Chapter 11
Spatio-Temporal Distribution of Hydrological and Meteorological Droughts in the South Morava Basin

Slaviša Trajković, Milan Gocić, Danilo Misic and Mladen Milanovic

Abstract Over the years, the appropriateness of selection and application of drought indices in a particular climate area have been discussed. A number of drought indicators have been defined for each type of drought (meteorological, hydrological, agricultural) based on different measured data. The Standardized Precipitation Index (SPI) and the Streamflow Drought Index (SDI) were used to establish the association between meteorological and hydrological droughts. Based on the availability, type and accuracy of data, SPI and SDI are the simplest indices to obtain. This paper analyzes the different ways of processing drought data for the South Morava basin in a GIS environment. The largest agricultural drought was recorded in 2007 and because of that this year was selected for the drought analysis. The intensity of the SPI index for the year 2007 was calculated based on monthly precipitation data from eight meteorological stations in the South Morava basin. The SDI data for the year 2007 are provided for 16 hydrological stations. The paper compares the results of meteorological and hydrological droughts in the South Morava basin for the year 2007. The data were processed in the Quantum GIS software package and as a result visualisation of spatial data on meteorological and hydrological droughts was obtained in order to be applied in drought monitoring at the regional level.

Keywords Meteorological drought · Hydrological drought · SPI · SDI · Quantum GIS

11.1 Introduction

Although it has been thought that Serbia could be classified as one of the most promising countries in Europe and the world by water wealth, but due to underdeveloped irrigation systems and lack of water treatment systems, we are witnesses of the devastating effects of droughts on agricultural production. Also, there are frequent

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M. Gocić et al. (eds.), *Natural Risk Management and Engineering*, Springer Tracts in Civil Engineering, https://doi.org/10.1007/978-3-030-39391-5_11

restrictions in water supply to the population and industry even in low-water periods that do not fall into the category of hydrological droughts.

Drought is caused by changes in climate that have been transmitted through the hydrological cycle, occurring in all climatic zones, but without the clear definition in its occurrence (Nguvava et al. 2019; Lavaysse et al. 2018; Parente et al. 2019). It can be classified as meteorological, hydrological, agricultural, and socio-economic drought (Wilhite and Glantz 1985). The meteorological drought occurs as the first one because of the reduced precipitation compared to the average precipitation in previous years, causing then agricultural and hydrological droughts (Park et al. 2018). The socio-economic consequences of drought depend on the current status in the areas of water resources management and on the use of water and land.

A number of quantitative indicators i.e. drought indicators have been developed in order to determine the intensity, duration and frequency of drought (Svoboda and Fuchs 2016). The determination of drought is especially important in arid and semi-arid regions, where availability of measured data is usually limited. In order to achieve the best selection of drought indicators, the relative low data requirements should exist. Also, an indicator should be applied easily in many regions providing a clear presentation of the results that can be used efficiently in decision making (Hao et al. 2019; Sun et al. 2019).

Considering these criteria, the following indicators have been created for different types of droughts: Reconnaissance Drought Index (RDI), Streamflow Drought Index (SDI), Standardised Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI) and Water Surplus Variability Index (WSVI). RDI, SPI, SPEI and WSVI are used for quantification of meteorological drought, because their main component is precipitation. Also, RDI, SPEI and WSVI can be used for analyzing agricultural drought, because they can describe adequately water balance including reference evapotranspiration in their calculation (Tsakiris and Vangelis 2005; Vicente-Serrano et al. 2010; Gocic and Trajkovic 2014b).

According to the World Meteorological Organisation (WMO), meterological services all over the world should apply SPI index (WMO, 2012). Using the SPI index, it is possible to analyze drought at different intervals such as 1, 3, 6, 9, 12 and 24 months. In Serbia, the Republic Hydrometeorological Service of Serbia (RHMSS) has determined the SPI values based on the amount of precipitation measured in the previous 30, 60 and 90 days since 2010. Also, it presents moisture conditions in the form of map and table per each meteorological station and can be a first step in developing an early warning system. More detailed analyzes of drought based on the SPI index for stations in Serbia can be found in Gocic and Trajkovic (2013a, b, 2014a) and Tosic and Unkasevic (2014).

The main disadvantage of the SPI index is that it cannot detect drought in the case of normal rainfall or due to the increased evapotranspiration or to show increased humidity conditions at high rainfall intensity over a short time interval (Frank et al. 2017). However, the SPI is based on a statistical approach, does not require climate adjustment and allows comparison of its values from region to region.

Hydrological drought is associated with the occurrence of reduced water in rivers and in different reservoirs such as lakes, groundwater, and artificial reservoirs. The intensity of the hydrological drought is most commonly defined at the basin level. It occurs with a significant delay compared to the meteorological and agricultural droughts because it is needed more time to deal with the effects of precipitation shortages in the hydrological system in the form of reduced soil moisture, or reduced water levels in rivers and lakes. Precipitation can cause decreasing in soil moisture, which can be immediately noticeable, but it will affect the runoff in rivers and water management systems in a few weeks or months. In addition to the weather as the primary cause of hydrological drought, the human factor also affects the hydrological characteristics of the basin using land and inappropriate infiltration and runoff intensity. The indicators used for hydrological drought analysis are the Palmer Hydrological Drought Index (PHDI) or Surface Water Supply Index (SWSI), which generally require more data and are more complicated for calculation (Jacobi et al. 2013; Doesken and Garen 1991). The Streamflow Drought Index (SDI) requires minimal input and is simple for the determination (Malik et al. 2018; Tabari et al. 2013).

The key objectives of this research are to calculate drought severity using SPI and SDI at eight meteorological and 16 hydrological stations, respectively, to consider spatial and temporal variability of hydrological and meteorological droughts at South Morava Basin during the year 2007.

11.2 Analysed Study Area and Its Characteristics

Serbia is located in the Balkans, the region of Southeast Europe, but also it is a part of Mediterranean countries considering geographical and climatic characteristics (Fig. 11.1a).

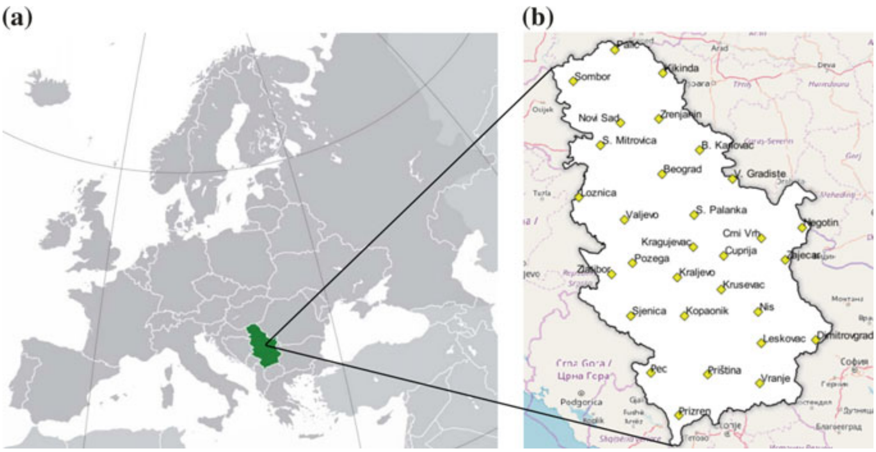

Fig. 11.1 **a** Position of Serbia in Europe, **b** locations of analyzed meteorological stations

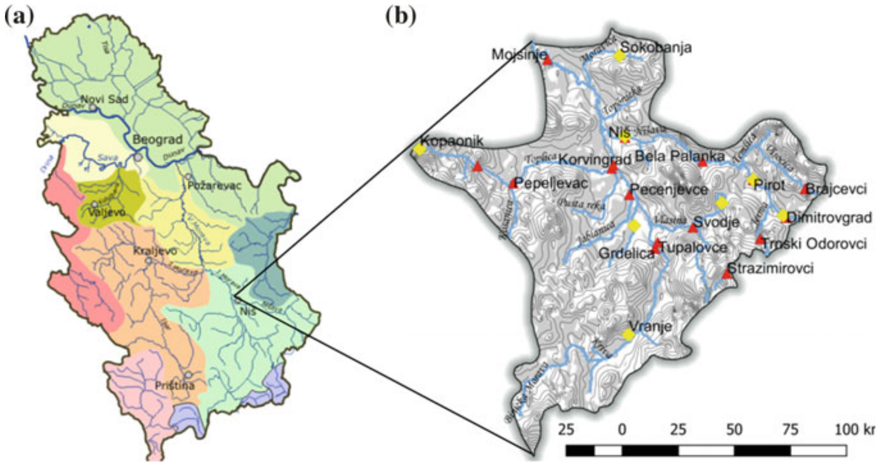

Fig. 11.2 **a** Main river basins in Serbia, **b** South Morava river basin

The climate of Serbia is moderately continental and depends on geographical location, relief and local influence. Two relief parts of Serbia can be identified, the northern part with plains, and the southern part with mountains forming a mountainous region (Trajkovic et al. 2019). The following geographical characteristics directly influence the climate of Serbia: the Alps, the Mediterranean Sea, the Pannonian Plain, the valley of the Morava River, Carpathian and Rhodope mountains (Stojkovic Piperac et al. 2018). The geographical locations of analyzed meteorological stations are presented in Fig. 11.1b.

In Fig. 11.2 the South Morava river basin with the drainage area of 15,696 km^2 is presented. It is located in the south of the Danube river basin connecting Aegean with the Pannonian basin. The South Morava river is 319 km long creating the Great Morava river with the West Morava river. Two most important tributary rivers are the Toplica and the Nisava that springs in western Bulgaria. The temperate-continental climate in this area depends on Vlasina climatic area and the valley of the river Nisava in the north and is characterized by low precipitation, mild winters and very hot summers.

11.3 Applied Drought Indices

11.3.1 Standardized Precipitation Index

In order to quantify precipitation deficit over different time periods i.e. 1, 3, 6, 9, 12 and 24-month periods, the Standardized Precipitation Index (SPI) was developed (McKee, 1993). The SPI index is based on the fact that the typical probability density

Table 11.1 Drought classification based on the SPI index

Drought class	SPI value
Exceptionally wet	SPI ≥ 2.326
Extremely wet	1.645 ≤ SPI < 2.326
Considerably increased moisture	1.282 ≤ SPI < 1.645
Moderately increased moisture	0.935 ≤ SPI < 1.282
Slightly increased moisture	0.524 ≤ SPI < 0.935
Near normal	−0.524 ≤ SPI < 0.524
Minor drought	−0.935 ≤ SPI < −0.524
Moderate drought	−1.282 ≤ SPI < −0.935
Severe drought	−1.645 ≤ SPI < −1.282
Extreme drought	−2.326 ≤ SPI < −1.645
Exceptional drought droughtdrdroughtdrought	SPI ≤ −2.326

distribution of precipitation for a given period of time is not symmetrical, but rather inclines to higher values of precipitation. Abramowitz and Stegun (1964) proposed using approximations for its calculation, transforming the cumulative probability into a standard normal random variable Z:

$$Z = SPI = \begin{cases} -\left(t - \frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right), t = \sqrt{ln\frac{1}{(H(x))^2}} 0 < H(x) \le 0,5 \\ +\left(t - \frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right), t = \sqrt{ln\frac{1}{(1-H(x))^2}} 0,5 < H(x) \le 1,0 \end{cases} \tag{11.1}$$

where $c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$. Deviations must be normalized both in time and space in order to obtain a relevant drought assessment. Drought in a time period x is defined as a period in which the value of SPI is continuously negative and SPI takes a value of −1 and less (McKee et al. 1993, 1995). The drought begins when the SPI value is below zero for the first time and ends when the SPI value becomes positive. The drought classification based on the SPI index is presented in Table 11.1.

11.3.2 Streamflow Drought Index

Nalbantis (2008) and Nalbantis and Tsakiris (2009) introduced Streamflow Drought Index (SDI) for the hydrological drought analysis. If a time series of monthly runoff $Q_{i,j}$ is available, in which i denotes the hydrological year, and j is the month within that hydrological year (j = 1 for October and j = 12 for September), then the cumulative runoff volume $V_{i,k}$ can be calculated for the i-th hydrological year of the k-th reference period, k = 1 for the period October–December, k = 2 for October–March, k = 3

Table 11.2 Drought classification based on the SDI index

Drought class	Description	SDI value
0	Non-drought	SDI $\geq$ 0.0
1	Mild drought	$-1.0 \leq$ SDI < 0.0
2	Moderate drought	$-1.5 \leq$ SDI < -1.0
3	Severe drought	$-2.0 \leq$ SDI < -1.5
4	Extreme drought	SDI < -2.0

for October–June, k = 4 for the period October–September. The SDI is determined for each reference period k and i-th hydrological year as:

$$SDI_{i,k} = \frac{V_{i,k} - \bar{V}_k}{s_k} \quad i = 1, 2, \ldots, \quad k = 1, 2, 3, 4 \tag{11.2}$$

The drought classification based on the SDI index is presented in Table 11.2.

11.4 Drought Analysis

In this paper, the precipitation data from 16 stations of the observed basin for the reference period 1961–2011 were used. Data for the four most significant stations (Vranje, Nis, Dimitrovgrad and Kopaonik) for the year 2007, one of the driest year, are presented in Fig. 11.3.

At all stations except Kopaonik, the highest monthly precipitation occurred in October and November. The highest precipitation at the Kopaonik station was measured in May (Gocic et al. 2016). The SDI values are shown as histograms in Fig. 11.4.

The use of GIS software packages can improve the representation of hydrological processes such as evapotranspiration and droughts (Ramirez-Cuesta et al. 2017; Thenkabail and Rhee 2017). The Quantum GIS 3.0.1 open source software package was used for the spatial presentation of meteorological and hydrological droughts. At the very beginning, the EPSG:4326-WGS 84 was selected as the reference coordinate system. The procedure consists of two separate parts. In the first part, a map of the Earth was loaded and a layer related to the borders of the territory of Serbia and the borders of the South Morava basin was created. In the second part, layers for the locations of meteorological and hydrological stations were created, calculated values of SPI and SDI were loaded, and data for drought representation were interpolated (Fig. 11.5).

The meteorological drought results based on the SPI values and the hydrological drought results based on the SDI values for the 12-month period are presented in Fig. 11.6. The SPI values for the year 2007 were determined using precipitation from eight meteorological stations in the South Morava basin (Vranje, Leskovac, Babusnica, Dimitrovgrad, Pirot, Nis, Sokobanja and Kopaonik). The SDI values for

Fig. 11.3 Precipitation in the South Morava basin in the year 2007

the year 2007 were calculated for the 16 hydrological stations in the South Morava basin. Based on these achieved data, the hydrological drought was compared with the meteorological drought at the basin level.

A rough network of meteorological stations also affects the accuracy of the data as well as the fact that certain hydrological stations are located in sub-basins at the national border. Only the Kopaonik station is at the border of the basin, while the others are concentrated towards the center of gravity of the basin. The hydrological stations, from which the data were used, are also distributed to the interior of the basin, except the Brajcevci, Dimitrovgrad, Trnski Odorovci and Strazimirovci stations.

Due to unavailability of data for precipitation and runoff from neighboring countries, it is not possible to get a more accurate presentation of the drought. As a consequence, there are some deviations in the occurrence of hydrological drought after meteorological e.g. for the period of October–December; SDI-12 values show severe drought although SPI-12 values show normal or increased humidity conditions for the same period (Fig. 11.6).

A comparative analysis of meteorological and hydrological droughts during the year 2007 in the South Morava basin is given respectively in Figs. 11.7 (1-month period), 11.8 (3-month period), 11.9 (6-month period) and 11.10 (12-month period). Moderate drought intensity occurs in the period of March–September, except for the month of April when the hydrological drought reaches the category of severe or extreme drought (Fig. 11.7).

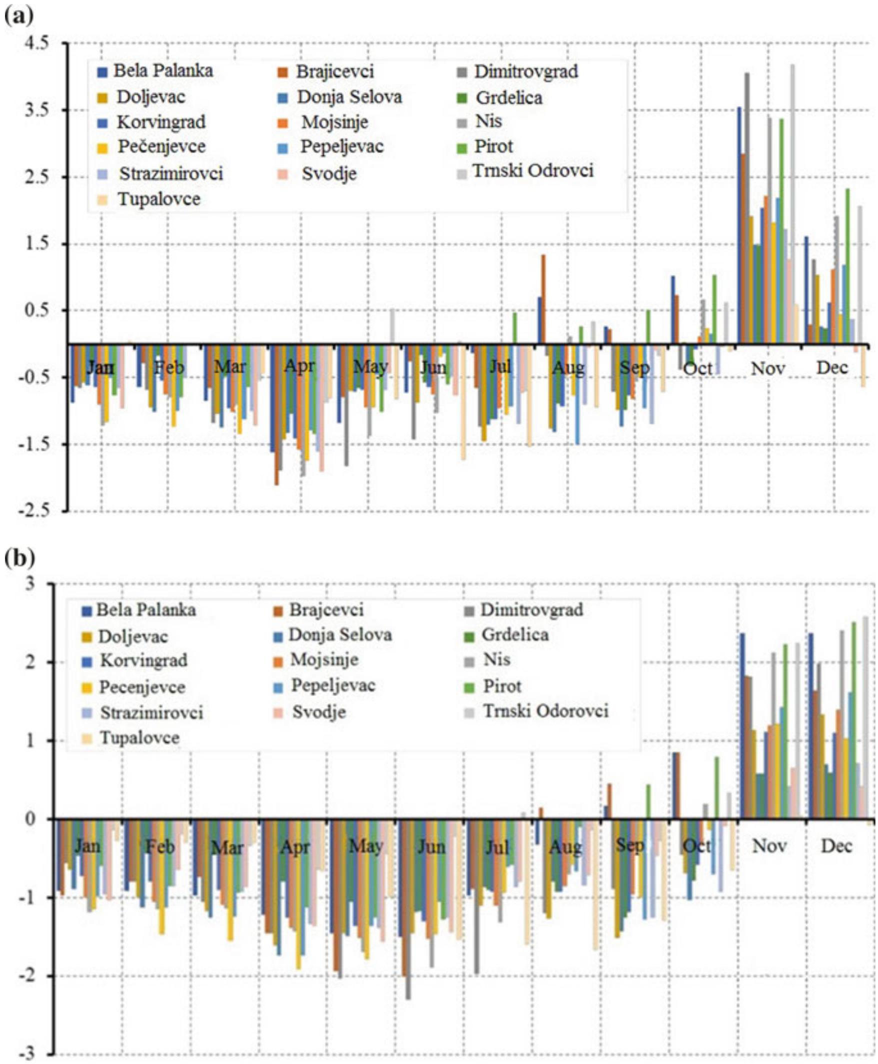

Fig. 11.4 Histogram of SDI values in the South Morava basin for the year 2007: **a** SDI-1, **b** SDI-3, **c** SDI-6 and **d** SDI-12

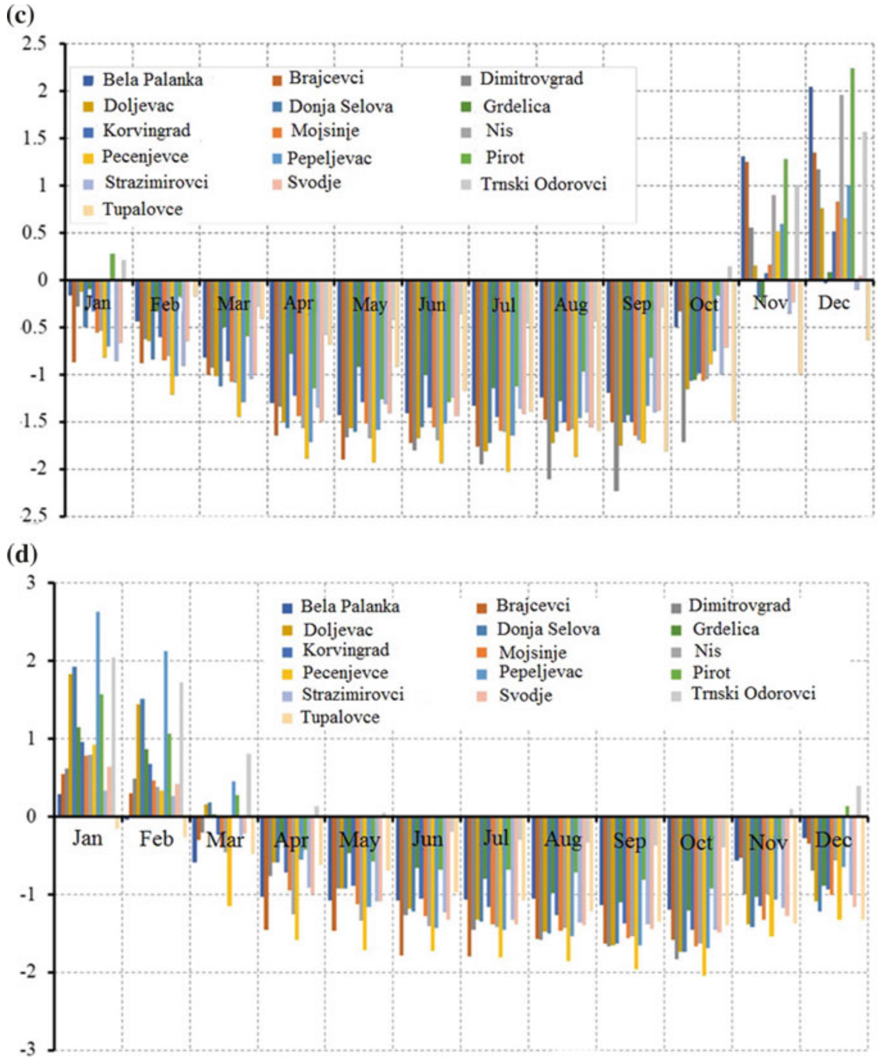

Fig. 11.4 (continued)

It can be seen from Fig. 11.8 that the hydrological drought is more intense than the meteorological one. According to the SPI-3, the humidity conditions are normal or increased throughout the whole year except in April and August when the meteorological drought is of high intensity while the hydrological drought is more intense during the period January–October, but does not exist during November and December.

The meteorological drought during the period of April–September is of high or extreme intensity in April and July (Fig. 11.9). During other months in the vegetation

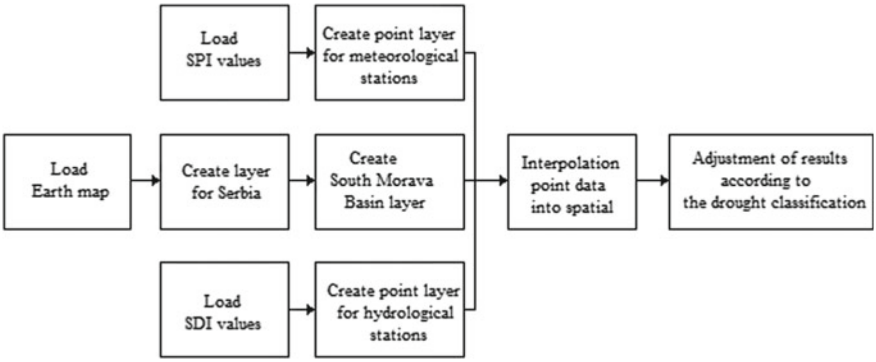

Fig. 11.5 Data processing process in GIS

period, humidity conditions are normal or extremely increased at the Pirot station. Moderate drought occasionally occurs locally in the area of Nis station. Considering the hydrological drought, it has moderate or strong intensity in the period of March–October, except for June when it is not present, as well as in November and December, when the values of the meteorological drought are severely or extremely increased.

According to the SPI-12, the meteorological drought in the basin of the South Morava during the vegetation period of April–September had moderate or strong intensity only during August and September, while it occurs as moderate in the northern part of the basin in July (Fig. 11.10). During other months, the values of meteorological droughts range from normal to severely increased during the winter months in the area of Pirot and Kopaonik stations. There is no hydrological drought from January to March, while in the period of April–December it is uniformly distributed throughout the basin when its intensity ranges from moderate to severe hydrological drought.

It can be further observed from Figs. 11.9 and 11.10 that the occurrence of hydrological drought based on SDI-6 and SDI-12 is mainly oriented around the very course of the South Morava River, and most intensively around the hydrological station Pecenjevce, located upstream of the Toplica and Nisava rivers which are the main tributaries of the South Morava. The reason is that the lack of precipitation in the basin causes a lower amount of flow in the tributary rivers which results in the most pronounced deficit in the main river flow in the basin.

11.5 Conclusions

The aim of this research is to present the spatio-temporal distribution of hydrological and meteorological droughts in the South Morava basin using the capabilities of GIS software. The methodology was based on the use of two drought indicators, Standardized Precipitation Index and Streamflow Drought Index.

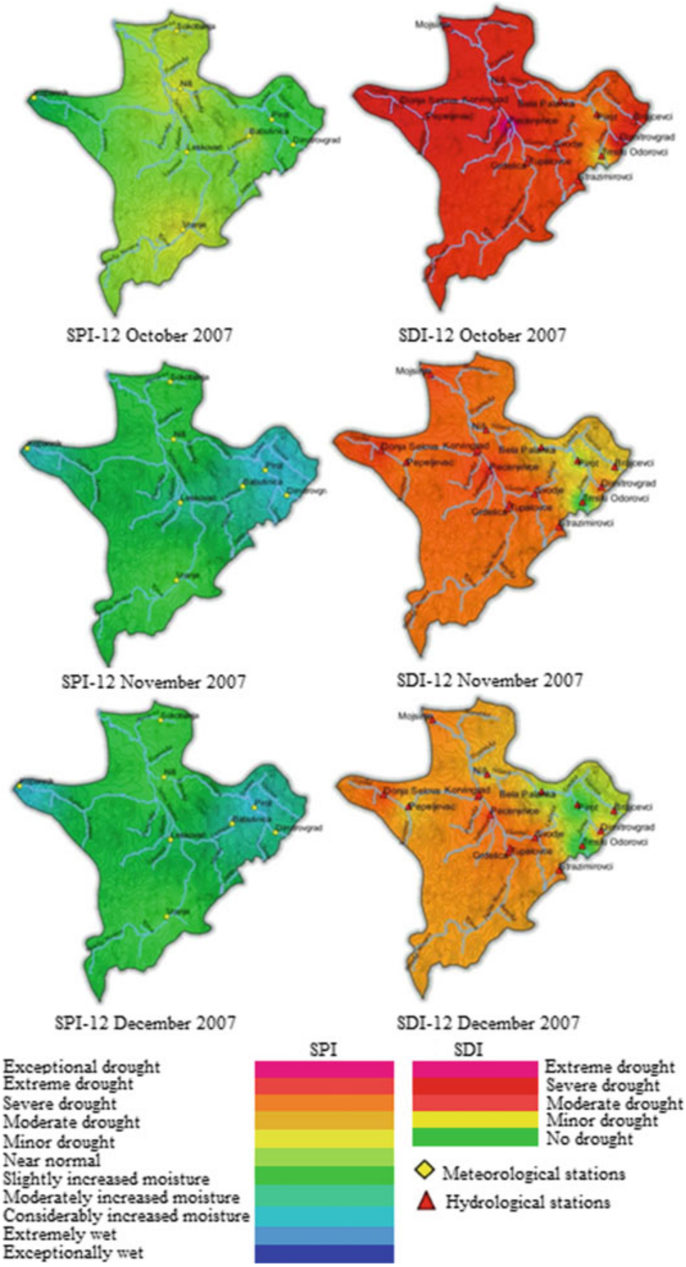

Fig. 11.6 SPI-12 and SDI-12 values for the period October–December 2007 in the South Morava basin

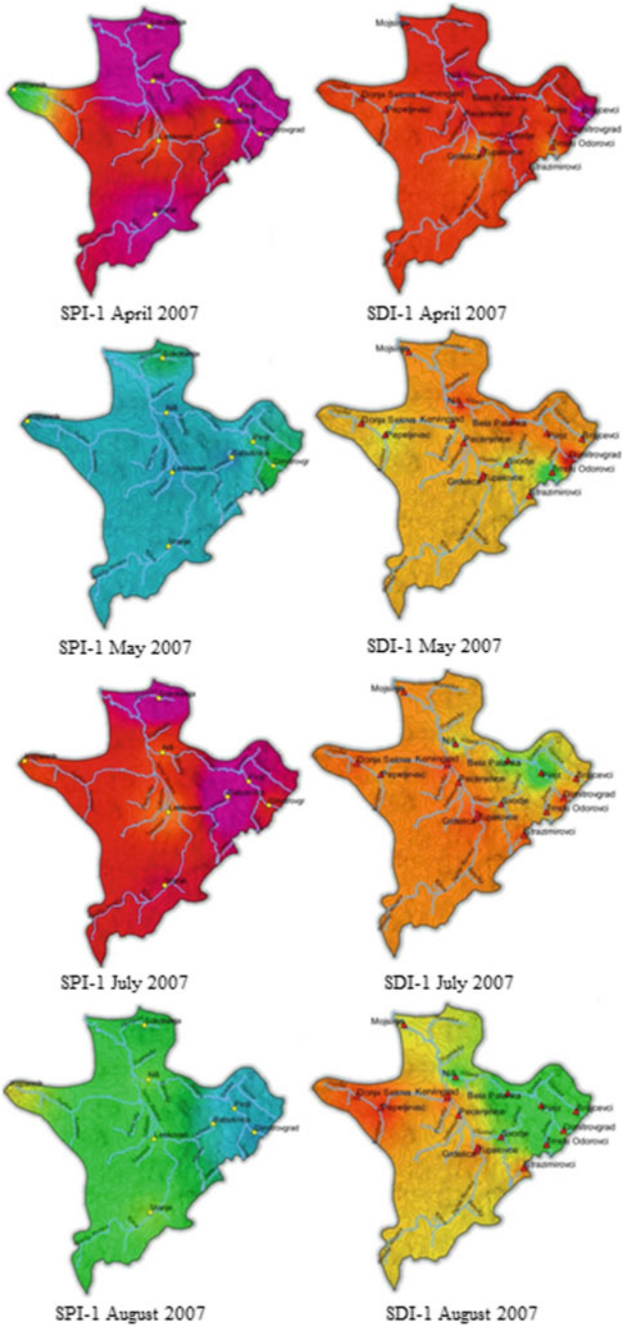

Fig. 11.7 Comparison of meteorological and hydrological droughts in the South Morava basin for the year 2007: SPI-1 and SDI-1 values

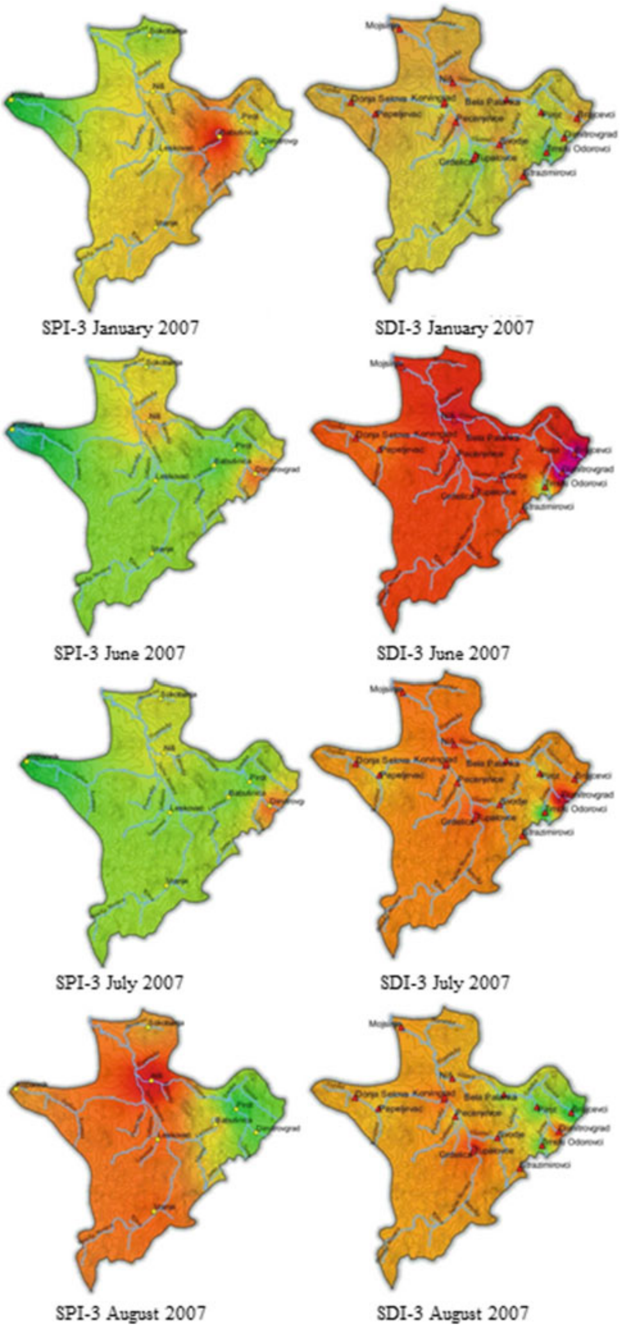

Fig. 11.8 Comparison of meteorological and hydrological droughts in the South Morava basin for the year 2007: SPI-3 and SDI-3 values

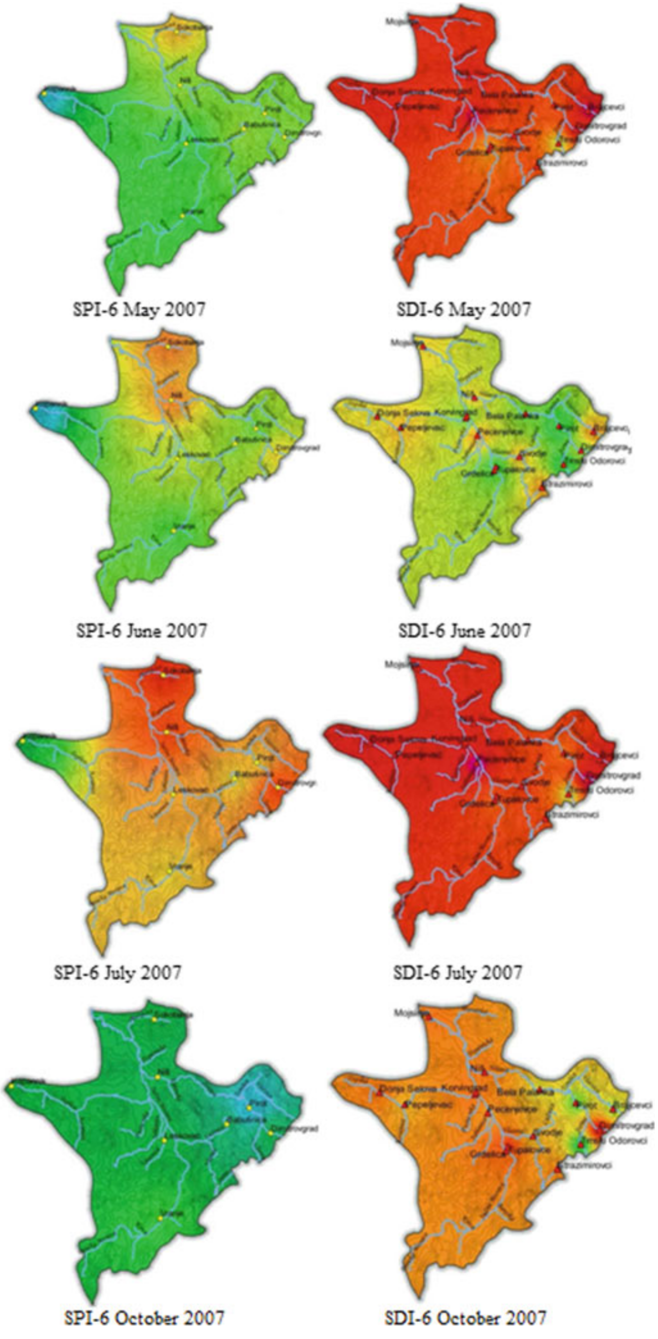

Fig. 11.9 Comparison of meteorological and hydrological droughts in the South Morava basin for the year 2007: SPI-6 and SDI-6 values

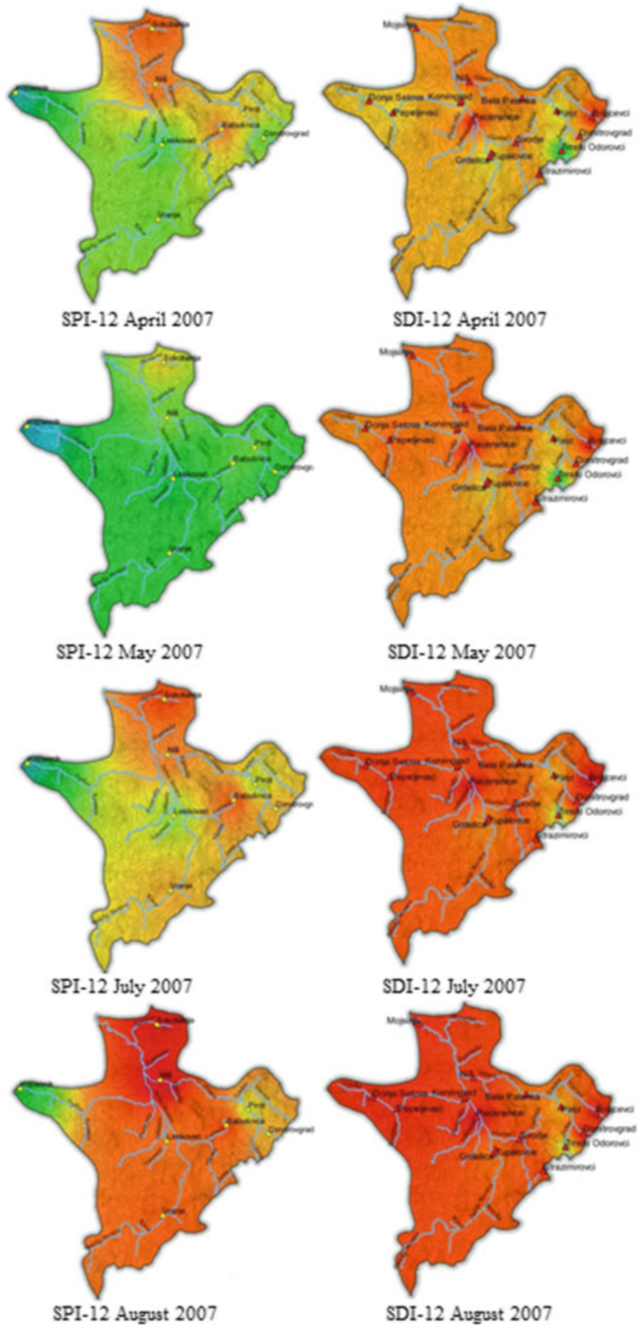

Fig. 11.10 Comparison of meteorological and hydrological droughts in the South Morava basin for the year 2007: SPI-12 and SDI-12 values

In the year 2007, the methodology was implemented to analyze the occurrence of hydrological drought as a consequence of meteorological drought. According to the SPI-3 values, the humidity are normal or increased throughout the year except in April and August. According to the SDI-3 values, the hydrological drought had high intensity while it has more intense during the period of January–October. By analysing the SPI-6 values, it can be concluded that the meteorological drought had high or extreme intensity in April and July, while using the SDI-6 values the hydrological drought had is moderate or heavy intensity in the period of March-October except for June.

According to the SPI-12 values, meteorological drought had moderate or severe intensity only during August and September, while it occurs as moderate in the northern part of the basin in July. Moderate to severe hydrological drought is uniformly distributed throughout the basin between April and December. The occurrence of a hydrological drought based on SDI-6 and SDI-12 is mainly oriented around the very course of the South Morava River, and is most intense around the hydrological station Pecenjevce.

The research also showed that the QGIS can be used adequately for the spatial presentation of drought values. Integration of data involving GIS application can have purpose in spatial planning and in integrating water resources management.

Acknowledgements The study is supported by the Ministry of Education, Science and Technological Development, Republic of Serbia (Grant No. TR37003), Bilateral science and technological cooperation program between Serbia and Hungary (Grant No. 451-03-02294/2015-09/10) and Serbian Academy of Sciences and Arts Branch in Nis (Grant No. O-15-18).

Conflict of Interest The authors declare that they have no conflict of interest.

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