ANALYSIS OF HYDROLOGICAL DROUGHT FOR SELECTION OF RECREATION PLACES AT EASTERN SLOVAKIA

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Abstract

Hydrological drought is an isolated natural phenomenon whose severity may be intolerable for environment. Drought influence also possibilities for tourism and recreation. Tourists prefer places with water for recreation. Understanding drought past manifestations allows us to better understand its frequency and the extent of its influence on the territory. For this purpose, the current article presents Standardized Stream flow Index (SSI) computed in 12 months time scales for classification of hydrological drought episodes during the period from 1972 to 2014 in 7 water meter stations localized in the Eastern part of Slovakia. A one-dimensional frequency analysis of hydrological drought was performed in order to determine the historical extreme episode of drought and average inter-arrival time of next one episode. The results show that the occurrence of drought extreme episodes will be more frequent in the Bodva sub-catchment. In the Dunajec and Poprad sub-catchment, extreme droughts can be expexted rarely. The most serious decade can be considered the period from 1982 to 1992, where in almost every monitored station a hydrological drought was recorded, the exception was only at the Bardejov station.

Key words: Hydrological drought analysis, Standardized Stream flow Index, extreme episode, inter-arrival time, Eastern Slovakia

Introduction

Drought and floods are the most extreme hydrological risks (Zeleňáková et al, 2015, Zeleňáková and Junáková, 2018) Drought is a recurrent extreme climate event that affects large number of sectors of human activity as well as can severely affect ecosystems (Madadgar et al., 2011). Hydrological drought is defined as a long-term decrease in surface water levels and a decrease in groundwater levels (Mishra and Singh, 2010). The following two indices are currently used to identify and quantify the severity of the hydrological drought: Stream flow Drought Index (Nalbantis, 2008) and Standardized Runoff Index (Shukla and Wood, 2008). The Streamflow drought index SDI was developed by Nalbantis (2008) for the detection of onset of hydrological drought. This index was investigated in deep by Vincente-Serrano et al. (2012). They presented a mathematical approach for its standardization in time and space and called this index as Standardized Streamflow Index (SSI).

The index of drought is indispensable method for monitoring dynamics of drought and defining its characteristics including duration, severity, intensity and inter-arrival time (Mishra et al. 2010). The SSI method has recently attained popularity in the analysis of hydrological drought as evidenced by a number of researchers (e.g. Madadgar et al. (2011), Vincente-Serrano et al. (2012), Telesca et al. (2012), Solakova et al. (2013), Huang et al. (2017), Nagy et al. (2020) and Shamshirband et al. (2020), Abdelkader et al. (2022)). Risk of drought by the SSI can be classified into five categories, which have important role in drought management.

Tab. 1: Classification of hydrological drought using SSI (Nalbantis, 2008).

SSI intervals	SSI classes	Probability events
$SSI \geq 0$	Non-drought	50%
$-1 \leq SSI < 0$	Mild drought	34,1%
$-1{,}5 \leq SSI < -1$	Moderate drought	9,2%
$-2 \leq SSI < -1{,}5$	Severe drought	4,4%
$SSI < -2$	Extreme drought	2,3%

The occurrence of hydrological drought can lead to a decrease in water supply, deterioration in water quality, disruption of aquatic habitats, bar land, reduction of hydropower production and other impacts on economic and social activities in catchment (Mishra and Singh, 2010). Therefore, river basin drought management plans are used to minimize the aforementioned negative impacts in the river basin. Drought management plans include measures that are necessary in times of drought to reduce the vulnerability of the territory to this phenomenon.
In this study, the SSI in 12 – month time scales is used to identify serious lack of stream flow volumes, as well as to assess the vulnerability of the eastern part of Slovakia to this phenomenon. The index is calculated by parametric approach during the years 1972 – 2014 in 7 water meter stations and exact sequence of steps is explained in the following subchapter.

Materials and methods
The case study considers seven water meter stations in the Eastern part of Slovakia (see Fig. 1 and Tab. 2) relatively to the period (1972-2014). Values of average daily flows are provided by Slovak Hydrometeorological Institute of Košice, but only in one station Ižkovce we have shorter time scale of stream flow from (1975-2014).

Tab. 2: Geographical coordinates of analyzed water meter stations

Station	Longitude	Latitude	Average daily flow during the years 1972-2014
Bardejov	49°18'56''N	21°12'44''E	3,03
Červený Kláštor	48°45'20''N	21°55'19''E	30,57
Humenné	48°55'60''N	22°55'00''E	13,36
Ižkovce	48°33'22''N	21°57'11''E	52,27
Medzev	48°42'00''N	20°53'30''E	0,72
Svidník	49°13'19''N	21°38'13''E	1,69
Ždiar	49°16'18''N	20°15'44''E	1,87

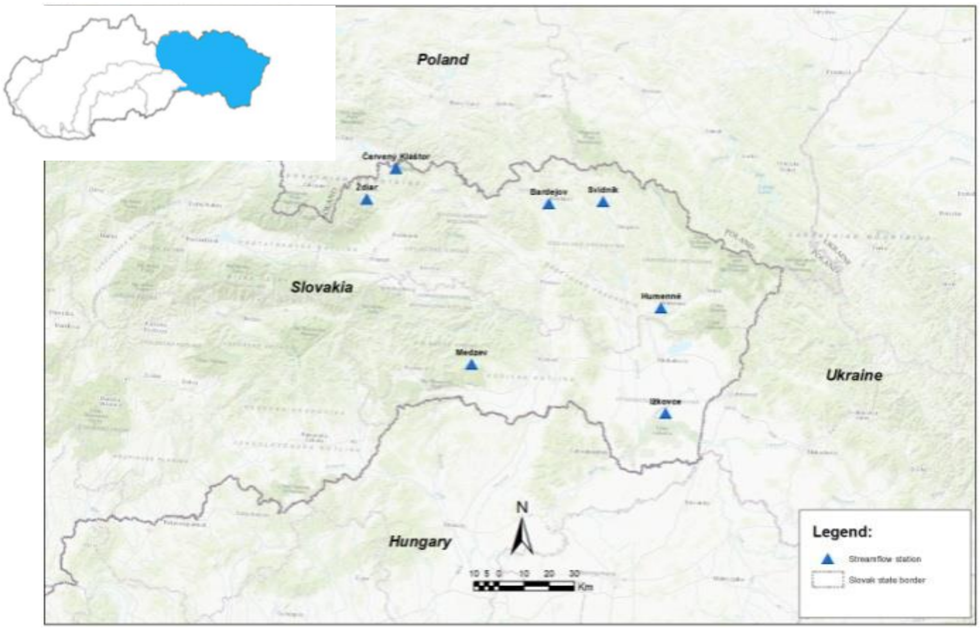


Fig. 1: Locations of water meter stations in Eastern Slovakia

The overall calculation procedure consists from six steps. First, preparation of statistical files, monthly stream flow in the period were aggregated in a 12-month moving window, for example, the value in May 2001 is generated by the streamflow from June 2000 to May 2001 and divided by the number of months. The calculated average values of streamflow over a 12-month time-interval are a statistical set. Second, determination a probability density function f(x) capable of describing the streamflow volumes in 12-month time scales and estimation of its parameters by maximum likelihood method (Kottegoda and Rosso, 1997). The selection of the most appropriate theoretical probability density function f(x) from 8 probabilities density function for each month separately (see Table 2) used Kolmogorov-Smirnov test at significant level $\alpha = 5\%$. The theoretical probability function that has the smallest distances with respect to the empirical probability function is selected. Third, calculation of the cumulative probability functions F(x) for each month separately. In Table 3, the math formulae of the selected cumulative probability functions F(x) are presented. Fourth, transforming the cumulative probability function F(x) into a standard normal distribution with random variable SSI:

$$SSI = \Phi^{-1}(F(x)) \quad (1)$$

Fifth, checking that SSI values do indeed have a normal distribution by Wu et al. (2007) who stated 3 criteria: i) Shapiro-Wilk statistic: W less than 0,96; ii) p-value less than 0,1 and iii) absolute value of median greater than 0,05. Sixth, detection of the beginning of historical extreme drought episodes during the period from 1972 to 2014 by RUN method (Yevjevich 1967) and estimating the average inter-arrival time of drought. As threshold level of drought we use SSI=–2 to capture the onset of the extreme drought episode. Thus duration of a drought, D_d, is a period during which SSI values are less than -2. The severity of a drought, S_d, is a summation of SSI index in drought condition. The inter-arrival time T_d is a time between two successive episodes of drought (Madadgar et al. 2011).

Tab. 3: Chosen cumulative distribution function

Probability density function	**Cumulative distribution function**
Gen. Extreme Value	$F_{(x)} = \exp(-(1+kz)^{-\frac{1}{k}})$ $z = \frac{x-\mu}{\sigma}$
Weibull 3P	$F_{(x)} = 1 - \exp(-(\frac{x-\gamma}{\beta})^{\alpha})$
Gamma 3P	$F_{(x)} = \frac{\Gamma_{\frac{(x-\gamma)}{\beta}}(\alpha)}{\Gamma(\alpha)}$
Gen. Gamma	$F_{(x)} = \frac{\Gamma_{\left(\frac{x}{\beta}\right)^{k}}(\alpha)}{\Gamma(\alpha)}$
Burr	$F_{(x)} = 1 - (1 + (\frac{x}{\beta})^{\alpha})^{-k}$
Lognormal 3P	$F_{(x)} = \Phi(\frac{ln(x-\gamma)-\mu}{\sigma})$
Pearson 6	$F_{(x)} = I_{x/(x+\beta)}(\alpha_1, \alpha_2)$
Normal	$F_{(x)} = \Phi(\frac{(x-\mu)}{\sigma})$

Results and discussion

The assessed water meter stations belong to the sub-catchments of Dunajec and Poprad, Bodva, Bodrog with a total catchment area of 10 112.4 km^2, which forest represent 41,3%, agricultural land 49,15%, artificial areas 5,11%, wet areas 0,15%, water 0,55%. The aim of the work was to identify the average return period of extreme drought and to analyze the vulnerability of the territory by hydrological drought. The extreme hydrological episodes were identified by 12-month Standardized Streamflow Index. The result of the analysis is presented in a Table 4 and Figures 2 to 8.

Tab. 4: Extreme episodes of hydrological drought identified by SSI -12

Station	Number of drought episodes	Duration	Cumulative severity	Average Inter-arrival time
Bardejov	3	11	-24,59	192
Červený Kláštor	2	8	-21,67	308
Humenné	5	9	-21,17	83,5
Ižkovce	3	3	-6,26	113
Medzev	5	9	-20,04	68,5
Svidník	4	14	-33,86	126,7
Ždiar	6	6	-15,66	96,4

From Table 4, it is possible to see how the extreme hydrological drought often occurred during the years 1972-2014. An extreme stream flow deficit can be expected on average from 5,7 to 25,6 years. The Figures 2 to 8 give SSI values for 12-month timescales for each observed stations, in which the periods with the SSI-12 value was less than -2 are identified in red.

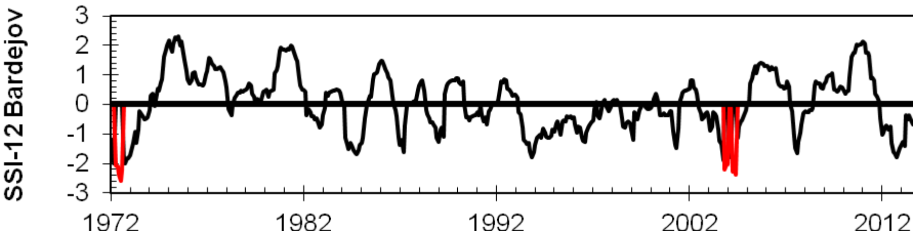


Fig. 2: SSI-12 at Bardejov gague station

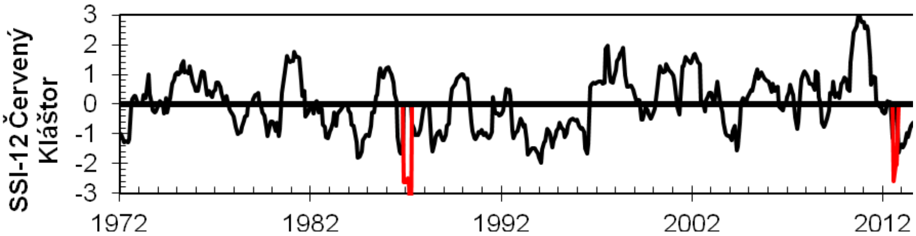


Fig. 3: SSI-12 at Červený Kláštor gague station

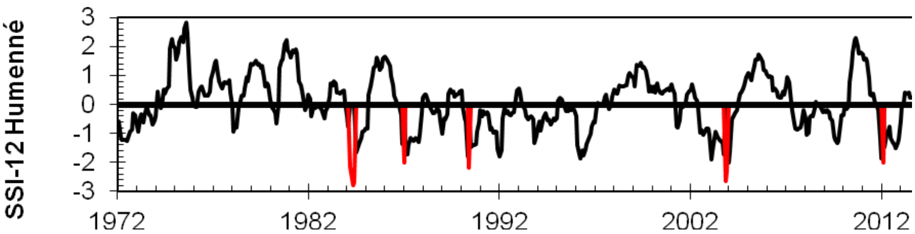


Fig. 4: SSI-12 at Humenné gague station

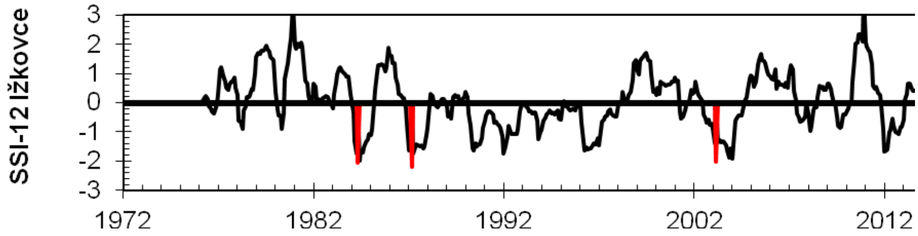


Fig. 5: SSI-12 at Ižkovce gague station

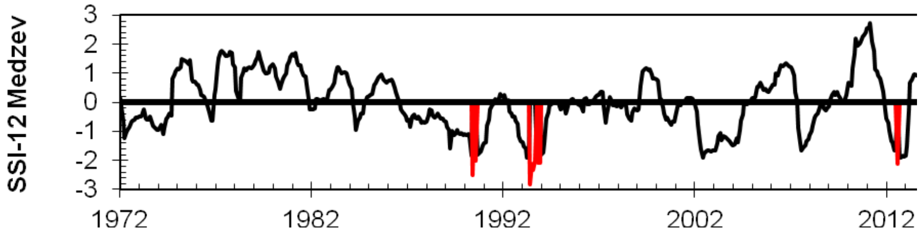


Fig. 6: SSI-12 at Medzev gague station

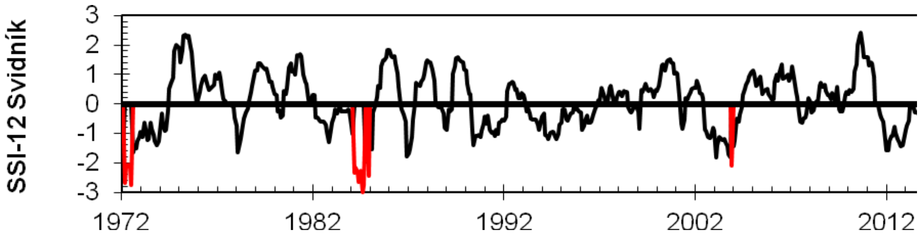


Figure 7 SSI-12 at Svidník gague station

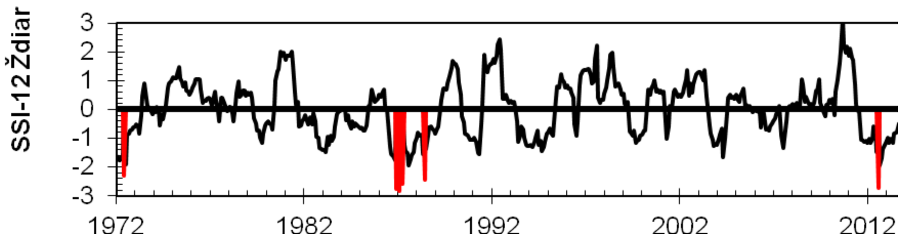


Fig. 8: SSI-12 at Ižkovce gague station

As seen in Figures 2 to 8, at the north of the Bodrog basin, in Bardejov gauge station, extreme events of the hydrological drought were recorded in 1972, 2002 and 2003 but at gauge Svidník station were recorded in 1984, 1985, 2003. At the Svidník station from March 1984 to September 1984, a drought with longest duration and with the largest cumulative severity was recorded. In the centre of the Bodrog basin, Humenné, there were five extreme hydrological events were recorded in 1984, 1987, 1990, 2003 and 2012. In the south of the Bodrog basin in Ižkovce in 1984, 1987 and 2003 can be considered the driest period. A more frequent occurrence of extreme drought events can be expected in Humenné. The average return time for drought in the Bodrog basin ranges from 83,5 to 192 months. Six extreme episodes of drought were detected in the Dunajec - Poprad basin, at the Ždiar water station during the period 1972-2014. The land around the water meter station Ždiar is more vulnerable to drought than in the station Červený Kláštor. The years 1972, 1986-1988 and 2012 represent the driest period in the catchment. The average return time for drought in the Dunajec - Poprad basin ranges from 96,4 to 308 months. The Bodva basin, which is represented by the Medzev station, has an average drought return time of 68,5 months. In the Bodva basin, the driest years include 1990, 1993, 1994 and 2012.

Calculated SSI-12 values at selected water meter stations can be considered as representative areas with attributes. For the spatial interpretation of the results, we used the Splain function in the ArcGIS program, which will ensure the analysis of the local geometry of the surface and its visibility. An illustrative example of the spatial analysis of hydrological drought in 2011 is shown in cartographic form (see figs 9 to 11). The degree of drought risk is color-coded in the maps (Figures 9 to 11), so there is no drought risk (purple, blue, light blue color) and mild drought risk (green color), moderate drought risk (yellow color), severe drought risk (orange color) and extreme drought risk (red color).

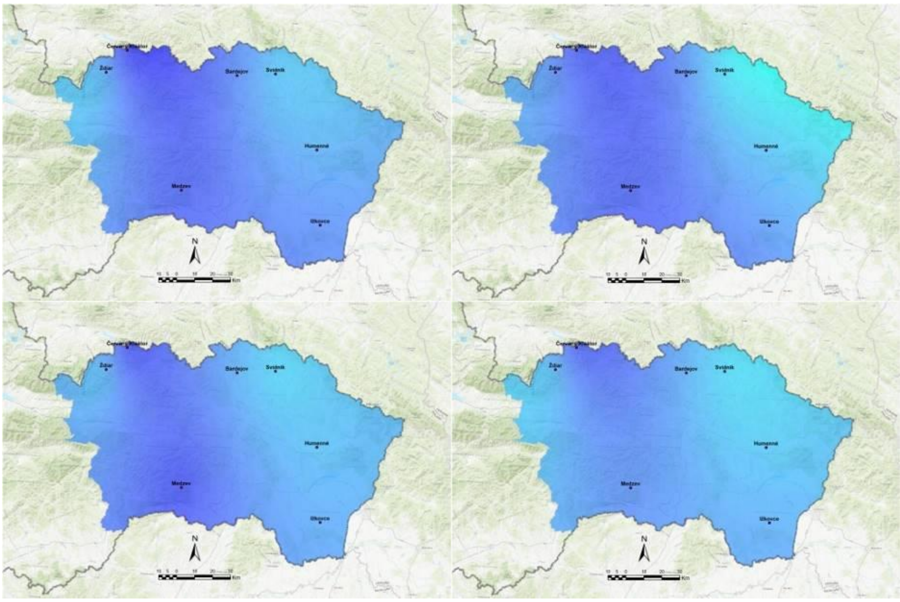


Fig. 9: Spatial distribution for the risk in the study area due to long-term hydrological drought in January, February, March and April 2011 using SSI-12

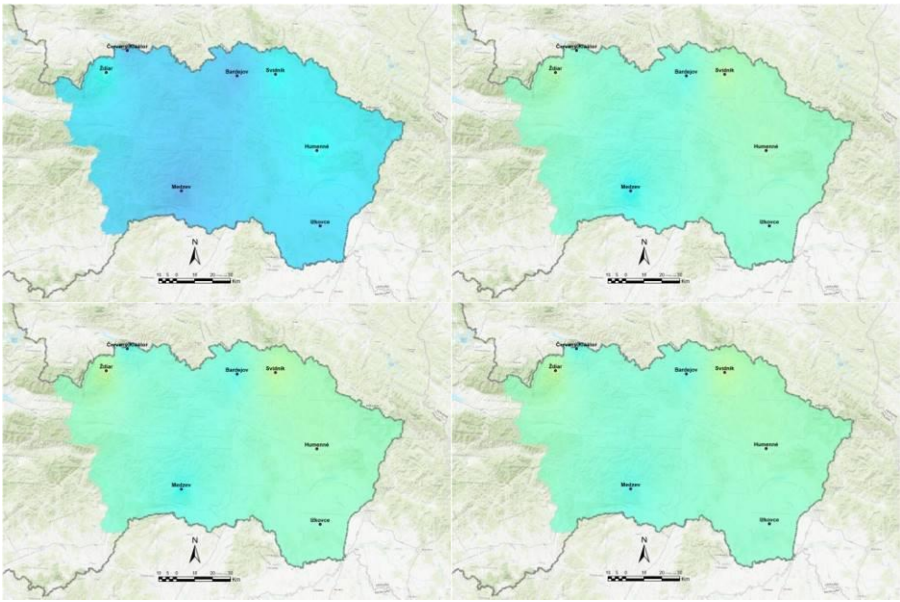
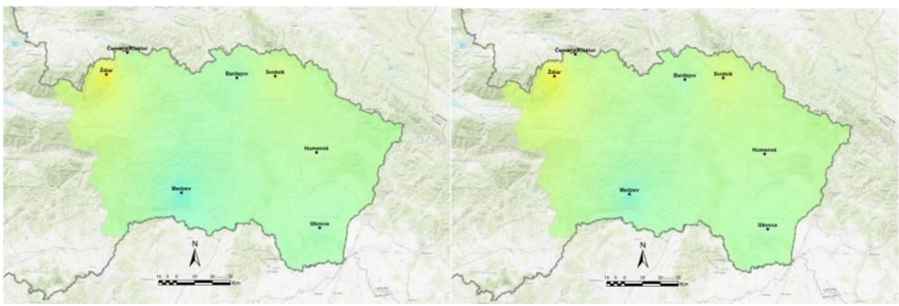


Fig. 10: Spatial distribution for the risk in the study area due to long-term hydrological drought in May, June, July and August 2011 using SSI-12



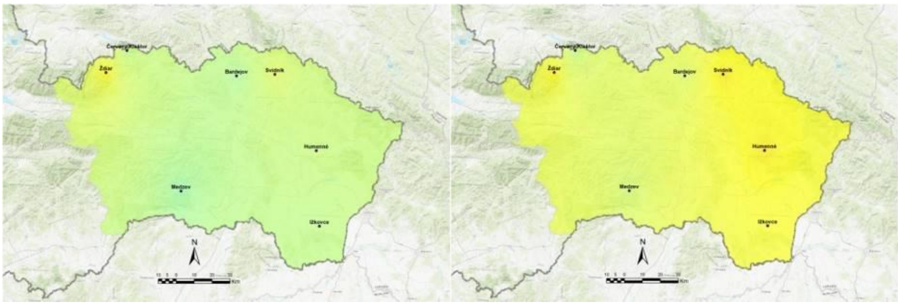


Fig. 11: Spatial distribution for the risk in the study area due to long-term hydrological drought in September, October, November and December 2011 using SSI-12

In 2011, the deficit of flows was recorded mainly in the autumn months and in December. In this year, the extréme hydrological drought did not occur at all.

Conclusion

Hydrological droughts are random natural phenomena with an increasing tendency depending on climate change. This phenomena affect also recreation. Understanding its manifestations in time and space leads to proper drought risk planning and management. For this purpose, the SSI approach was utilized to asses the extreme historical hydrological drought episodes during the years from 1972 to 2014 in Bodrog, Bodva, Dunajec and Poprad sub-catchment. Fifteen events of hydrological drought with a total cumulated severity of -85,88 were recorded in the Bodrog basin. Five extreme episodes of hydrological drought were detected in the Bodva basin with a total cumulated severity of -20,04. In the Dunajec and poprad basin, extreme hydrological drought were detected eight time with a total cumulated severity of -37,33. The most voulnerable area of the hydrological drought is the Bodva basin, where this phenomenon is expexted to occur more often. The benefits from the SSI analysis, it can be used to identify the degree of drought vulnerability. The results achieved can be the basis for the development of a drought management plan, which deals with prevention, protection and readiness for a drought risk in the catchment. From the presented analysis the south Slovakia seems to be more suitable for recreation (Junáková et al, 2020) as it is less vulnarable to drought.

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Souhrn

Hydrologické sucho je ojedinělý přírodní jev, jehož závažnost může být pro životní prostředí neúnosná. Sucho má také vliv na cestovní ruch a možnosti rekreace. Turisté se nejraději rekreují v místech s vodou. Poznání projevů sucha v minulosti nám umožňuje lépe pochopit jeho četnost a rozsah jeho dopadu na území. Za tímto účelem je v tomto článku prezentován standardizovaný index průtoku (SSI) vypočítaný na 12měsíční škále pro klasifikaci epizod hydrologického sucha v letech 1972-2014 na 7 vodoměrných stanicích nacházejících se ve východní části Slovenska. Byla provedena jednorozměrná analýza četnosti hydrologického sucha s cílem určit historickou epizodu extrémního sucha a průměrnou dobu mezi příchodem další epizody. Výsledky ukazují, že v dílčím povodí Bodvy se budou epizody extrémního sucha vyskytovat častěji. V dílčích povodích Dunaje a Popradu lze ojediněle očekávat extrémní sucha.

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