen, 2012H; Vu-Thanh et al., 2013; Eklund and Seaquist, 2015; Vorobevskii et al., 2022). On the other side, floods can also occur when the river discharge exceeds the capacity of the river channel. Although flooding can bring some benefits (Dobrovičova et al., 2015), such as making the soil more fertile and groundwater level increase, it is also a destructive power that negatively influences human activity including loss of lives and economic losses (Jonkman 2005; Bouwer et al., 2007; Jonkman and Vrijling, 2008; Huang et al., 2008; Kron, 2009; De Silva and Kawasaki, 2020). Flood and drought risks vary in distribution across land and are multi-dimensional events with varying affected areas, duration, and intensities that often occur in specific, confined locations. (Bouwer et al., 2007). For that reason, it is very important to recognize temporal and spatial fluctuation in river discharge. Also, detecting factors that influence these fluctuations such as precipitation, temperature, vegetation cover, basin morphology, land use, soil properties, and others is very important too.

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https://doi.org/10.18485/srbjgeosci.2022.8.1.3

Meteorological and hydrological droughts are more or less connected and many researchers tried to find and explain the strength and nature of the connection (Zehtabian et al., 2013; Azareh et al., 2016; Bąk and Kubiak-Wójcicka, 2017; Patel et al., 2018; Kubiak-Wójcicka and Bąk, 2018; Kubiak-Wójcicka and Juśkiewicz, 2020; Giri et al., 2021; Kubiak-Wójcicka et al., 2021). For this purpose, most of the authors use standardized streamflow and precipitation indices (SDI and SPI), including a few studies in our region (Bonnaccorso et al., 2003; Caloiero et al., 2018; Leščešen et al., 2019; Blauhut et al., 2022; Stoyanova and Nikolova, 2022). The main objective of this paper is to study the variations in discharge in the upper Nišava River Basin, focusing specifically on high and low discharge events. The influence of precipitation on these fluctuations is also analyzed.

2. Study area

The study area covers the upstream part of the Nišava River Basin. It is located in Eastern Serbia and Western Bulgaria, in the border area, and is part of the mountainous system of Carpatho-Balkanides. The study area includes two sub-basins (Figure 1). The first sub-basin covers about 417 km2 and includes part of the main river basin, upstream of the Dimitrovgrad hydrological station. The sub-basin area is mostly hilly, the average surface height is 858 m, but the smaller area is 2,000 m above sea level. The second sub-basin covers the Gaberska River Basin, upstream of the Mrtvine hydrological station. The Gaberska River is the most important upstream tributary of the Nišava River, with a length of 40.51

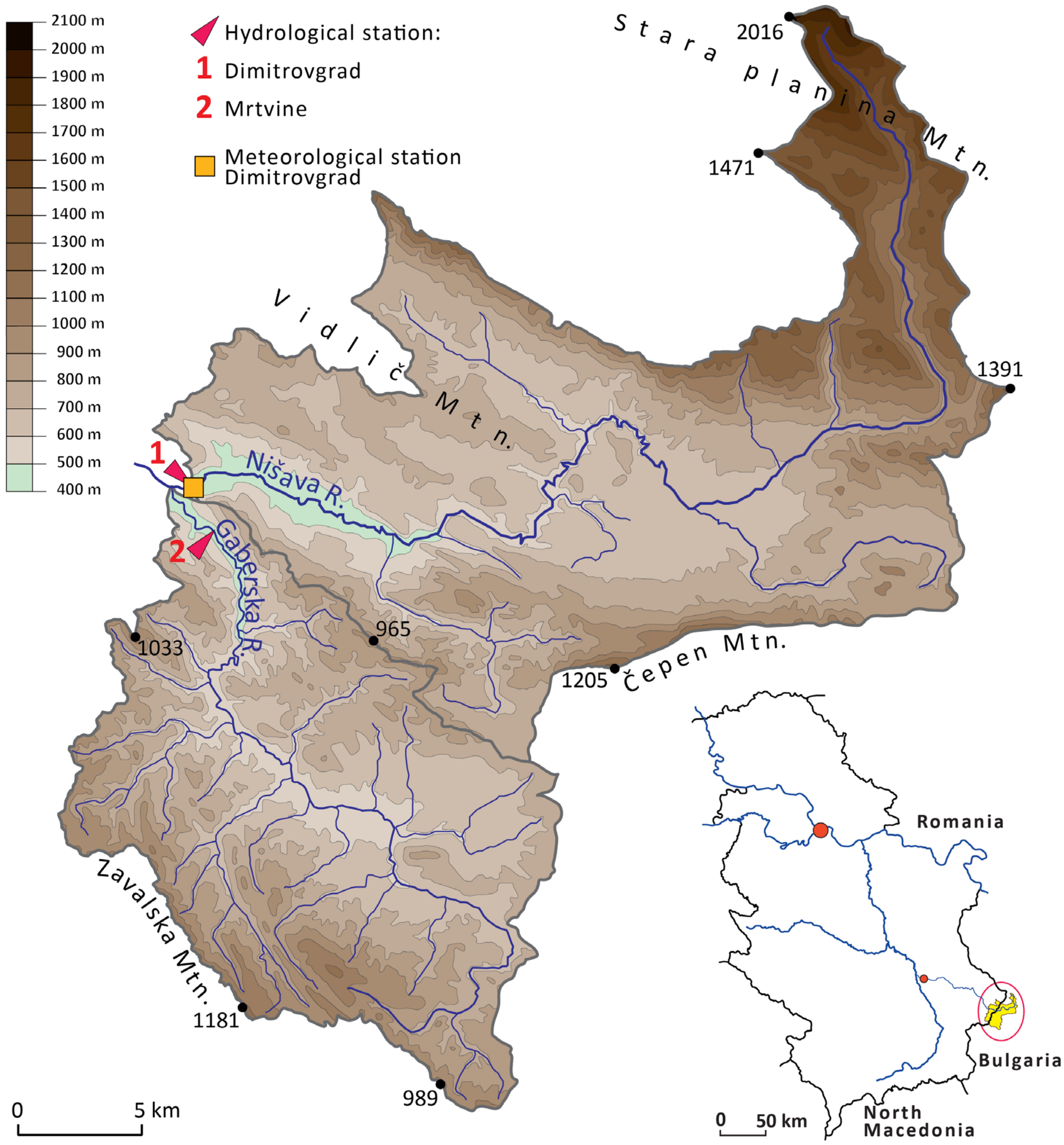

Figure 1. Geographical location of Dimitrovgrad and Mrtvine hydrological stations and their sub-basins.

km. The study area of the Gaberska River drainage basin covers about 245 km2, it is mostly hilly, and the average terrain height is 745 m above sea level (Đokić, 2015).

The study area is characterized by a relatively high average summer temperature (over 14ºC), and low average winter temperature (under 4ºC), and it belongs to a temperate-cold climate (Rakičević, 1980). The warmest month is July (19.7ºC on average in Dimitrovgrad) and the coldest is January (-0.8ºC on average in Dimitrovgrad). The predicted average annual precipitation amounts between 636 mm in the lower parts of the river basins and 1,145 mm in the highest part of the river basin (Đokić, 2015). The amount of precipitation is highest in June and lowest in February. The Nišava and Gaberska rivers belong to the type of pluvio-nival river regime, a temperate continental variant, with the highest discharges in March and April and the lowest discharges in September and August. The discharge regime of both sub-basins is affected by snow melting and in this way connected with the air and soil temperature. The vegetation cover consists mostly of a forest, transitional woodland/shrub, and agricultural land (Copernicus, 2018). The study area is sparsely populated with Dimitrovgrad Municipality with 10115 inhabitants as the biggest settlement according to the 2011 census (Statistical Office of the Republic of Serbia, 2011), and Godeč (4425 inhabitants) and Dragoman (3333) in Bulgaria (Ethnic composition of Bulgaria, 2011). The human influence on the water regime is weak.

3. Data collection and methodology

3.1. Hydrological data

There are two hydrological stations in the study area: Dimitrovgrad on the Nišava River (453 m above sea level) and Mrtvine on the Gaberska River (440 m above sea level) (Figure 1). Data were collected and published in Hydrological Yearbooks by the Republic Hydrometeorological Service of Serbia (Hydrological Yearbooks, 1964-2009). Data include average monthly discharges, as well as annual discharges. The 45 hydrological year periods, which begin on October 1st and end on September 30th, were used in this study.

3.2. Meteorological data

Meteorological station Dimitrovgrad is located in the lowest part of the study area at 440 m above sea level. The station is one of 29 main meteorological stations in Serbia and data have been collected since 1926. Data used in this paper was published in Meteorological Yearbooks by the Republic Hydrometeorological Service of Serbia, for the same period as hydrological data (Meteorological Yearbooks, 1964-2009). Data includes average monthly and annual precipitation and air temperature.

3.3. Streamflow Drought Index (SDI)

The Streamflow Drought Index (SDI) is based on only one input parameter, discharge, and thus it is not data-demanding. The SDI is simple to compute and is based on the Standardised Precipitation Index (SPI) used for detecting and characterizing meteorological droughts (McKee et al., 1993). Nalbantis (2008), Nalbantis and Tsakiris (2009), Tabari et al., (2013), Myronidis et al., (2018), Malik et al., (2019), Jahangir and Yarahmadi (2020), Abbas and Kousar (2021), Tareke and Awoke (2022), and others used the SDI for the hydrological drought monitoring and analysis purpose.

The SDI is defined for discharges or average discharges for each reference period k of the i-th hydrological year as follows:

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V_k}}{S_k}, i = 1, 2, \ldots\ k = 1, 2, \ldots$$

where, $V_{i,k}$ is the discharge for the i-th hydrological year and the k-th reference period (k = 1 for October, k = 2 for November, k = 3 for December, k = 4 for January, k = 5 for February, k = 6 for March, k = 7 for April, k = 8 for May, k = 9 for Jun, k = 10 for July, k = 11 for August, k = 12 for September, and k = 13 for October-September period), while $\overline{V_k}$ and S_k is the mean and the standard deviation of monthly discharges and annual average discharges in hydrological year of the reference period k over the study period. The k-th reference period can be based on different time scales, such as 1, 3, 6, 9, 12, 24, and 48 months. In most hydrological drought studies, cumulative discharges are used, for example, October-December, October-March, October-September, and October-September periods, but in this study, indices were calculated for single 1-month periods and average 12-month (hydrological year) periods. In that way, we can analyze individual discharges compared to other discharges in a particular month or hydrological year during the study period. More importantly, we can compare discharge in two different basins, as well as precipitation (SPI) influences TO the river's discharges. Hydrological drought, as well as high-discharge periods, could be noticed over the study period. The weakness of this approach could be the significant influence of extreme hydrological events.

Classification of the SDI values is presented in Table 1 (Lloyd-Hughes and Saunders, 2002; Hong et al., 2015). The

Table 1. Streamflow Drought Index (SDI) and Standardized Precipitation Index (SPI) categories.

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

SDI values between 1 and -1 can be classified as "near normal" (Tapoglou et al., 2019). Although the SDI is originally used for the analysis of hydrological drought, it can also indicate the occurrence of high-discharge events (a wet category in the classification table).

3.4. Standardized Precipitation Index (SPI)

The SPI was developed by McKee et al. (1993). It is one of the most ordinarily used indicators for detecting and characterizing meteorological drought (Blagojević et al., 2013; Karabulut, 2015; Malakiya and Suryanarayana, 2016; Jang, 2018; Abbas, 2021).

The SPI is calculated in the same way as the SDI, for precipitation or average precipitation of each reference period k of the i-th hydrological year as follows:

$$SPI_{i,k} = \frac{X_{i,k} - \overline{X_k}}{S_k}, i = 1, 2, \ldots\ k = 1, 2, \ldots$$

where, *Xi,k* is the precipitation for the i-th hydrological year and the k-th reference period, while $\overline{X_k}$ and Sk is the mean and the standard deviation of monthly precipitation and annual average precipitation in hydrological year, of the reference period k over the study period. In this study, same as for the SDI, the standardized precipitation indices were calculated for single 1-month periods and average 12-month (hydrological year) periods, and show not only the drought periods (lower precipitation) but also higher precipitation periods (a wet category in the classification table) during the study period. Detailed classification of the SPI values is presented in Table 1 (Lloyd-Hughes and Saunders, 2002; Karabulut, 2015), although the SPI values between 1 and -1 can be also classified as "near normal" (Zhang et al., 2009; Svoboda et al., 2012; Jang, 2018).

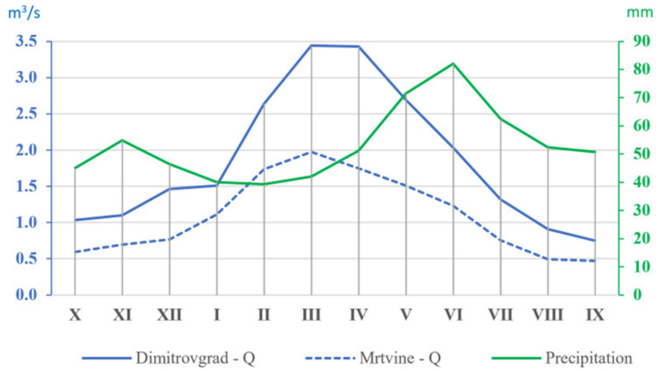

Figure 2. Average monthly discharges (m^3/s) at the hydrological stations Dimitrovgrad and Mrtvine, and average monthly precipitation (mm) in Dimitrovgrad, for the period 1964-2009.

4. Results and discussion

The average discharge of the Nišava River at the hydrological station Dimitrovgrad in the period 1964-2009 was 1.86 m^3/s, which gives the runoff of 4.46 $l/s/km^2$. At the Mrtvine hydrological station, the average discharge for the same period was 1.09 m^3/s, with a runoff of 4.44 $l/s/km^2$ (Figure 2). Thus the amount of water in both sub-basins is very similar. Monthly discharge distribution is similar too, with the highest values in March and lowest values in September. The second highest discharge value in Dimitrovgrad is in April and at Mrtvine in February and April, which can be explained by higher altitudes in parts of the Nišava River Basin and consequently the later snow melting compared to the Gaberska River Basin.

On average, the highest precipitation at the Dimitrovgrad meteorological station is recorded in June, the period when discharge decreases, which can be explained by the growth of vegetation that consumes water, as well as by higher air temperatures which increase evaporation (Figure 2). The lowest precipitation is recorded during the winter period, in February and January. Relatively high discharges in that period can be explained by low temperature (low evaporation) and vegetation being dormant.

The Streamflow Drought Index values calculated for single 1-month periods and average 12-month (hydrological year) periods are shown in Table 2 and Table 3. Shades of red color show months and years when discharge was below the average and shades of blue color indicate discharge values above the average.

Annual discharges at the Dimitrovgrad hydrological station varied a lot during the study period (Table 2), but still, in the period from 1964/65 to 1980/81, there were more hydrological years distinguished by higher discharges (10) compared to lower discharges (7). As well, positive values are more conspicuous, with one extremely wet (1972/73), one severely wet, and three moderately wet years, while negative values indicate only one moderately drought (1971/72) and six mild drought years. In this period the lowest discharge hydrological year is followed by the highest discharge hydrological year, which can be partially explained

Table 2. Monthly and annual discharge SDI values for the Dimitrovgrad hydrological station (1964-2009).

Hyd. Year	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
1964/65	-0.16	0.82	-0.39	0.31	-0.41	0.67	-0.34	0.37	0.18	-0.42	-0.30	0.34	0.08
1965/66	-0.30	-0.44	-0.20	1.01	3.49	-0.26	-0.07	-0.15	1.22	-0.27	0.01	-0.19	0.77
1966/67	-0.24	-0.24	-0.21	-0.31	-0.23	-0.37	-0.41	0.01	0.47	1.64	0.23	0.36	0.00
1967/68	-0.04	0.03	0.01	0.06	0.80	0.27	-0.79	-0.94	-1.11	-0.74	-0.51	-0.77	-0.43
1967/69	-0.44	-0.34	-0.26	-0.13	2.87	1.22	0.91	-0.09	0.69	0.32	0.01	-0.32	1.07
1968/70	-0.31	-0.55	-0.57	0.59	0.94	1.43	0.64	1.10	0.71	4.43	0.21	-0.03	1.55
1970/71	-0.07	-0.25	-0.66	-0.06	-0.50	0.40	0.14	-0.59	-0.15	-0.33	-0.33	0.46	-0.29
1971/72	-0.20	-0.34	-0.69	-0.70	-0.78	-0.93	-1.48	-0.90	-1.07	-0.78	-0.56	3.86	-1.19
1972/73	6.00	2.91	1.09	0.36	0.50	0.82	1.28	0.51	-0.32	-0.09	-0.41	-0.61	2.02
1973/74	-0.26	-0.50	0.18	-0.06	-0.33	-0.80	-0.64	0.61	-0.68	-0.24	-0.68	-1.06	-0.64
1974/75	-0.25	0.12	-0.16	0.38	-0.48	-0.14	-0.46	0.38	0.60	0.27	0.00	-0.08	-0.06
1975/76	-0.10	-0.09	-0.14	-0.16	-0.68	-0.81	-1.01	-0.09	0.47	0.42	1.32	1.24	-0.28
1976/77	-0.15	2.03	1.79	0.54	0.75	0.15	0.09	-0.41	0.54	0.05	-0.15	-0.19	0.65
1977/78	-0.24	-0.31	-0.34	0.14	0.49	1.69	1.85	0.68	0.33	0.08	-0.09	0.76	1.01
1978/79	-0.01	-0.23	0.49	1.96	1.29	-0.47	0.39	0.01	-0.21	-0.07	0.21	0.25	0.50
1979/80	-0.11	-0.09	-0.36	-0.09	0.14	0.51	0.50	4.07	2.10	0.09	0.27	0.25	1.25
1980/81	0.09	0.68	2.18	-0.02	0.05	1.82	-0.45	0.93	-0.01	-0.27	-0.08	-0.13	0.81
1981/82	-0.11	-0.08	1.37	0.44	-0.61	-0.15	0.04	0.33	-0.76	-0.39	-0.29	-0.23	-0.14
1982/83	-0.28	-0.29	0.44	-0.30	-0.33	-0.77	-1.13	-1.17	0.84	2.89	0.31	0.72	-0.16
1983/84	-0.13	-0.23	-0.01	-0.10	0.52	0.90	1.03	0.45	-0.43	-0.39	-0.20	-0.15	0.42
1984/85	-0.26	-0.33	-0.78	-0.74	-0.68	0.19	-0.32	-0.54	-1.07	-0.62	-0.47	-0.55	-0.83
1985/86	-0.37	0.50	-0.05	1.17	0.46	0.66	-0.54	-0.86	-0.55	0.57	-0.25	-0.70	0.07
1986/87	-0.39	-0.67	-0.98	-0.83	0.40	-0.32	1.66	1.46	-0.06	-0.58	-0.46	-0.84	0.07
1987/88	-0.38	-0.24	0.30	-0.48	-0.60	0.12	0.01	-0.61	-0.08	-0.49	-0.41	-0.60	-0.49
1988/89	-0.37	-0.53	0.46	-0.92	-1.00	-1.15	-1.53	0.09	0.78	-0.31	-0.23	-0.30	-0.96
1989/90	0.21	-0.28	-0.50	-0.79	-0.67	-1.06	-0.85	-0.51	-0.71	-0.38	-0.49	-0.88	-1.07
1990/91	-0.46	-0.68	0.13	-0.53	-0.71	-0.24	0.52	2.89	2.13	0.14	0.08	0.02	0.51
1991/92	-0.04	-0.03	-0.82	-0.85	-0.81	-0.67	-0.40	-0.86	0.22	-0.21	-0.37	-0.71	-0.87
1992/93	-0.40	-0.58	-1.01	-1.05	-1.05	-0.95	-0.84	-0.78	-1.25	-0.74	-0.62	-1.00	-1.54
1993/94	-0.47	-0.77	-1.03	-1.00	-1.03	-1.23	-1.00	-0.70	-1.28	-0.66	-0.70	-1.22	-1.66
1994/95	-0.52	-0.84	-1.26	-1.09	-0.71	-1.07	-1.06	0.00	-0.89	-0.65	-0.48	-0.58	-1.37
1995/96	-0.48	0.14	1.14	0.04	-0.57	-0.55	2.37	0.07	-1.06	-0.55	-0.37	2.27	0.14
1996/97	-0.01	0.23	2.98	2.34	-0.64	-0.93	0.55	0.04	-0.14	-0.39	-0.15	-0.77	0.22
1997/98	-0.29	-0.33	-0.01	-0.61	-0.20	-1.02	-1.25	-0.92	-0.85	-0.39	-0.43	0.35	-1.07
1998/99	1.12	1.43	0.28	0.52	0.04	0.11	0.25	-0.23	1.98	0.45	0.21	1.00	0.88
1999/00	0.05	0.04	2.01	0.05	0.40	0.76	1.02	-0.51	-0.70	-0.45	-0.66	-1.14	0.32
2000/01	-0.56	-0.93	-1.31	-1.33	-1.18	-1.06	-0.64	-0.28	-1.32	-0.55	-0.61	-0.56	-1.54
2001/02	-0.48	-0.88	-1.26	-1.21	-1.00	-1.28	-0.85	-1.24	-1.28	-0.40	2.71	0.57	-1.24
2002/03	1.41	-0.52	-1.05	3.64	-0.13	-0.80	-0.38	0.19	1.25	-0.51	-0.44	-0.61	0.21
2003/04	-0.36	-0.46	-1.04	-0.59	0.02	0.68	-0.73	-0.72	-0.43	-0.67	-0.55	-0.86	-0.66
2004/05	-0.26	-0.22	-1.00	-1.05	1.76	2.28	2.10	0.86	2.45	-0.25	5.31	2.15	2.28
2005/06	1.10	-0.51	0.89	-0.24	-0.16	1.51	1.12	-0.34	1.01	0.19	0.06	-0.12	0.85
2006/07	-0.17	-0.28	-0.65	-0.77	-0.73	-1.02	-1.44	-1.16	-1.16	-0.71	-0.29	-0.69	-1.45
2007/08	-0.31	4.54	1.42	0.57	-0.47	-0.58	0.87	-0.68	-0.66	-0.33	-0.25	-0.25	0.29
2008/09	0.01	-0.42	-0.43	1.86	1.73	2.45	1.28	0.23	0.25	2.26	0.89	1.54	1.97
Average+	1.25	1.12	1.01	0.89	0.93	0.93	0.89	0.73	0.96	0.99	0.85	1.01	0.78
Average -	-0.27	-0.41	-0.61	-0.59	-0.62	-0.75	-0.78	-0.64	-0.70	-0.45	-0.38	-0.56	-0.81

Symbology		
	≥ 2 Extremely wet	≤ -2 Extreme drought
	1.5 to 1.99 Severely wet	-1.5 to - 1.99 Severe drought
	1 to 1.49 Moderately wet	-1 to -1.49 Moderate drought
	0 to 0.99 Mildly wet	0 to 0.99 Mild drought

using the air temperature data and SPI values for the meteorological station Dimitrovgrad (Table 4). The beginning of the 1971/72 hydrological year was very dry when the first 9 months were with negative values of the SPI, and a severe meteorological drought was recorded in March. During July, August, and especially September 1972 SPI values are higher, but not enough to significantly increase discharges. Rainy weather continued during October 1972 (the hydrological year 1972/73), and a large amount of precipitation was recorded, while temperatures were below the average in that period of the year. It caused high SDI values during the next three months, especially October followed by November.

Table 3. Monthly and annual discharge SDI values for the Mrtvine hydrological station (1964-2009).

Hyd. Year	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
1964/65	0.66	1.20	-0.07	0.40	1.14	0.86	1.08	1.97	1.62	-0.40	-0.45	-0.59	1.28
1965/66	-0.55	-0.67	-0.47	-0.07	2.11	-0.03	0.19	0.49	1.28	0.00	1.12	0.60	0.76
1966/67	0.04	0.46	1.30	0.64	0.34	-0.54	-0.80	0.17	0.04	1.98	0.86	0.40	0.49
1967/68	0.01	0.42	0.63	0.08	0.51	0.66	-0.32	-0.81	-0.41	-0.44	-0.13	-0.12	0.02
1967/69	-0.41	-0.27	0.98	0.29	3.46	2.49	0.95	-0.12	0.25	0.15	0.29	0.28	1.57
1968/70	-0.33	-0.33	-0.18	-0.16	0.81	1.75	0.43	1.23	0.83	2.86	1.46	0.65	1.39
1970/71	0.79	-0.05	-0.17	-0.03	-0.53	1.07	1.17	-0.50	0.09	-0.36	0.02	0.88	0.26
1971/72	0.11	0.09	-0.12	-0.43	-0.78	-1.08	-1.33	-0.74	-0.98	-0.69	-0.27	1.29	-0.95
1972/73	5.50	1.63	-0.17	-0.52	0.28	1.09	1.87	0.82	0.50	0.06	-0.03	0.22	1.37
1973/74	0.02	-0.28	0.70	0.31	-0.09	-0.39	0.85	2.57	1.50	0.22	0.28	0.29	0.85
1974/75	0.35	0.67	0.72	-0.12	-0.54	-0.03	-0.34	0.58	2.16	0.92	0.55	0.12	0.55
1975/76	0.36	0.69	0.63	0.17	-0.15	-0.71	-0.44	1.03	3.40	2.08	2.94	2.24	1.29
1976/77	1.06	3.77	3.49	1.43	1.44	1.60	0.70	0.41	0.45	0.12	0.04	0.40	1.86
1977/78	-0.21	-0.21	0.36	0.07	-0.27	1.13	1.67	1.98	1.13	-0.28	-0.42	0.30	0.88
1978/79	-0.14	-0.38	0.37	1.30	0.44	-0.66	-0.03	-0.90	-1.03	-0.57	-0.65	-0.35	-0.31
1979/80	-0.37	-0.56	-0.99	-0.85	-0.63	-0.39	-0.55	1.48	1.61	0.58	-0.05	-0.32	-0.04
1980/81	-0.20	0.11	0.56	0.71	0.23	0.70	0.34	0.36	0.38	0.78	1.95	2.04	0.91
1981/82	1.73	1.75	2.28	0.27	-0.62	0.56	0.83	0.87	-0.49	0.03	0.27	-0.12	0.71
1982/83	-0.11	0.25	0.88	-0.57	-0.63	-1.06	-1.28	-1.11	0.11	3.14	-0.01	0.05	-0.33
1983/84	-0.24	-0.14	0.11	-0.38	0.53	1.14	0.72	-0.12	-0.30	-0.38	-0.36	-0.52	0.18
1984/85	-0.53	-0.53	-0.94	-0.52	-0.23	0.35	-0.89	-0.76	-0.84	-0.58	-0.68	-0.47	-0.79
1985/86	-0.56	0.25	-0.59	0.27	0.77	0.67	-0.43	-0.52	-0.55	0.17	-0.07	-0.31	0.05
1986/87	-0.18	-0.28	-0.44	-0.15	0.06	-0.27	1.74	-0.46	-0.67	-0.56	-0.55	-0.60	-0.23
1987/88	-0.50	-0.12	0.29	-0.55	-0.85	-0.23	-0.58	-0.79	-0.55	-0.54	-0.63	-0.52	-0.84
1988/89	-0.37	-0.33	0.77	-0.71	-0.96	-1.20	-1.45	-0.45	-0.44	-0.38	-0.21	-0.05	-1.02
1989/90	-0.29	-0.48	-0.86	-0.46	-0.73	-1.14	-0.97	-0.73	-0.94	-0.75	-0.75	-0.71	-1.22
1990/91	-0.58	-0.83	-0.08	-0.48	-0.46	0.84	1.22	2.64	0.25	-0.32	-0.52	-0.84	0.38
1991/92	-0.58	-0.82	-1.33	-0.90	-1.00	-1.42	-0.71	-1.05	-0.66	-0.34	-0.82	-0.89	-1.45
1992/93	-0.79	-0.74	-1.07	-0.95	-1.09	-0.61	-0.99	-0.63	-1.02	-0.88	-0.92	-0.97	-1.41
1993/94	-0.90	-1.11	-1.39	-0.66	-0.92	-1.25	-0.83	-0.40	-0.88	-0.74	-0.82	-0.90	-1.41
1994/95	-0.82	-0.97	-1.29	-0.66	-0.73	-1.18	-1.11	-0.60	-0.36	-0.60	-0.53	-0.30	-1.23
1995/96	-0.53	-0.12	0.73	-0.21	-0.47	-0.44	2.10	0.13	-0.52	-0.40	-0.28	0.59	-0.03
1996/97	-0.01	-0.28	1.01	0.60	-0.60	-0.87	0.20	-0.24	-0.40	-0.37	-0.03	-0.32	-0.32
1997/98	-0.29	-0.30	-0.24	-0.46	0.57	-0.86	-1.30	-0.98	-0.99	-0.68	-0.82	-0.72	-0.91
1998/99	-0.36	-0.34	-0.17	-0.33	-0.40	-0.01	-0.38	-0.22	-0.57	-0.30	0.27	-0.10	-0.43
1999/00	-0.30	-0.19	0.80	-0.12	0.06	0.01	-0.60	-0.71	-0.78	-0.61	-0.73	-0.90	-0.53
2000/01	-0.86	-1.09	-1.56	-0.86	-1.04	-1.23	-1.16	-0.70	-0.27	-0.40	-0.76	-0.65	-1.41
2001/02	-0.70	-0.91	-1.37	-0.81	-0.88	-1.25	-0.38	-0.95	-1.02	-0.68	-0.12	-0.48	-1.34
2002/03	0.49	-0.02	0.05	5.09	0.12	-0.51	0.17	0.11	-0.24	-0.63	-0.65	-0.20	0.67
2003/04	0.72	0.19	-0.46	-0.32	-0.49	-0.23	-0.86	-0.79	-0.45	-0.43	-0.50	-0.80	-0.64
2004/05	-0.28	-0.04	-1.10	-0.47	2.93	1.59	0.70	0.04	0.60	-0.70	-0.14	-0.70	0.86
2005/06	0.18	-1.06	-0.27	-0.42	-0.46	1.51	-0.49	-0.94	-0.50	-0.68	-0.70	-0.88	-0.48
2006/07	-0.73	-0.96	-1.36	-0.80	-0.74	-0.94	-1.27	-0.89	-0.87	-0.68	0.00	0.03	-1.30
2007/08	0.52	3.25	0.34	0.49	-0.41	-0.48	1.06	-0.93	-0.93	-0.33	-0.67	-0.61	-0.04
2008/09	0.17	-0.32	-0.31	1.89	0.90	0.96	1.47	1.18	1.50	2.60	4.22	4.54	2.33
Average+	0.79	1.05	0.85	0.87	0.93	1.06	0.97	1.00	0.98	1.05	1.02	0.88	0.89
Average -	-0.44	-0.48	-0.68	-0.48	-0.62	-0.70	-0.78	-0.67	-0.66	-0.52	-0.46	-0.53	-0.78

Symbology		
≥ 2 Extremely wet	≤ -2 Extreme drought
1.5 to 1.99 Severely wet	-1.5 to - 1.99 Severe drought
1 to 1.49 Moderately wet	-1 to -1.49 Moderate drought
0 to 0.99 Mildly wet	0 to 0.99 Mild drought

Positive values last till May 1973. Although in the period June-September discharges are below average, the overall hydrological year 1972/73 is extremely wet.

The annual SDI values are mostly negative (10 years), with only 4 barely positive values at the Dimitrovgrad hydrological station, in the period from 1981/82 to 1994/95. The monthly SDI values are even more dominantly negative compared to matching months, especially October and November with only one positive value in 14 years period, followed by August and September with two positive SDI values (Table 2). The SPI values follow this trend (only 5 years with a slightly positive discharge values) and probably are the

Table 4. Monthly and annual Standardized Precipitation Index (SPI) values for the Dimitrovgrad climatological station (1964-2009).

Hyd. Year	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
1964/65	0.51	1.36	-0.97	1.03	1.07	-0.72	0.44	0.17	0.46	-1.04	-0.80	-0.83	0.05
1965/66	-1.24	-0.04	2.15	1.85	1.27	0.07	0.56	-0.89	0.70	-0.45	0.05	-0.64	0.60
1966/67	-0.47	0.47	1.54	-1.01	-0.63	-0.33	0.82	-0.21	0.93	1.48	-0.34	-0.39	0.78
1967/68	-0.43	-0.26	0.05	0.03	-0.06	0.11	-1.97	-0.99	0.57	-1.00	0.22	-0.22	-1.14
1967/69	-1.10	1.79	0.65	0.19	2.94	0.54	-0.47	-0.77	2.70	0.58	-0.69	-0.09	1.91
1968/70	-1.23	-1.27	1.39	-0.17	2.50	0.66	-0.54	2.05	-0.37	1.81	-0.26	-0.71	0.91
1970/71	1.09	-0.95	-0.89	0.50	0.44	1.95	-1.76	0.89	-0.06	-0.09	-0.42	1.44	0.73
1971/72	-1.03	-0.78	-1.05	-0.98	-0.75	-1.59	-0.32	-0.26	-0.51	0.20	0.63	1.97	-1.03
1972/73	2.27	0.04	-1.70	-0.30	0.08	0.01	0.62	-0.46	-0.16	0.36	0.69	-0.08	0.58
1973/74	0.41	-0.38	0.09	-0.11	-0.55	-0.99	0.92	1.70	0.02	-0.31	-0.51	-0.77	-0.13
1974/75	0.55	0.68	0.38	-1.12	-1.11	0.58	-1.08	1.53	1.77	-0.51	0.20	-0.47	0.84
1975/76	1.04	0.32	-1.35	-0.13	-1.49	-1.45	-0.13	0.86	0.57	1.64	0.60	-0.31	0.66
1976/77	-0.53	1.77	0.06	-0.02	0.03	1.36	-0.31	0.41	0.87	0.56	-0.68	-0.52	0.97
1977/78	-1.07	0.67	0.54	-0.20	0.28	3.21	-0.25	-0.54	1.14	-1.11	-0.92	1.92	0.96
1978/79	-1.08	-1.17	0.58	0.52	-0.30	-0.48	0.17	-0.95	-0.41	-0.78	1.18	-0.89	-1.36
1979/80	-0.19	-0.07	-0.98	0.80	-0.90	0.89	-0.31	2.68	0.38	-0.83	0.17	-1.12	0.15
1980/81	0.89	-0.18	1.41	0.08	-0.85	0.33	-0.82	0.32	-0.86	1.01	0.42	-0.01	0.66
1981/82	-0.10	-0.11	-0.06	-1.00	-0.74	0.02	1.41	-0.94	-1.02	1.13	-0.04	-0.18	-0.54
1982/83	-0.02	0.10	0.57	-0.47	-0.46	-1.12	-1.27	-0.97	1.49	0.85	-0.35	0.47	0.11
1983/84	-0.50	-0.16	-0.60	-0.30	0.88	0.26	-0.36	-0.30	-0.45	-0.59	-0.81	-0.90	-1.44
1984/85	-1.19	-0.51	-0.78	1.57	-0.08	-0.26	-0.18	-0.06	-1.19	-0.79	0.14	-1.13	-1.74
1985/86	-0.99	2.72	-1.03	1.50	0.88	-0.36	-0.20	-1.02	-0.38	2.05	-1.46	-1.17	0.11
1986/87	-0.69	-1.47	-0.83	2.70	-0.47	0.33	1.79	0.88	-1.24	-1.48	-0.11	-0.80	-1.07
1987/88	0.02	1.23	0.18	-1.10	0.16	1.75	-0.65	-1.06	0.21	-1.36	-0.21	-0.43	-0.53
1988/89	-0.18	1.17	-0.61	-1.39	-1.50	-1.07	0.36	0.56	0.12	-0.35	-0.34	0.37	-0.53
1989/90	0.19	-0.28	-0.58	-1.20	-0.66	-0.87	1.54	0.12	-1.00	-1.28	-0.42	-0.71	-1.77
1990/91	-0.23	-1.14	2.93	-1.18	1.13	-0.68	1.53	0.58	-0.96	1.09	-0.42	-0.82	0.23
1991/92	0.57	-0.37	-0.56	-1.24	-0.41	-0.99	0.54	-1.08	1.59	2.26	-0.47	-1.08	0.06
1992/93	0.17	0.60	-1.16	-0.80	-0.56	0.16	-0.53	-0.45	-1.46	-1.47	-0.67	-0.22	-2.10
1993/94	-0.94	-0.43	0.40	0.09	-1.34	-0.97	1.32	-0.18	-0.11	-0.03	-1.15	-0.41	-1.23
1994/95	-0.59	-0.98	-0.47	0.57	0.04	-0.24	-0.47	-0.20	2.00	-0.52	0.89	0.25	0.27
1995/96	-1.12	0.61	1.18	-0.55	0.17	0.56	-0.62	-0.40	-1.69	-0.10	0.28	3.28	0.46
1996/97	-0.86	-0.05	1.14	-0.96	-1.07	0.00	0.61	0.29	-1.41	-0.08	0.83	-1.03	-0.97
1997/98	2.20	-0.85	0.09	-0.50	0.54	-0.81	-1.44	-0.91	-0.02	-0.23	-0.36	0.61	-0.30
1998/99	2.21	0.51	-0.61	-0.22	0.62	-1.27	0.75	-0.40	0.37	0.77	-1.19	0.89	1.00
1999/00	0.71	0.00	1.58	0.37	-0.32	-0.63	-0.89	-1.23	-0.94	-1.08	-1.41	-0.30	-1.46
2000/01	-1.08	-1.03	-1.36	-0.20	1.35	-0.11	1.99	0.66	0.20	-0.64	-0.43	2.64	0.44
2001/02	-1.08	-0.95	-0.29	-0.71	-0.78	-0.20	1.13	0.89	-0.82	0.57	2.70	0.56	0.38
2002/03	0.48	-0.68	-0.24	2.60	-0.60	-1.74	0.48	1.90	-1.10	-0.68	-0.52	0.41	-0.03
2003/04	1.75	-0.88	-0.57	0.13	0.27	0.33	-0.94	-0.38	0.65	-0.40	-0.10	0.61	0.31
2004/05	0.65	0.60	-0.25	1.08	1.60	0.10	0.85	1.29	-0.61	-0.21	3.40	0.65	2.67
2005/06	0.28	-0.82	0.63	-0.67	0.45	1.79	-0.35	-1.36	0.11	0.77	1.84	-0.66	0.54
2006/07	-0.02	-0.57	0.03	0.13	-0.46	0.55	-1.82	0.41	-0.83	-1.39	1.94	0.26	-0.54
2007/08	1.87	2.68	-0.77	-0.63	-1.53	0.57	1.00	-1.73	-0.37	0.84	-1.00	0.52	0.71
2008/09	0.11	-0.97	0.13	1.42	0.92	0.76	-1.15	-0.46	1.10	0.83	-0.13	0.05	0.82
Average+	0.90	1.02	0.81	0.90	0.84	0.73	0.94	0.96	0.86	1.04	0.95	0.99	0.66
Average -	-0.72	-0.56	-0.77	-0.66	-0.73	-0.77	-0.75	-0.70	-0.75	-0.70	-0.58	-0.60	-0.99

Symbology		
	≥ 2 Extremely wet	≤ -2 Extreme drought
	1.5 to 1.99 Severely wet	-1.5 to - 1.99 Severe drought
	1 to 1.49 Moderately wet	-1 to -1.49 Moderate drought
	0 to 0.99 Mildly wet	0 to 0.99 Mild drought

cause of the hydrological drought period (Table 4). Even severe or extreme precipitation in some months often cannot increase river discharge significantly.

In the remaining period (from 1995/96 to 2008/09) low and high SDI values alternate, with slightly more (9) above-the-average discharges compared to under-the-average discharges (5). It is also notable that in this period there are many hydrologically extremely wet months (15), in addition to 5 severely wet months. The hydrological year 2004/05 is characterized by the largest SDI value and extreme discharge during the whole study period, and even 5 months (March, April, June, August, and September) are in the category of extremely wet, compared to the corresponding month. High discharge values partially can be explained by high SPI values (Table 4). Another hydrological year that is distinguished by high SDI values, is 2008/09 (Table 2).

In contrast to the Nišava River discharges, which varied a lot during the study period, at the Mrtvine station (Gaberska River) two hydrologically different periods can be distinguished (Table 3). In the period from 1964/65 to 1977/78, positive values of the SDI (12) prevail compared to negative ones (1). During that period, there were 2 hydrologically severely wet years, as well as 4 moderately wet and 6 mildly wet years, while the hydrological 1971/72 year is the only dry year, in the mildly dry years category. In this period, there are many hydrologically extremely wet months (13), as well as 7 severely wet years. Hydrologically dry months are rarer with only two moderately dry months. During the next four years, from 1978/79 to 1981/82, two years with positive and two years with negative SDI values were recorded, but again positive values are more pronounced.

The next period (from 1982/83 to 2008/09) is distinctly dry, with only 5 wet years distinguished by positive SDI values in the mildly wet category. It is noticeable that although negative SDI values dominate, they mostly belong to the mild and moderate drought categories, with only one month value in the severe drought category. Again, although positive SDI values are rare compared to negative ones, extremely high monthly discharges are more common (6 extremely wet months). Precipitation indices partially explain described extended hydrologically dry period, but not to the expected degree. However, the meteorologically driest period (from 1983/84 to 1992/94, Table 4) does coincide with the hydrologically driest period.

The study period at the hydrological station Mrtvine finishes with the highest discharges and only annual SDI value in the extremely wet years category. Monthly SDI values are high including 3 extremely wet, 1 severely wet, and 3 moderately wet months. SPI values show above-the-average precipitation, but not enough to fully explain so high discharges. Even air temperatures, and therefore evaporation, were above the average values.

Hydrological drought monitoring and analysis using SDI values showed that in most cases discharges are "near normal" that is, they belong to the mildly wet or mildly drought category. On an annual basis, 35 out of 45 (77.8%) hydrological years at the gauge station Dimitrovgrad, and 29 out of 45 (64.4%) hydrological years at the gauge station Mrtvine are in this category (Table 5). There are more extreme events that include higher discharges compared to lower discharges. At the hydrological station Dimitrovgrad, two extremely wet and two severely wet years occurred. Similarly, one extremely wet and two severely wet years were recorded at the Mrtvine station. On the other side, considering both hydrological stations, no extreme drought, and only 3 severe droughts at the Dimitrovgrad station occurred.

Analysis of monthly SDI values shows a similar tendency. Many more hydrologically dry months occurred during the study period compared to hydrologically wet years (Table 5). In total, Dimitrovgrad hydrological station shows negative SDI values for 342 out of 540 months (63.3%). Mrtvine hydrological station shows below-the-average discharges in 336 out of 540 months (62.2%). Extreme positive values are much more common. Extremely wet hydrological months are recorded at Dimitrovgrad station 28 and at Mrtvine 24 times. Severely wet months occurred at Dimitrovgrad and Mrtvine stations 13 and 17 times, respectively. Again, no extreme drought and just one severe hydrological drought were recorded in Dimitrovgrad, and one in Mrtvine. Extreme discharges occur more often because of high precipitation that can happen in a relatively short period, or throughout a longer period. Another reason is snow melting which can fastly increase the amount of water in the river bed or even a combination of rainfalls and snow melting. Extreme monthly SDI values occur during the whole year and are caused by the different reasons mentioned above.

Positive SDI values are rarer compared to negative values but they are more expressive. In Tables 2 and 3 we can see that the average positive values are predominantly higher than negative values, at both Dimitrovgrad and Mrtvine hydrological stations.

On an annual basis, positive SPI values for the Dimitrovgrad climatological station occur more often, but the difference is not that expressed. On the other side, climatologically drought years are a little more extreme compared to wet years (Tables 4, 5). On the monthly level, drought months (306 out of 540, or 56.7%) are more numerous than wet months (234 out of 540, or 43.3%). Also, there were 22 extremely wet months and 28 severely wet months, but only 9 severely dry and no extremely dry months in the study period. This shows that dry periods last longer and that precipitation often occurs as a more extreme event.

In Figure 3 we can observe low-discharge and high-discharge periods over the study period. Until 1981/82, SDI/discharge values are mostly positive, and from 1986/87 to 2003/04, mostly negative. One of the most important benefits of using standardized values is the possibility to compare discharges in two or more different river basins. In most years (29 ot of 45, or 69%), SDI values for Dimitrovgrad and Mrtvine hydrological stations are both positive or negative. In 16 ases when one SDI value is positive and the other one is negative, the average difference is 0.96. Sub-basins of the Nišava and the Gaberska River are neighboring and in many ways alike (geology, soil, vegetation, altitude, slopes) so one might expect even more similarities in river discharges over time. However, both sub-basins are small in area, vegetation is degraded, river courses are unregulated, and tributaries' basin slopes are steep, which results in the torrential nature of the rivers (Đokić et al., 2015). Torrential flows, as well as small and medium basins, are very sensitive to local precipitation (Blagojević et al., 2013), which can lead to an increase in discharge in only one of the two sub-basins. Discharge differences in winter and early spring periods can be explained by slightly higher altitudes in the part of the Nišava River Basin, which can cause later snow melting.

Table 5. The number of different SDI values for hydrological stations Dimitrovgrad and Mrtvine, and SPI values for meteorological station Dimitrovgrad (from 1964/65 to 2008/09).

SDI values - Mrtvine	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year	Month sum
≥ 2 Extremely wet	1	2	2	1	3	1	1	2	2	4	2	3	1	24
1.5 to 1.99 Severely wet	1	2	0	1	0	4	3	2	2	1	1	0	2	17
1 to 1.49 Moderately wet	1	1	2	2	2	4	5	4	4	0	2	1	4	28
0 to 0.99 Mildly wet	13	9	16	12	13	9	11	10	10	10	9	13	14	135
0 to 0.99 Mild drought	29	28	17	29	24	18	18	25	24	30	31	28	15	301
-1 to -1.49 Moderate drought	0	3	7	0	3	9	7	2	3	0	0	0	9	34
-1.5 to - 1.99 Severe drought	0	0	1	0	0	0	0	0	0	0	0	0	0	1
≤ -2 Extreme drought	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	45	45	45	45	45	45	45	45	45	45	45	45	45	540

SDI values - Dimitrovgrad	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year	Month sum
≥ 2 Extremely wet	1	3	3	2	2	2	2	2	3	3	2	3	2	28
1.5 to 1.99 Severely wet	0	0	1	2	2	3	2	0	1	1	0	1	2	13
1 to 1.49 Moderately wet	3	1	4	2	1	2	5	2	3	0	1	2	3	26
0 to 0.99 Mildly wet	4	8	9	12	13	13	12	17	12	10	11	10	16	131
0 to 0.99 Mild drought	37	33	21	22	22	17	17	21	17	31	31	26	19	295
-1 to -1.49 Moderate drought	0	0	7	5	5	8	6	3	9	0	0	3	0	46
-1.5 to - 1.99 Severe drought	0	0	0	0	0	0	1	0	0	0	0	0	3	1
≤ -2 Extreme drought	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	45	45	45	45	45	45	45	45	45	45	45	45	45	540

SPI values - Dimitrovgrad	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year	Month sum
≥ 2 Extremely wet	3	2	2	2	2	1	0	2	2	2	2	2	1	22
1.5 to 1.99 Severely wet	2	2	2	3	1	3	4	3	2	2	2	2	1	28
1 to 1.49 Moderately wet	2	3	4	3	4	1	4	1	3	4	1	1	1	31
0 to 0.99 Mildly wet	13	10	14	11	14	18	12	13	14	10	12	12	24	153
0 to 0.99 Mild drought	15	23	17	18	18	16	18	20	17	19	23	23	8	227
-1 to -1.49 Moderate drought	10	5	5	8	5	4	4	5	6	8	5	5	7	70
-1.5 to - 1.99 Severe drought	0	0	1	0	1	2	3	1	1	0	0	0	2	9
≤ -2 Extreme drought	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Total	45	45	45	45	45	45	45	45	45	45	45	45	45	540

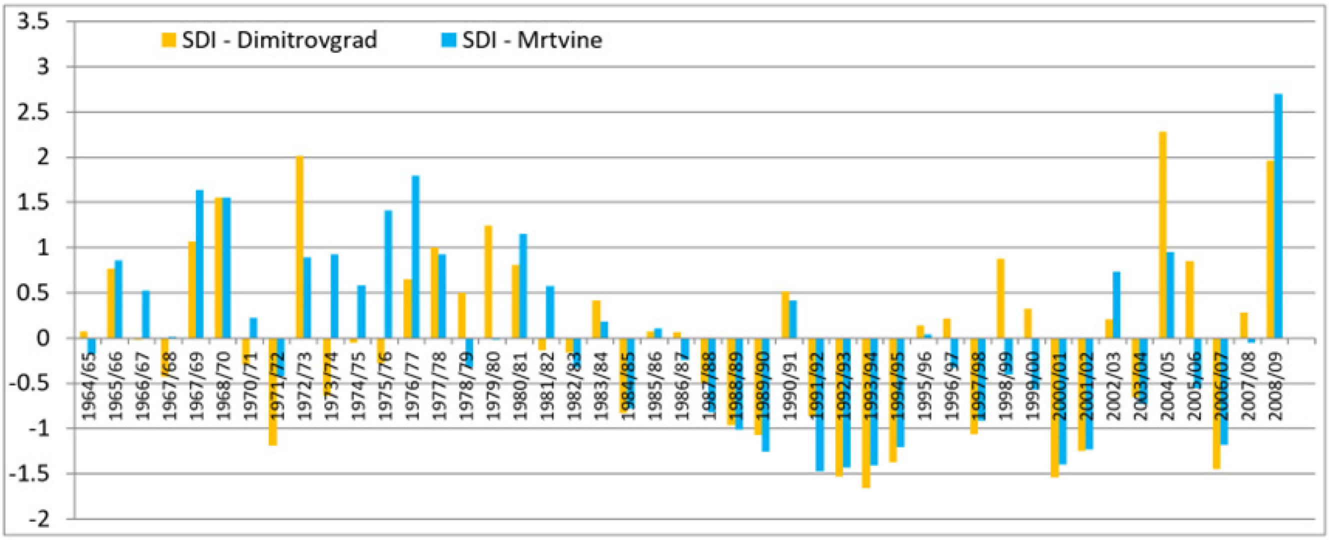

Figure 3. Comparative display of annual SDI values at hydrological stations Dimitrovgrad and Mrtvine for the period 1964-2009.

5. Conclusion

It is noticeable that although some hydrological years are severely or even extremely wet, often some periods within years are characterized by below the average discharge. And the opposite, although some hydrological years are severely or extremely dry, some periods may be characterized by the above-the-average discharge.

It showed up that in some extended dry periods even extreme or severely wet months cannot produce high river discharge in the long term. That is probably caused by very dry soil which absorbs a large amount of precipitation and reduces the inflow of precipitation to the river beds.

Hydrological drought is strongest when the dry period covers the entire hydrological year or most of it, although the monthly drought values do not have to be extreme or severe. Hydrological drought is less notable compared to hydrologically wet years. In other words, extremely high discharge events occur more often compared to extremely low discharge values. In general, there are more hydrologically dry years in which drought months distinctly dominate compared to wet months. Hydrologically wet years with noticeably more wet months than drought months are rare.

It is noticeable that often discharges cannot be clearly explained using only SDI, SPI, and temperature values. Yet, the study showed that precipitation is the most important factor that affects discharges. Also, we can assume that a big problem for a more accurate analysis of river discharges using standardized indices is the lack of precipitation stations, especially at higher altitudes. Local showers can cause a sudden increase in discharge without being registered at all at the existing climatological stations. The occurrence of long-term precipitation over significant areas of the river basin is also possible, and again not being noticed and measured at the currently existing stations.

The study showed that two neighboring and by physical–geographical characteristics similar rivers could have significant differences in discharge. There are similarities, but the differences are significant.

It has been shown that due to standardized values SDI and SPI are good indicators that can be used to compare river discharge in different basins.

Acknowledgements

This paper was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia contracts 451-03-68/2022-14/200017, 451-03-68/2022-14/200124 and 451-03-47/2023-01/200124.

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