www.gi.sanu.ac.rs, www.doiserbia.nb.rs
J. Geogr. Inst. Cvijic. 2020, 70(2), pp. 89–100

Original scientific paper

UDC: 911.2:551.577(497.11)
https://doi.org/10.2298/IJGI2002089L

Received: January 12, 2020
Reviewed: July 7, 2020
Accepted: July 14, 2020

HYDROLOGICAL DROUGHT ASSESSMENT OF THE TISZA RIVER

Igor Leščešen[1], Dragan Dolinaj[1], Milana Pantelić[1], Tamás Telbisz[2], György Varga[2]*

[1]University of Novi Sad, Climatological and Hydrological Research Center, Novi Sad, Serbia; e-mails: igorlescesen@yahoo.com, dragan.dolinaj@dgt.uns.ac.rs, milanap@dgt.uns.ac.rs
[2]Eötvös Loránd University, Institute of Geography and Earth Sciences, Department of Physical Geography, Budapest, Hungary; e-mails: telbisztom@caesar.elte.hu, varga.gyorgy@csfk.mta.hu

Abstract: Drought is a natural phenomenon that occurs when the availability of water is significantly below the normal levels during a shorter or longer period of time and cannot meet the necessary demand. This study focused on hydrological drought assessment of the Tisza River on four gauging stations: Vásárosnamény, Szolnok, Szeged, and Senta for the period 1964–2018. An effective Streamflow Drought Index (*SDI*) has been recently proposed and widely used for determining hydrological droughts. Both long- and short-term droughts have very severe impacts on the investigated locations. Two drought periods can be singled out: the first period was from 1983 to 1993, with the exceptions in 1985 and 1987. This period is characterized by higher absolute *SDI* values on Vásárosnamény (–0.84) and Szolnok (–0.87) than on Szeged (–0.29) and Senta (–0.40) stations. The second period was more severe and lasted from 2011 to 2015, with an average *SDI* value of –1.32 on Vásárosnamény, –1.08 on Szolnok, –0.53 on Szeged, and –0.57 on Senta station. The Mann-Kendall test results indicate that there is no trend indicating transition from humid towards more arid condition over the investigated period.

Keywords: drought; Streamflow Drought Index; Tisza River; Serbia; Hungary

Introduction

Drought is a natural hazard that is related to a significant decrease of water availability during a shorter or longer period of time. Drought can affect people's activities and lives, and can have a great influence on the environment and earth's ecosystems (Soleimani Sardou & Bahrenabd, 2014). Droughts have attracted the attention of scientists from different fields of science such as geographers, ecologists, hydrologists, meteorologists, agricultural scientists, etc. Although there is not any universal definition of drought in the most general sense, drought can be defined with different disciplinary perspectives, such as meteorological, agricultural, hydrological and socioeconomic drought (Tigkas, Vangelis, & Tsakiris, 2015; Yang, 2010). The main cause of droughts is the decrease of precipitation, which further leads to a reduction of storage volumes and fluxes that are involved in the hydrological cycle (Beran & Rodier, 1985). Drought indicators are mainly based on the application of the physical datasets such as streamflow, rainfall, groundwater, soil moisture and reservoir storage, and they are usually classified as hydrological, meteorological, and agricultural drought indicators (Wable, Jha, & Shekhar, 2019).

*Corresponding author, e-mail: igorlescesen@yahoo.com

Different hydrological variables can be used to describe droughts, but streamflow is the most significant variable from the aspect of quantity of water. That is why a hydrological drought is related to streamflow deficit relative to normal conditions. Droughts can be defined by four distinctive characteristics: its severity (expressed by a drought index), its time of onset and duration, its areal extent, and its frequency of occurrence (Soleimani Sardou & Bahrenabd, 2014). To this end, Nalbantis and Tsakiris (2009) developed the streamflow drought index (*SDI*). The *SDI* was used for estimating hydrological droughts all over the world, from the Achaia and Korinthia Prefectures in Northern Peloponnese in Greece (Tigkas, Vangelis, & Tsakiris, 2012), the northwest of Iran (Tabari, Nikbakht, & Hosseinzadeh Talaee, 2013), on the Yangtze River in China (Li, Xiong, Dong, & Zhang, 2013), the Diyala River Basin that is shared between Iran and Iraq (Al-Faraj, Scholz, & Tigkas, 2014). In Europe, *SDI* was used in several studies, namely for Neman River Basin (Rimkus et al., 2013), the Cetina River basin in Croatia (Ljubenkov & Kalin, 2016), the Vistula River in Poland (Bąk & Kubiak-Wójcicka, 2017; Kubiak-Wójcicka & Bąk, 2018), and 121 catchments in the United Kingdom (Barker, Hannaford, Chiverton, & Svensson, 2016). One of the main conditions in the assessment of drought indices is that a high-quality dataset (for a period of at least 30 years) should be used in the calculations due to sampling uncertainties in frequency-analysis-based hydrological research (Guttman, 1994).

The investigation of the hydrologic drought occurrence, frequency and magnitude by applying the *SDI* index on the Tisza River is the main scope of this study. For this purpose, discharge values from four stations located along Tisza River were used, from Vásárosnamény, Szolnok and Szeged station in Hungary and Senta station in Serbia.

Study area

The area of the Tisza River basin is about 157,220 km^2 and the length of the river is 966 km, and it represents the largest tributary of the Danube River. The basin of this river lies in the territories of five countries: Romania, Hungary, Slovakia, Ukraine and Serbia (Leščešen, Pantelić, Dolinaj, & Lukić, 2014). For the purpose of determining the *SDI* of the Tisza River in Hungary and Serbia, monthly discharge values obtained from Vásárosnamény, Szolnok, Szeged and Senta gauging stations were used (Figure 1).

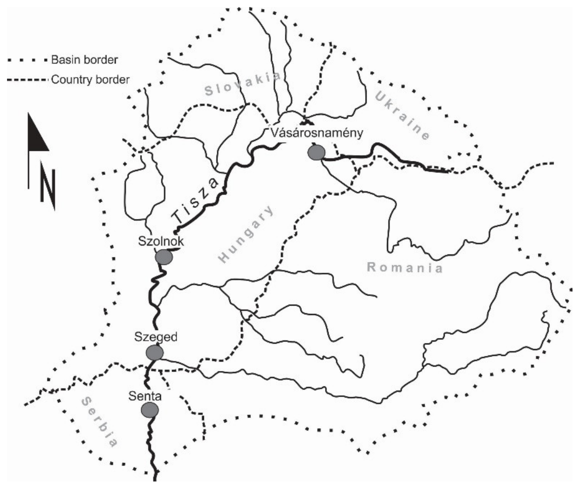

Figure 1. Geographical location of the research area and the location of Vásárosnamény, Szolnok, Szeged and Senta stations at the Tisza River.

The Carpathian mountain range forms the northern, northeastern, eastern and southeastern borders of the Tisza river basin, while the western basin stretches to the low hills that represent a watershed between the rivers Danube and Tisza (Štrbac, 2014). Northern and northeastern parts of the basin that have higher altitude are covered with forests, while lower parts and alluvial plains are used for intensive agricultural production.

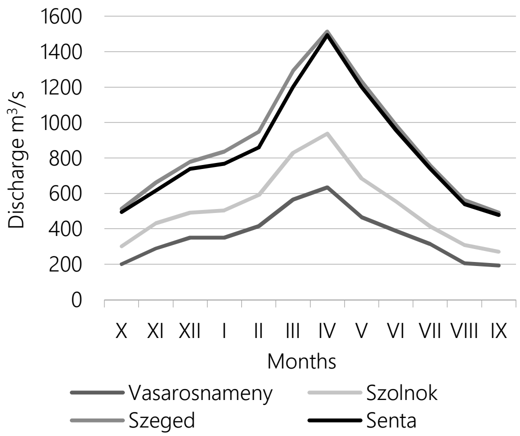

Figure 2. Comparative presentation of average monthly discharge value at the investigated stations.

Based on the relief, the Tisza basin can be divided into three parts: the Carpathian Mountains, the Transylvanian Basin with Mount Bihar in Romania, and the low Tisza Valley. In the upper course—from Rahovo to the mouth of the river Samos, the length of the course is 266 km, and the total drop is 1,578 m. The middle course of the river (from the mouth of the Samos to Moris) is 525 km long, while the total drop is 26 m. The lower course (from Moris to the mouth of the Danube) is 175 km long with a drop of only 6 m (Gavrilović & Dukić, 2002). At the point of 1,214.5 km, the Tisza flows into the Danube River (Pavić, Dolinaj, & Dragićević, 2009). Due to the small fall of the river bed throughout history, there have been minor or major floods all along the river. After the catastrophic flood in 1830, a decision was made on major regulatory works. During the 19th century, a total of 112 meanders were cut, during which the flow was shortened to today's 966 kilometers (Pavić et al., 2009).

The Tisza River Basin is under the influence of the Continental climate that determines the regional precipitation distribution. About 60% of the Carpathian part of the Tisza River Basin gets more than 1000 mm of precipitation annually. The middle part of the basin receives around 700 mm of precipitation while lower parts receive around 500 mm of yearly precipitation. Two precipitation peaks can be observed: the first is in April–June and the second is in October (International Commission for Protection of the Danube River [ICPDR], 2009).

Different morphological features and the annual amount of precipitation in the basin cause that the highest discharges on the Tisza River are during April and May due to precipitation and melting snow in the Carpathian Mountains. The lowest flows are in August and during autumn (September and October). Low flows occur due to summer droughts and high evaporation during the warm part of the year (Figure 2). The second minimum flow occurs in the winter period of the year (December–February), which occurs due to snowfall that is retained mostly in the mountains and that melts during the spring.

Material and methods

The public database of the Republic Hydrometeorological Service of Serbia (RHMS, 1964–2018) was used for the Senta station for the period 1964–2018 while data for stations on the territory of Hungary was obtained from the General Directorate of Water Management (GDWM, 2018) for the same period (1964–2018). This data was used to determine the *SDI* of the Tisza River. As suggested by McKee, Doesken, and Kleist (1993), the Standardized Precipitation Index (*SPI*) procedure can also be applied to other water variables, such as soil moisture, snowpack, streamflow, reservoir and groundwater. The *SDI* developed by Nalbantis and Tsakiris (2009) have computation procedures very similar to that of the *SPI*. According to Nalbantis (2008), if a time series of monthly streamflow volumes $Q_{i,j}$ is available, in which i denotes the hydrological year and j the month within that hydrological year (j = 1 for October and j = 12 for September), $V_{i,k}$ can be obtained based on the equation:

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,j} \qquad i = 1, 2, \ldots \qquad k = 1, 2, 3, 4 \tag{1}$$

in which $V_{i,k}$ is the cumulative streamflow volume for the i-th hydrological year and the k-th reference period, k = 1 for October–December, k = 2 for January–March, k = 3 April–June, and k = 4 for July–September. Based on the cumulative streamflow volumes $V_{i,k}$, the *SDI* is defined for each reference period k of the i-th hydrological year as follows:

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V}_k}{S_k} \qquad i = 1, 2, \ldots \qquad k = 1, 2, 3, 4 \tag{2}$$

in which $\overline{V}_k$ and S_k are respectively the mean and the standard deviation of cumulative streamflow volumes of the reference period k as these are estimated over a long period of time. In this definition the truncation level is set to $\overline{V}_k$ although other values based on rational criteria could also be used.

Generally, for small basins, streamflow may follow a skewed probability distribution which can be well approximated by the family of the gamma distribution functions. The distribution is then transformed into normal. Using the two-parameter log-normal distribution (for which the normalization is simply reclaiming the natural logarithms of streamflow), the *SDI* index is defined as:

$$SDI_{i,k} = \frac{y_{i,k} - \bar{y}_k}{S_{y,k}} \qquad y = 1, 2, \ldots \qquad k = 1, 2, 3, 4 \tag{3}$$

in which:

$$y_{i,k} = \ln(V_{i,k}) \qquad i = 1, 2, \ldots \qquad k = 1, 2, 3, 4 \tag{4}$$

are the natural logarithms of cumulative streamflow with mean $\bar{y}_k$ and standard deviation $S_{y,k}$ as these statistics are estimated over a long period of time. According to Ozkaya and Zerberg (2019) states (classes) of hydrological droughts are defined as presented in Table 1.

Table 1
Description of hydrological drought based on the streamflow drought index (SDI)

State	Description	Criterion	Probability (%)
0	Non drought	*SDI* ≥ 0.0	50
1	Mild drought	–0.99 ≤ *SDI* < 0.0	34.1
2	Moderate drought	–1.49 ≤ *SDI* < –1.0	9.2
3	Severe drought	–1.99 ≤ *SDI* <–1.5	4.4
4	Extreme drought	*SDI* < –2.0	2.3

Note. From "A 40-Year Analysis of the Hydrological Drought Index for the Tigris Basin, Turkey" by A. Ozkaya & Y. Zerberg, 2019, *Water, 11*, p. 657. CC BY 4.0.

The *SDI* trends were analyzed for four periods of the year using two statistical approaches, linear trend equation calculation and Mann-Kendall (MK) test. The first approach was used to determine the sign of the *SDI* (Gavrilov, Marković, Jardi, & Korać, 2015). The second statistical approach, MK test (Gilbert, 1987; Kendall, 1975) was used to determine if the trend is statistically significant. This test is widely used in the analysis of hydrological time series (Yue & Wang, 2004) as well as for other climatological and geophysical time series. The main advantages of this test are that it is a non-parametric test, that it is simple and robust and can cope with missing values as well with values below the detection limit. By applying the MK test for the detection of the significant trends, the researcher tests two hypotheses: H_0, the null hypothesis, is that there is no trend in the time series, and the H_a, alternative hypothesis, is that there is a statistically significant trend in the time series at the given significance level. Probability p in percent (Gavrilov et al., 2015) was calculated for the determination of the level of confidence in the hypothesis. When the computed p value is lower than the chosen significance level α (in most studies α = 5%), the H_0 should be rejected, and the H_a should be accepted, and vice versa. The XLSTAT 2014 statistical analysis software was used for hypothesis testing and calculation of the p probability.

Results and discussion

The *SDI* values were calculated from the time series of the monthly discharge of the Tisza River at Vásárosnamény, Szolnok, Szeged, and Senta stations. This helped to assess the temporal variation of hydrological drought and drought probability. The calculated *SDI* values were classified in drought categories as presented in Table 1. The time series of the occurrence of drought categories are shown in graph plotted hydrological year (12-month period between October–September) vs. *SDI* value for four stations located on the Tisza River (Figure 3).

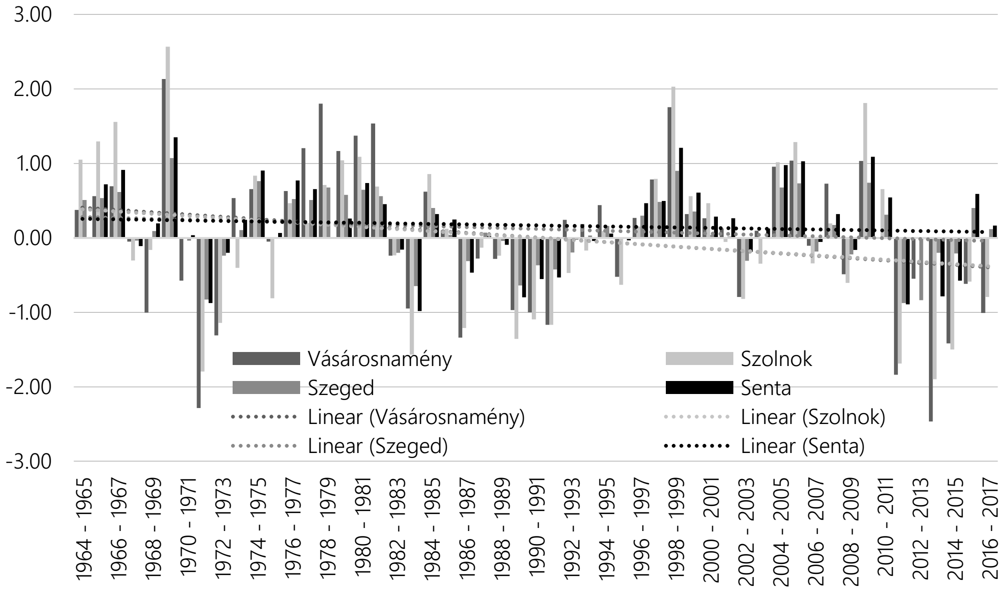

Figure 3. Annual *SDI* values at Vásárosnamény, Szolnok, Szeged and Senta stations.

Figure 3 shows an oscillation between periods with positive and negative *SDI* values. Two drought periods can be observed. The first period was from 1983 to 1993, with the exceptions of 1985 and 1987. This period is characterized with higher absolute *SDI* values at Vásárosnamény (–0.84) and Szolnok (–0.87) than on Szeged (–0.29) and Senta (–0.40) stations. These results coincide well with the results presented by ICPDR in which they conclude that on the Tisza River, each year from 1983 to 1995, with the exception of 1987, 1988, and 1991, were drought years (ICPDR, 2011). The second period lasted from 2011 to 2015, with an average *SDI* value of –1.32 at Vásárosnamény and –1.08 at Szolnok station.

During the studied period, severe and extreme droughts occurred only at Vásárosnamény and Szolnok stations. In total, severe drought events occurred five times at Szolnok station, of which three times happened in the last ten years, while at Vásárosnamény two extreme drought events occurred, –2.29 (1971–1972) and –2.47 (2013–2014). The last extreme drought event was preceded by one severe and followed by one moderate drought event. The annual values of *SDI* show that during the studied period, at Szeged and Senta stations there were only mild hydrological droughts as there were no *SDI* values lower than –1. Droughts are a recurrent event in the Tisza region and can cause considerable damages to the agriculture of Serbia and Hungary. Statistics shows that 36% of the total agricultural loss in Hungary originates from drought, followed by hail, floods and frosts. Each year from 1983 to 1995 was drought year (Bakonyi, 2010), which is confirmed by *SDI* presented in Figure 3 where the same drought period can be seen , with an exception of two-year-long period from 1984 to 1986. Especially concerning drought event was in the 1992 (United Nations Environment Programme [UNEP], 2004), particularly in upstream stations (Vásárosnamény and Szolnok, both –1.17 *SDI*). Damaging water shortage needs to be taken into account in 4 out of 10 years on average (UNEP, 2004). For instance, between 1986 and 1995, there were 7 drought years in Hungary (UNEP, 2004), and 8 in Serbia. Of these drought events, six were moderate droughts (2 on Vásárosnamény and 4 on Szolnok station), and other events can be considered as mild droughts. According to Bussay and Szinell (1996) the series of dry years between 1986 and 1995 meaningfully reduced the effectiveness of Hungarian agriculture. The same authors also point out that the main cause of the reduced agricultural effectiveness is caused by significant fall of the water level, which has appeared on two main Hungarian rivers (Danube and Tisza). The presented *SDI* values and previous experiences show that Hungary and Serbia must be prepared to prevent and avoid damages that can occur during water shortage. In the beginning of the 21st century, the Tisza region was affected by serious drought in 2003 when the river level was 2.8 meters lower than the mean water level in the city of Szolnok (UNEP, 2004). This hydrological drought is also identified in *SDI*, which has shown hydrological drought of mild intensity on all the four investigated stations. Over the last decade, drought has been causing more and more problems to the professionals of the local Water Directorates. The extreme low water level of the river represents a big problem, especially in the low flat areas of the Tisza River Basin (Vizi, Fehér, Lovas, & Kovács, 2018). For example, on Vásárosnamény station, out of seven drought events, one was extreme and one was severe, two were moderate, and three were mild. On Szolnok station three out of five severe drought events in total occurred in last ten years. As presented by Mezősi (2017), the Tisza River basin, from Szolnok till its confluence into the Danube River is highlighted as an area greatly affected by drought, both meteorological and hydrological. On all the four stations there is no statistically significant trend of *SDI* values when MK test is applied.

Further on, seasonal drought analysis was conducted (Figure 4). Seasons were defined as suggested by Milošević et al. (2016): winter (January, February, March), spring (April, May, June), summer (July, August, September), and autumn (October, November and December), with no overlapping periods.

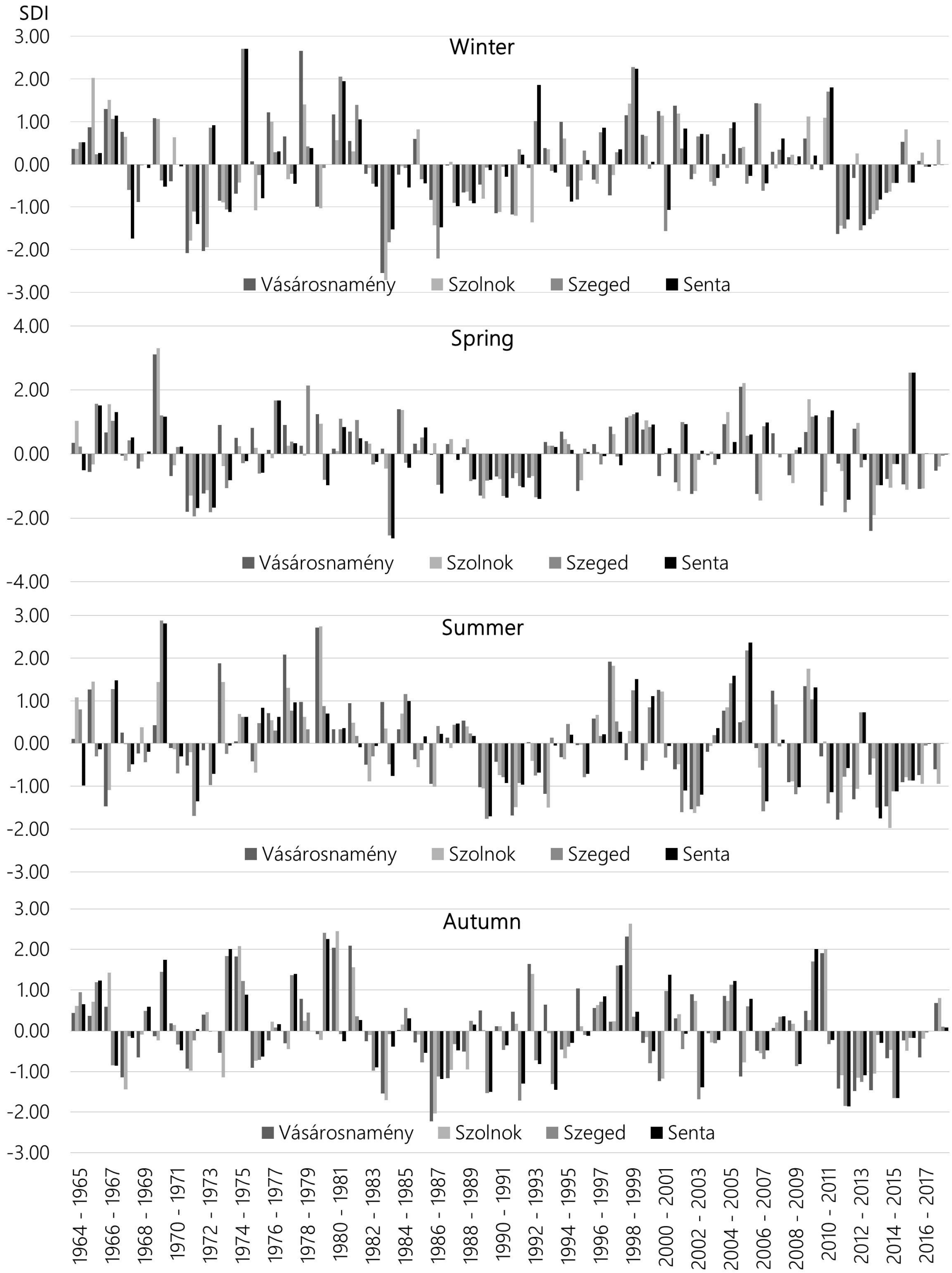

Figure 4. Seasonal *SDI* values for Vasarosnameny, Szolnok, Szeged and Senta stations.

According to the investigated hydrological station data (which represents the integrated runoff in most of the catchment (Figure 4), long hydrological drought period that lasted for 8 years was observed during winter, summer and autumn from 2010 to 2017.

As presented in Figure 4, at Vásárosnamény and Szolnok stations the lowest *SDI* values were measured during winter 1983–1984 with –2.55 and –2.71, respectively. The wettest season at these upstream stations was during spring of 1969–1970 with *SDI* values of 3.12 and 3.31, respectively. At Szeged station, the minimum *SDI* was –2.54 (spring 1983–1984) while the wettest event was during the summer of 1969–1970 (*SDI* = 2.88). On Senta station, the same periods and same years are highlighted as the driest and wettest (*SDI* = –2.63 and 2.82, respectively). At all stations, the maximum absolute difference between *SDI* values was recorded during spring with 5.51 (Vásárosnamény), 5.22 (Szolnok), 5.08 (Szeged), and 5.17 (Senta) while the minimum difference was observed during autumn with 4.54 (Vásárosnamény), 4.67 (Szolnok), 4.26 (Szeged), and 4.11 (Senta). During the summer of 1970, Tisza River basin was hit by a catastrophic flood that lasted for over 100 days (180 days) (ICPDR, 2011). According to some accounts, this flood (1970) was even greater than the flood in 1879 (Gavrilović & Dukić, 2002). Because of this flood, high values of *SDI* were experienced at Szeged and Senta stations.

Seasonal analysis presented that the longest dry period was during winter months from 1982 to 1991 at Szeged and Senta stations, while at Vásárosnamény and Szolnok stations this dry period lasted two years longer (until 1993). Regarding other seasons, the longest dry period for spring was from 1986 to 1993 for all stations. At Vásárosnamény and Szolnok stations, the longest spring dry period lasted for five years, from 2013 to 2018. At Szeged station the longest dry period lasted for four years—it occurred twice, in the periods 1989–1993 and 2013–2017. At Senta station, the longest dry period during the same period lasted for five years, from 1989 to 1994. Regarding autumn, two seven-year-long hydrological droughts were recorded at both stations—the first of them lasted from 1989 to 1996, whereas the second one was in the period 2010–2017. Even though in the recent twenty years only one extreme drought event occurred at the investigated stations (at Vásárosnamény in 2013–2014 with *SDI* value –2.40), the drought events with smaller absolute *SDI* values were getting more frequent toward the end of the investigated period.

According to the MK test, a statistically significant decreasing trend of *SDI* is observed only during summer at Vásárosnamény and Szolnok stations (Vasarosnameny p = 0.017; Szolnok p = 0.017), while all other cases show a lack of trend because the computed values of probability p for the time series are greater than the significance level (α = 5%) (Table 2). The statistically significant negative trend of summer *SDI* values at Vásárosnamény and Szolnok is in good accordance with seasonal mean monthly discharge trends that are also negative and statistically significant (MK test for Vásárosnamény p = .019 and Szolnok p = .027). Decreasing discharge trend of the Tisza River, especially during summer is in good accordance with the results presented by Alfieri, Burek, Feyen, and Forzieri (2015) where they point out that reduced summer precipitation will to lead to the reduction of river discharge during summer. Rojas, Feyen, Bianchi, and Dosio (2012) projected decreasing discharge trends in southern and south-eastern Europe and the increase in northern and north-eastern Europe. Discharge reductions can be intensified by water reduction, especially during summer when water consumption is the highest and water input is normally low. These changes will contribute to the further decrease of water availability during summer months (Forzieri et al., 2014).

Table 2
The trend equation y and probability p of level of significance for each station and for different periods of the year

	Vásárosnamény		Szolnok	
	Trend equation	MK *p*-value	Trend equation	MK *p*-value
Winter	0.000x – 0.005	.933	0.0029x – 0.079	.718
Spring	–0.017x + 0.461	.112	–0.015x + 0.409	.286
Summer	–0.019x + 0.541	.017	–0.023x + 0.623	.017
Autumn	–0.004x + 0.127	.665	–0.004x + 0.130	.644
	Szeged		**Senta**	
	Trend equation	MK *p*-value	Trend equation	MK *p*-value
Winter	–0.008x + 0.222	.463	–0.000x + 0.019	.795
Spring	0.002x + 0.032	.968	0.007x – 0.209	.603
Summer	–0.013x + 0.315	.246	–0.010x + 0.278	.229
Autumn	–0.019x + 0.483	.075	–0.010x + 0.279	.144

As presented in Table 1, the probability of drought occurrence decreases as the severity of drought increases. Figure 5 shows seasonal percentage of drought occurrences at Vásárosnamény, Szolnok, Szeged and Senta stations based on *SDI*.

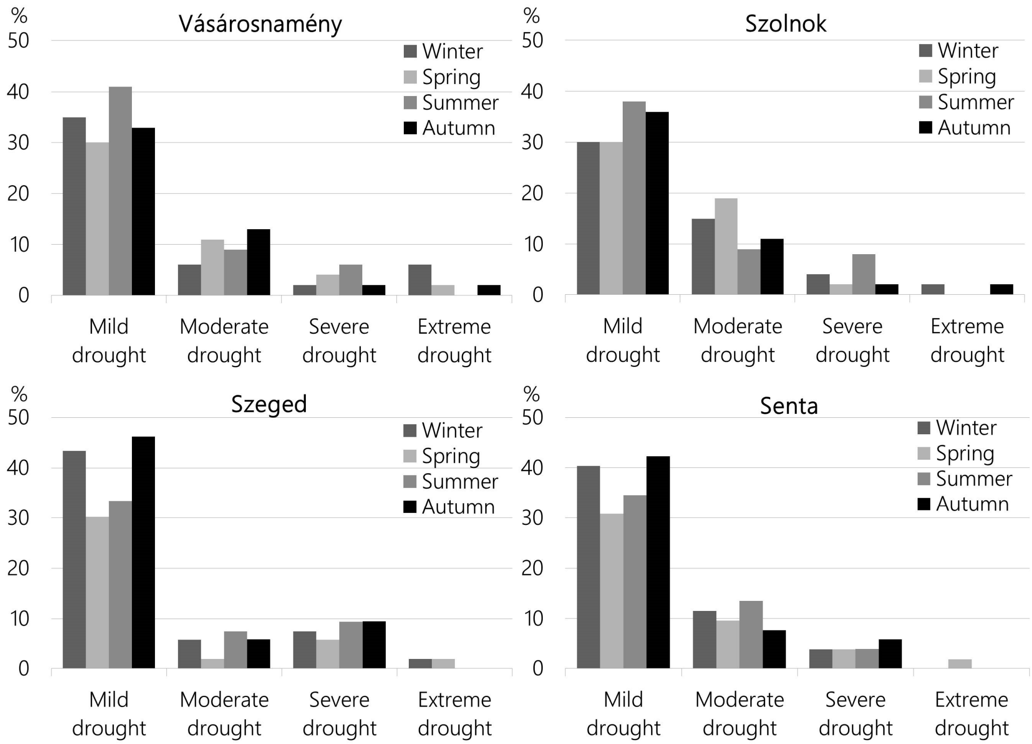

Figure 5. Percentage of drought occurrence according to *SDI* on Vásárosnamény, Szolnok, Szeged, and Senta stations.

According to Table 1, the theoretical probability of mild drought events is 34.1%, if normal distribution is assumed. However, this percentage was exceeded during winter and summer (at Vásárosnamény), during summer and autumn at Szolnok, and during winter, summer and autumn at Szeged and Senta stations. The theoretical probability of moderate droughts (9.2%) was exceeded at Vásárosnamény during spring (11%) and autumn (13%), at Szolnok during winter (15%), spring (19%), and autumn (11%), at Senta station during winter (12%), spring (10%), and summer (14%). At Szeged station no moderate droughts were measured. The theoretical frequency of severe droughts (4.4%) was exceeded at Vásárosnamény during summer (5.6%), at Szolnok also during summer (8%), at Szeged during all seasons (winter 8%, spring 6%, summer 9%, and autumn 10%) while at Senta station only during autumn (6%). Extreme drought events frequency was exceeded only during winter at Vásárosnamény with 5.6%.

Conclusion

This study estimated hydrological droughts by using the *SDI* on the Tisza River over the period 1964–2018. The hydrological drought analysis based on the annual and seasonal time scales indicated that the number of extreme, severe and moderate drought events decreases as the calculation time scale gets longer. As indicated by *SDI*, two longer hydrological droughts occurred between 1988 and 1993 with an average *SDI* value of –0.84 at Vásárosnamény station, –0.87 at Szolnok, –0.29 at Szeged and –0.40 at Senta. The second longest drought period lasted from 2011 to 2015 with SDI values of –1.26 (Vásárosnamény), –0.89 (Szolnok), –0.57 (Senta), and –0.53 (Szeged). The largest hydrological drought at an annual scale occurred at Vásárosnamény during the hydrological year 2013–2014 with *SDI* value of –2.47. In the same year the most severe hydrological drought was measured at Szolnok station with *SDI* value of –1.90. The largest drought event at Szeged station took place during the hydrological year 2011–2012 with *SDI* value of –0.87, while at Senta station, the driest year was during the hydrological year 1983–1984 with –0.98 SDI.

Severe and extreme droughts may have a serious impact on Hungarian and Serbian economies; such are the loss in agricultural production in general, the loss in fishery production (damage to fish habitat, loss of fish and other aquatic organisms due to decreased discharge), loss in tourism industry (reduced activities such as fishing, boating, etc.), energy-related effects (reduced supply because of drought-related power shortages), losses of water suppliers, losses in the transportation industry (loss from unsuitability of waterways), and much more. All this indicates that drought management should become an essential element of water resources strategies and policies.

Future research will be focused on widening the number of gauging stations that will include stations located on the biggest tributaries of the Tisza River so the better understanding of hydrological droughts in the Tisza River basin can be achieved.

References

Al-Faraj, F. A. M., Scholz, M., & Tigkas, D. (2014). Sensitivity of Surface Runoff to Drought and Climate Change: Application for Shared River Basins. *Water*, *6*(10), 3033–3048. https://doi.org/10.3390/w6103033

Alfieri, L., Burek, P., Feyen, L., & Forzieri, G. (2015). Global warming increases the frequency of river floods in Europe. *Hydrology and Earth System Sciences*, *19*, 2247–2260. https://doi.org/10.5194/hess-19-2247-2015

Bąk, B., & Kubiak-Wójcicka, K. (2017). Impact of meteorological drought on hydrological drought in Torún (central Poland) in the period of 1971–2015. *Journal of Water and Land Development*, *32*(1), 3–12. https://doi.org/10.1515/jwld-2017-0001

Bakonyi, P. (2010). *Flood and Drought Strategy of the Tisza River Basin*. Budapest, Hungary: VITUKI.

Barker, L. J., Hannaford, J., Chiverton, A., & Svensson, C. (2016). From meteorological to hydrological drought using standardised indicators. *Hydrology and Earth System Sciences*, *20*, 2483–2505. https://doi.org/10.5194/hess-20-2483-2016

Beran, M. A., & Rodier, J. A. (1985). *Hydrological aspects of drought*. Paris, France: United Nations Educational, Scientific and Cultural Organization.

Bussay, A., & Szinell, C. (1996). Drought Continues in Hungary in 1995. *Drought Network News (1994-2001)*, 11. Retrieved from https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1010&context=droughtnetnews

Forzieri, G., Feyen, L., Rojas, R., Flörke, M., Wimmer, F., & Bianchi, A. (2014). Ensemble projections of future streamflow droughts in Europe. *Hydrology and Earth System Sciences*, *18*, 85–108. https://doi.org/10.5194/hess-18-85-2014

Gavrilov, M. B., Marković, S. B., Jarad, A., & Korać, V. M. (2015). The Analysis of temperature trends in Vojvodina (Serbia) from 1949 to 2006. *Thermal Science*, *19*(2), 339–350. https://doi.org/10.2298/TSCI150207062G

Gavrilović, Lj., & Dukić, D. (2002). *Reke Srbije* [Rivers of Serbia]. Belgrade, Serbia: Zavod za udžbenike.

General Directorate of Water Management. (2018). Nemzeti öntözési igény felmérés adatbázisa [Database of the national water demand survey]. Retrieved from http://www.vizugy.hu/

Gilbert, R. O. (1987). *Statistical Methods for Environmental Pollution Monitoring*. New York, NY: John Wiley & Sons.

Guttman, N. B. (1994). On the Sensitivity of Sample L Moments to Sample Size. *Journal of Climate*, *7*(6), 1026–1029. https://doi.org/10.1175/1520-0442(1994)007<1026:OTSOSL>2.0.CO;2

International Commission for Protection of the Danube River. (2009). *Sub-Basin Level Flood Action Plan Tisza River Basin*. Vienna, Austria: ICPDR.

International Commission for Protection of the Danube River. (2011). *Integrated Tisza River Basin Management Plan*. Vienna, Austria: ICPDR.

Kendall, M. G. (1975). *Rank Correlation Methods* (4th ed.). London, UK: Charles Griffin.

Kubiak-Wójcicka, K., & Bąk, B. (2018). Monitoring of meteorological and hydrological droughts in the Vistula basin (Poland). *Environmental Monitoring and Assessment*, *190*, 691. https://doi.org/10.1007/s10661-018-7058-8

Leščešen, I., Pantelić, M., Dolinaj, D., & Lukić, T. (2014). Assessment of water quality of the Tisa river (Vojvodina, North Serbia) for ten year period using Serbian Water Quality Index (SWQI). *Geographica Pannonica, 18*(4), 102–107. https://doi.org/10.5937/GeoPan1404102L

Li, S., Xiong, L., Dong, L., & Zhang, J. (2013). Effects of the Three Gorges Reservoir on the hydrological droughts at the downstream Yichang station during 2003–2011. *Hydrological Process*es, *27*(26), 3981–3993. https://doi.org/10.1002/hyp.9541

Ljubenkov, I., & Kalin, K. C. (2016). Evaluation of drought using standardised precipitation and flow indices and their correlations on an example of Sinjsko polje. *Građevinar, 68*(2), 135–143. https://doi.org/10.14256/JCE.1337.2015

McKee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of drought frequency and duration to time scale. In *Proceedings of the 8th Conference on Applied Climatology* (Vol. 17, pp. 179–183). Boston, MA: American Meteorological Society.

Mezősi, G. (2017). *The Physical Geography of Hungary.* Cham, Switzerland: Springer.

Milošević, D. D., Savić, S. M., Pantelić, M., Stankov, U., Žiberna, I., Dolinaj, D., & Leščešen, I. (2016). Variability of seasonal and annual precipitation in Slovenia and its correlation with large-scale atmospheric circulation. *Open Geosciences*, *8*(1), 593–605. https://doi.org/10.1515/geo-2016-0041

Nalbantis, I. (2008). Drought and Streamflow. *European Water*, *23*(24), 65–76. Retrieved from https://www.ewra.net/ew/pdf/EW_2008_23-24_06.pdf

Nalbantis, I., & Tsakiris, G. (2009). Assessment of hydrological drought revisited. *Water Resources Management*, *23*(5), 881–897. https://doi.org/10.1007/s11269-008-9305-1

Ozkaya, A., & Zerberg, Y. (2019). A 40-Year Analysis of the Hydrological Drought Index for the Tigris Basin, Turkey. *Water, 11*(4), 657. https://doi.org/10.3390/w11040657

Pavić, D., Dolinaj, D., & Dragićević, S. (2009) Termički režim vode i režim leda na reci Tisi u Srbiji [Thermal regime of water and ice on Tisza River in Serbia]. *Zbornik radova - Geografski fakultet Univerziteta u Beogradu*, *57*, 35–46. Retrieved from https://scindeks-clanci.ceon.rs/data/pdf/1450-7552/2009/1450-75520957035P.pdf

Republic Hydrometeorological Service of Serbia. (1964–2018). *Annual Report – Hydrological yearbook* [Database]. Belgrade, Serbia: Republic Hydrometeorologcal Service of Serbia.

Rimkus, E., Stonevičius, E., Korneev, V., Kažys, J., Valiuškevičius, G., & Pakhomau, A. (2013). Dynamics of meteorological and hydrological droughts in the Neman river basin. *Environmental Research Letters*, *8*(4), 045014. https://doi.org/10.1088/1748-9326/8/4/045014

Rojas, R., Feyen, L., Bianchi, A., & Dosio, A. (2012). Assessment of future flood hazard in Europe using a large ensemble of bias-corrected regional climate simulations. *Journal of Geophysical Research, 117*(D117), 1–22. https://doi.org/10.1029/2012JD017461

Soleimani Sardou, F. & Bahrenabd, A. (2014). Hydrological Drought Analysis Using SDI Index in Halilrud Basin of Iran. *Environmental Resources Research*, *2*(1), 47–56. https://doi.org/10.22069/ijerr.2014.1678

Štrbac, S. (2014). *Sadržaj i mobilnost teških metala i organskih jedinjenja u ekosistemu reke Tise* [Content and mobility of heavy metals and organic compounds in the ecosystem of the Tisza River] (Doctoral dissertation). Retrieved from http://nardus.mpn.gov.rs/bitstream/handle/123456789/2705/Disertacija.pdf?sequence=4&isAllowed=y

Tabari, H., Nikbakht, J., & Hosseinzadeh Talaee, P. (2013). Hydrological Drought Assessment in Northwestern Iran Based on Streamflow Drought Index (SDI). *Water Resources Management*, *27*, 137–151. https://doi.org/10.1007/s11269-012-0173-3

Tigkas D., Vangelis, H., & Tsakiris, G. (2015). DrinC: A software for drought analysis based on drought indices. *Earth Science Informatics*, *8*(3), 697–709. https://doi.org/10.1007/s12145-014-0178-y

Tigkas, D., Vangelis, H., & Tsakiris, G. (2012). Drought and climatic change impact on streamflow in small watersheds. *Science of the Total Environment*, *440*, 33–41. https://doi.org/10.1016/j.scitotenv.2012.08.035

United Nations Environment Programme. (2004). *Rapid environmental assessment of the Tisza River basin*. Geneva, Switzerland: UNEP/Regional Office for Europe.

Vizi, D. B., Fehér, J., Lovas, A., & Kovács, S. (2018). Modelling of extreme hydrological events on a Tisza river basin pilot area, Hungary. *Journal of Environmental Geography*, *11*(3–4), 57–66. https://doi.org/10.2478/jengeo-2018-0013

Wable, P. S., Jha, M. K., & Shekhar, A. (2019). Comparison of Drought Indices in a Semi-Arid River Basin of India. *Water Resources Management*, *33*, 75–102. https://doi.org/10.1007/s11269-018-2089-z

Yang, W. (2010). *Drought Analysis under Climate Change by Application of Drought Indices and Copulas* (Doctoral dissertation). Retrieved from https://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1715&context=open_access_etds

Yue, S., & Wang, C. (2004). The Mann-Kendall Test Modified by Effective Sample Size to Detect Trend in Serially Correlated Hydrological Series. *Water Resources Management*, *18*, 201–218. https://doi.org/10.1023/B:WARM.0000043140.61082.60