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HYDROLOGICAL HAZARD ASSESSMENT BY INDEX METHODS IN EASTERN SLOVAKIA

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ABSTRACT

The paper presents two indexes for the classification and space – temporal modelling of drought historical events during the year 1972 to 2014 in 7 gauging stations localized in the eastern part of Slovakia. Two different types of drought, namely: I) the meteorological drought is detected by SPI Standardized precipitation index – computed from monthly precipitations and II) the hydrological drought is detected by SSI – Standardized streamflow index – computed from monthly streamflow time’s series. These two indexes have the same mathematical background and can by computed by non-parametric approach as well as parametrical approach. As case study we have considered seven monthly time series, 43 years long, in gauging stations namely: Bardejov, Červený Kláštor, Humenné, Ižkovce, Medzev, Svidník a Ždiar for streamflow river stations: Bardejov, Červený Kláštor, Kamenica nad Cirochou, Vysoká nad Uhom, Štós, Tisinec and Skalnaté Pleso for precipitation, both in the period 1972 – 2014. The main contribution of this work is to reveal the temporal vulnerability of the studied area to drought and representation of results that could be used for monitoring, minimized future negative effects and managed with water resources in studied river basins.

1. Introduction

The effects of climate change, occurring over the last few decades, intensify, and therefore have become an object of interest to governments, the international community, and

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science. Results of scientific research [7] indicate that the consequences of climate change pose a threat to the social and economic development of many countries worldwide. The World Economic Forum, in its Global Risks Report [25], which regularly evaluates the 50 greatest global risks in terms of their impact, likelihood and interaction, has included extreme weather conditions, water scarcity, natural disasters and climate change mitigation adaptation to the adverse effects of climate change among the top five risks of the present. Changes in climate will have significant impact on local and regional hydrological regimes, which will in turn affect ecological, social and economic systems [9, 5]. The study of the frequency development of the hydro-meteorological variables on the longest time series provides information on the hydro-meteorological characteristics and, consequently, the likelihood of their occurrence in the future [4, 18, 21] e.g. by water management, the low flow period limits the use of surface water, the use of water for different purposes, the use of energy flows, navigation and so on. [16]. Assessment of extreme hydrological hazards documents the steps to be abstract value of these risks in catchment translated into scientifically measurable quantities, evaluation and re-transform them into information necessary for water management and proposal of efficient and beneficial measures.

The Intergovernmental Panel on Climate Change (IPCC) projection suggests a 0,85 °C rise in the temperature of 20th century, and consequently droughts will be more frequent and more severe. Therefore, there is an urgent need to improve drought preparedness through measures that respond to forecasts and drought consequences, thereby reducing the vulnerability of the territory. In this context, it is also important to distinguish between the different categories of drought and the causes of their formation [5].

The paper is focused on hydrological hazards, mainly to drought and its occurrence from temporal point of view in stations located in eastern Slovakia.

2. Methodology

Different methods have been proposed to identify, characterize and monitor the drought phenomenon, but among the most commonly used are drought indexes, which are a special combination of indicators including meteorological, hydrological, and other data. Depending on the type of drought, the most suitable indexes are selected [23].

2.1. Standardized precipitation index

The Standardized precipitation index (SPI) is based on the probability of precipitation for different time periods. McKeen et al. [8] proposed SPI to quantify precipitation dynamics and identify meteorological drought. The standardized precipitation index is widely used to characterize extreme dry as well as rainy seasons (Tab. 1), including recent publications: eg [1, 2, 12, 17, 19, 24, 26].

The calculation of the SPI can be performed using a parametric or non-parametric method. The differences between them are in the method of determining the probability density function $F(x)$ of long-term rainfall time series, and then a common step is to transform the cumulative probability function $F(x)$ into a standard normal distribution with random variable Z, which represents SPI [8]. Parametric methods have usually been favored over non-parametric methods in calculating SPI because precipitation is usually not normally distributed [1] and have been also used in this study.

Table 1. Classification based on index [1, 19]

Index	Category	Probability	Frequency
2.0 and more	Extremely wet	2,3%	1 time in 200 years
1,5 to 1,99	Very wet	4,4%	2 to 3 times in 100 years
1,0 to 1,49	Moderately wet	9,2%	8 times in 100 years
-0.99 to 0.99	Near normal	68,2%	16 times in 100 years
-1,0 to -1,49	Moderately dry	9,2%	8 times in 100 years
-1,5 to -1,99	Severely dry	4,4%	2 to 3 times 100 years
-2 and less	Extremely dry	2,3%	1 time in 200 years

Positive SPI values indicate that there is no dry period; they are higher than median of precipitation. Negative SPI values are less than median precipitation and indicate drought. SPI values range from 3 to -3 as can be seen in Tab. 1 [1, 3].

2.2. Standardized streamflow index

Nalbantis [14] has developed a Streamflow drought index (SDI) to evaluate the drought period according to long-term flow records. The SDI calculation procedure is very similar to the standardized SPI precipitation index, which measures the lack of precipitation, while the SDI evaluates the flow depression. According to Nalbantis [14], the calculation of SDI is based on aggregated monthly observed flow volumes. Modarres [13] introduced Standardized Streamflow Index (SSI) in 2007, and Telesca et al. [22] investigated it further. In this method, daily or monthly streamflow data can be applied and normalization is used associated with SPI as same as SDI calculation. SSI can be calculated for both observed and forecasted data and it can give a perspective for drought and wet periods [6]. SSI is a probability-based index and this makes SSI sensitive to the aspects and assumptions that regulate probabilistic hydrology. Tab. 1 shows the range of SSI values along with their classifications [15].

2.3. Study area

The studied area is the area of eastern Slovakia, including the administrative territory of the Danube and Vistula river basins. The analyzed river stations (Tab. 2) belong to the following sub-basins: Bodrog, Bodva, Dunajec (Fig. 1).

Table 2. Localization of evaluated stations

Gauge station / River station	Altitude	Longitude	Latitude
Bardejov / Bardejov	312 / 312	49°18'56"N/ 49°18'56"N	21°12'44"E/ 21°12'44"E
Červený Kláštor / Červený Kláštor	469 / 469	48°45'20"N/48°45'20"N	21°55'19"E/ 48°45'20"N
Kamenica nad Cirochou / Humenné	176 / 155	48°59'15"N/48°55'60"N	22°09'07"E/ 21°55'00"E
Vysoká nad Uhom / Ižkovce	230 / 100	49°18'20"N/ 48°33'22"N	21°34'05"E/ 21°57'11"E
Štós / Medzev	516 / 318	48°42'36"N/48°42'00"N	20°47'11"E/ 20°53'30"E
Tisinec / Svidník	192 / 216	49°13'16"N/49°13'19"N	21°38'13"E/ 21°38'13"E
Skalnaté Pleso / Ždiar	1778 / 896	49°11'21"N/ 49°16'18"N	20°14'01"E/ 20°15'44"E

Figure 1. Study area within river basins of Slovakia

Flow deficiency is noted in the observed watercourses, especially in winter (influenced by the duration of negative air temperatures) and in the summer-autumn period. In the summer-autumn period, the drainage of river basin reserves results from river network flow and evapotranspiration [20].

2.4. Data

The Slovak Hydrometeorological Institute provided time series of daily rainfall for 7 precipitation stations (Tab. 2). The data are collected for the period from 1972 to 2014, with no station missing data. There are zero monthly precipitation amounts in precipitation stations: in Bardejov in 2006 for August and September, in Ižkovce in March 1974, and also in Medzev in March 1974 and in February 1999.

For the calculation of SSI (Standardized Flow Index), the Slovak Hydrometeorological Institute provided daily flow rates for the period 1972 – 2014 for 7 river stations (Tab. 2) with the exception of Ižkovce, where daily flow schedules represent the period 1974 – 2014. Evaluated river stations have unchanged hydrological flow regime by human intervention (construction of water structures, excessive water abstraction and others).

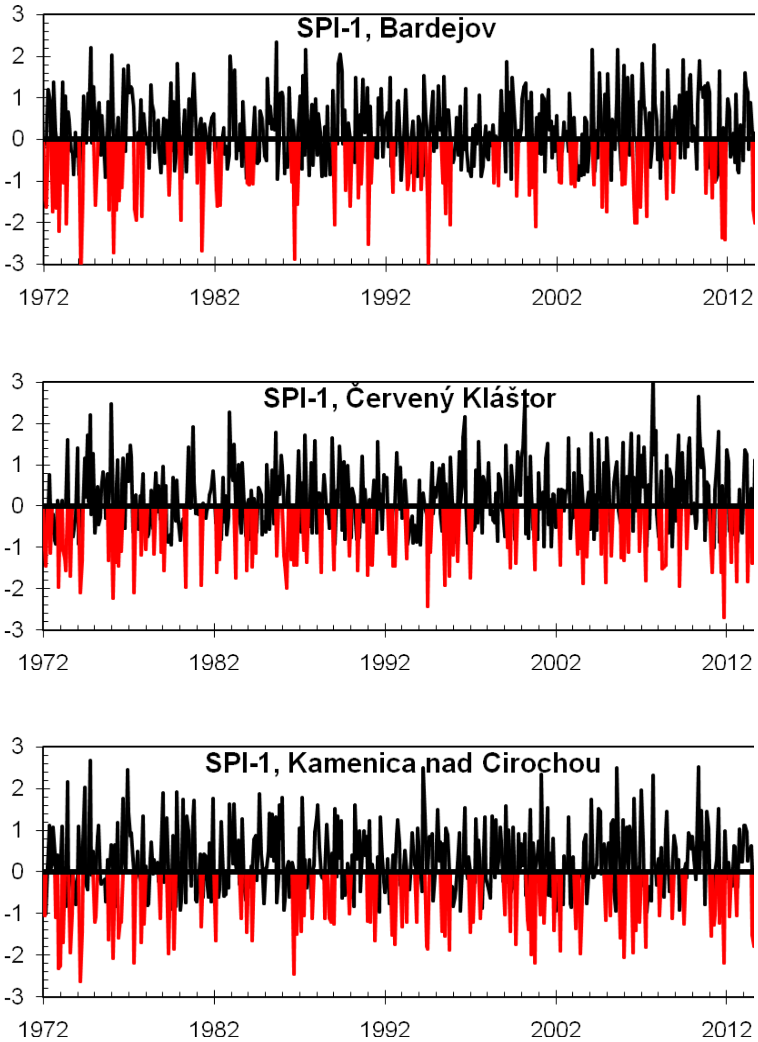
3. Results

The analysis and assessment of the occurrence of hydrological hazards is processed using the SPI and SSI indexes, which are irreplaceable in assessing the severity of droughts through their classification.

At present, indexes are an indispensable tool for drought management. The calculation of SPI and SSI at different time intervals (1, 3, 6, 12, 24 months) allows to characterize short and long term extreme deficits according to water resource management needs. Drought indicators are an essential tool for assessing the effects of drought and defining drought parameters, including the duration, severity and time of drought recovery. Understanding historical droughts is important in planning water resource management and forecasting and avoiding potential damage caused by river basin droughts [11].

3.1. Analysis and evaluation of mild to extreme meteorological droughts in the period 1972 – 2014

The occurrence of mild to extreme short-term meteorological drought was identified using the SPI-1 during 1972 – 2014 at 7 gauge stations. If the SPI was less than -1, it is characterized by its dry parameters (red in the graph) and with a probability of occurrence of 9,2%. Results are graphically processed in Fig. 2.



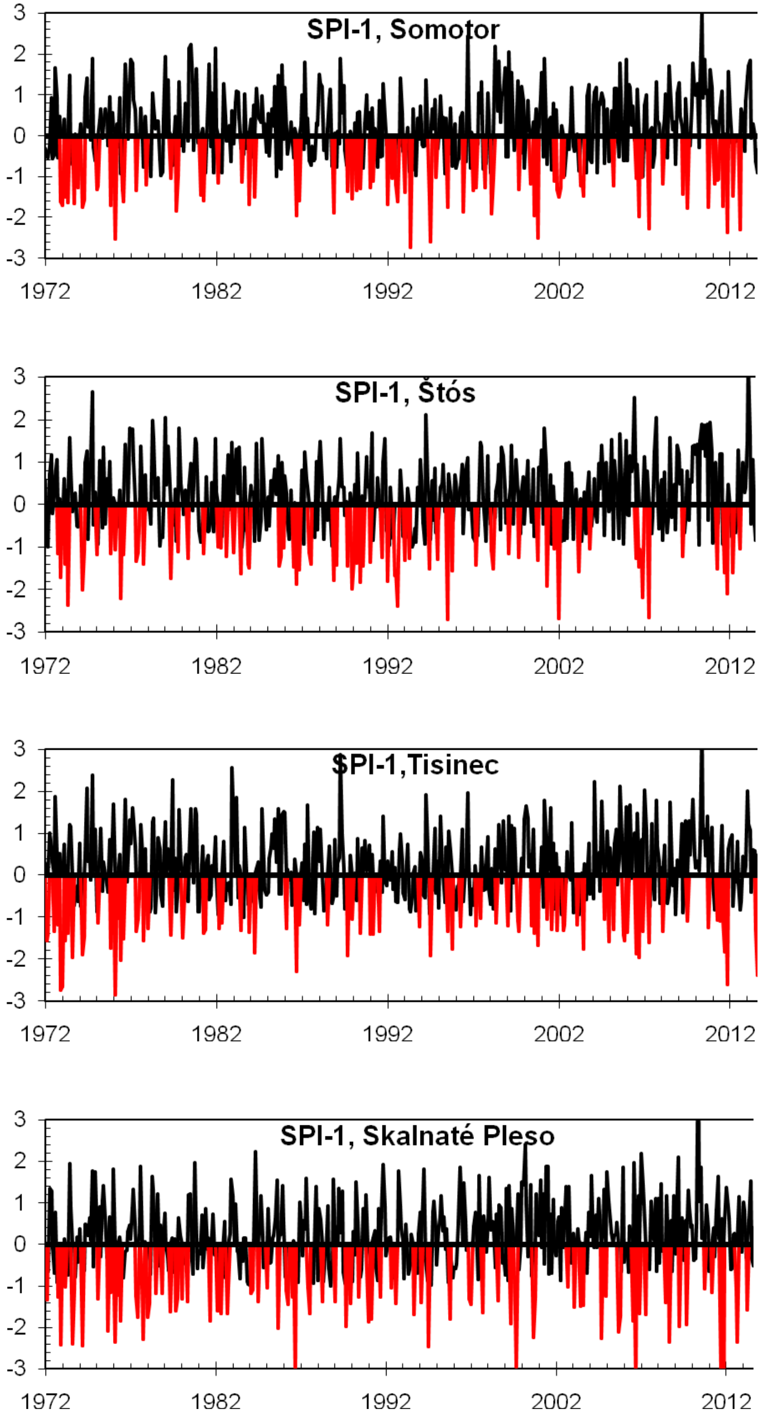
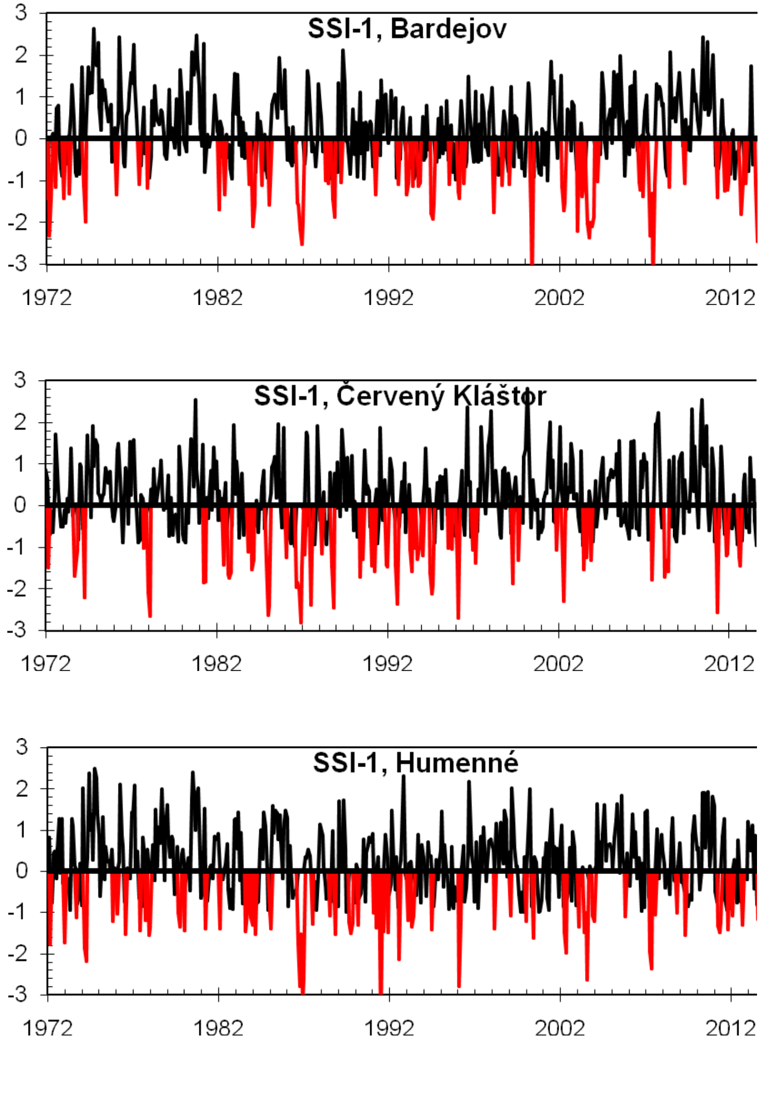


Figure 2. Graphical presentation of meteorological drought classification using SPI-1 in the selected stations in Slovakia

The most severe decade was the period from 1972 – 1981, when the most short-term meteorological drought events were recorded. The events of moderate drought during the period 1972 – 2014 were identified in Skalnaté Pleso and in Červený Kláštor.

3.2. Analysis and evaluation of mild to extreme hydrological droughts in the period 1972 – 2014

The incidence and identification of the basic parameters of short-term hydrological drought was calculated using SSI-1 from 1-month average flow rates collected over a 43-year period with the exception of Ižkovce. The results are presented in Fig. 3.



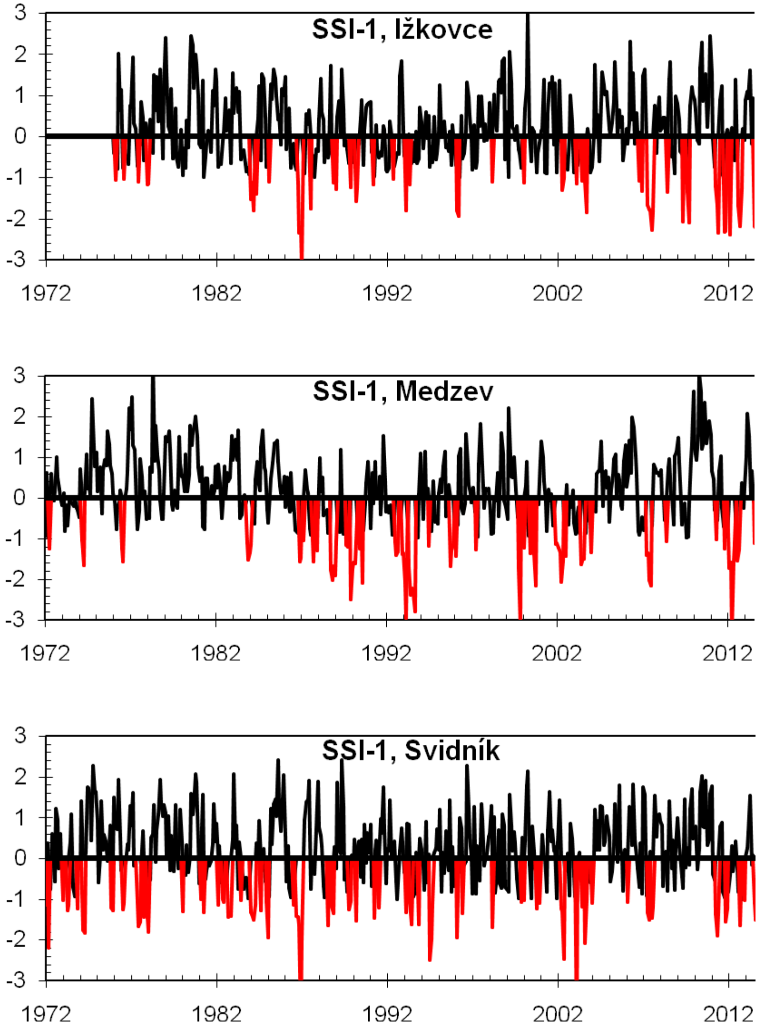


Figure 3. Graphical presentation of hydrological drought classification using SPI-1 in the selected stations in Slovakia

The largest record of short-term hydrological events was in the decade of 1982 – 1991. The longest duration of drought between the other stations was recorded in Svidník and Medzev river stations.

4. Conclusion

Assessment of extreme hydrological phenomena documents the steps to be abstract value of these risks in catchment translated into scientifically measurable quantities, evaluation and re-transform them into information necessary for water management and proposal of efficient and beneficial measures.

Determining the vulnerability of the area by hydrological drought is an important basis for proper management of water resources at the time of occurrence of this phenomenon, as well as eliminating its impacts on fauna and flora, as well as human activity through effective measures. Planning and anticipating the adverse effects of drought events in a river basin depends mainly on information on its extent, severity and duration. This information can be obtained through drought monitoring, which is usually done using drought indexes, which provide quantitative information on drought characteristics.

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REFERENCES

1. *Blain, G. C.* Revisiting the Probabilistic Definition of Drought: Strengths, Limitations and an Agrometeorological Adaptation. Bragantia. 2012. 71, 1, 132-141.

2. *Bothe, O., Fraedrich, K., Zhu, X.* The Large-Scale Circulations and Summer Drought and Wetness on the Tibetan Plateau. International Journal of Climatology, 2010, 30, 844 – 855.

3. *Hayes, J.* Understanding Your Risk and Impacts. National Drought Mitigation Center. Lincoln: University of Nebraska-Lincoln, Climate Impacts Specialist, 2006 http://www.drought.unl. edu /risk/impactvulner ability.htm, visited on 8.7.2018.

4. *Huh, S., Dickey, D. A., Meador, M. R., Ruhl, K. E.* Temporal Analysis of the Frequency and Duration of Low and High Streamflow: Years of Record Needed to Characterize Streamflow Variability. Journal of Hydrology, 2005, 310, 78 – 94.

5. IPCC (International Panel for Climatic Changes). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 2012. 582 p.

6. *Kermen, C., Onuşluel Gül, G.* Comparing Two Streamflow-Based Drought Indexes. In: Gastescu, P., Bretcan, P. ed. Water Resources and Wetlands, 4th International Conference Water Resources and Wetlands, 5-9 September 2018, Tulcea (Romania), pp. 190 – 195.

7. *Kundzewicz Z.W., Radziejewski M., Pińskwar I.* Precipitation Extremes in the Changing Climate of Europe. Climate Research, 2006, 31, 51 – 58.

8. *McKee, T. B., Doesken N. J., Kleist, J.* The Relationship of Drought Frequency and Duration to Time Scale. In: Proceedings of the Eighth Conference on Applied Climatology, Anaheim, California, 17–22 January 1993. Boston, American Meteorological Society, 179 – 184.

9. ME SR (Ministry of the Environment of the Slovak Republic). Strategy of the Adaptation of the Slovak Republic to the Adverse Consequences of the Climate Change – Actualization. 2017. https://climate-adapt.eea.europa.eu/repository/11273729.pdf, visited on 29.4.2019.

10. ME SR (Ministry of the Environment of the Slovak Republic). Preliminary Overview of Significant Water Management Problems. The Vistula River Basin District for the

Planning Period 2015-2021. ME SR. 2009. www.vuvh.sk/download/RSV/V_VH_problemy_ Visla2013.pdf, visited on 8.7.2018.

11. *Mishra, K., Singh, P.* A Review of Drought Concepts. Journal of Hydrology, 2010, 391, 202 – 216.

12. *Mo, K. C., Schemm, J. E.* Relationship Between ENSO and Drought over the Southeastern United States. Geophysical Research Letters, 2008, 35, L15701.

13. *Modarres, R.* Streamflow Drought Time Series Forecasting. Stochastic Environmental Research and Risk Assessment, 2007, 21, 223 – 233.

14. *Nalbantis, I.* Evaluation of a Hydrological Drought Index. European Water, 2008, 23, 67 – 77.

15. *Nalbantis, I., Tsakiris, G.* Assessment of Hydrological Drought Revisited. Water Resources Management. 2009, 23, 881 – 897.

16. *Pekárová, P., Pramuk, B., Miklánek, P.* Are Floods in Slovakia Larger and Droughts Longer than in the Past? (in Slovak) In XX. Okresné dni vody: Reviewed proceeding. Bratislava; Michalovce; Košice: ÚH SAV, 2016, p. 21-26.

17. *Santos, J. F., Pulido-Calvo, I., Portela, M. M.* Spatial and Temporal Variability of Droughts in Portugal. Water Resources Research, 2010, 46, W03503.

18. *Shiau, J. T.* Return Period of Bivariate Distributed Extreme Hydrological Events. Stochastic Environmental Research and Risk Assessment, 2003, 17, 42 – 57.

19. *Sienz, F., Bothe, O., Fraedrich, K.* Monitoring and Quantifying Future Climate Projections of Dryness and Wetness Extremes: SPI Bias. Hydrology and Earth System Sciences, 2012, 2143 – 2157.

20. *Szolgay, J., Dzubák, M., Hlavčová, K.* Hydrology. Runoff and Surface Water Hydrology (in Slovak), Bratislava, 1994, p. 46 – 276. ISBN 80-227-0641-8.

21. *Szolgay, J., Hlavčová, K., Lapin, M., Danihlík, R.* Impact of Climate Change on Mean Monthly of Runoff in Slovakia. Meteorologický časopis, 2003, 6, 9 – 21.

22. *Telesca, L., Lovallo, M., Lopez-Moreno, I. Vicente-Serrano, S.* Investigation of Scaling Properties in Monthly Streamflow and Standardized Streamflow Index Time Series in the Ebro Basin (Spain). Physica A: Statistical Mechanics and its Applications, 2012, 391, 1662 – 1678.

23. *Tsakiris G., Loukas A., Pangalou D., Vangelis H., Tigkas D., Rossi G., Cancelliere A.* Drought Characterization [Part 1. Components of Drought Planning. 1.3. Methodological Component]. In: Iglesias A. (ed.), Moneo M. (ed.), López-Francos A. (ed.). Drought Management Guidelines Technical Annex. Zaragoza: CIHEAM / EC MEDA Water, 2007, p. 85 – 102.

24. *Vicente-Serrano, S. M.* Differences in Spatial Patterns of Drought on Different Time Scales: An Analysis of the Iberian Peninsula, Water Resources Management, 2006, 20, 37 – 60.

25. WEF (World Economic Forum). The Global Risks Report 2017, 12th Edition, 2017.

26. *Zhang, L., Singh, V. P.* Gumbel–Hougaard Copula for Trivariate Rainfall Frequency Analysis. Journal of Hydrological Engineering, 2007, 12, 4, 409 – 419.