FREQUENCY ANALYSIS SEVERE METEOROLOGICAL DROUGHT IN THE EASTERN PART OF SLOVAKIA

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Abstract

This study deals with two drought indexes: Standardized precipitation index (SPI) and Reconnaissance drought index (RDI) during the time interval 1972-2022. Then the identification of severe meteorological drought event was detected if the index value was less than -1.5. In the recent years eastern Slovakia has faced intensit meteorological drought due to climate change and it will be more frequent in the future. This fact establishes importace to analyze and predicted the meteorological drought in monitored territory in order to minimize the negative effect on fauna and flora as well as environment.

Keywords: assessment of drought, Standardized Precipitation Index, Reconnaissance Drought Index, severe droughts, Slovakia

Introduction

Meteorological drought is a natural phenomenon with temporally negative and severe deviation from average value of precipitation totals (COM (2007). The primary cause of the meteorological drought in eastern Slovakia is a persistent deficit of rainfall, and its severity is additionally influenced by other factors like air humidity, wind speed, sunlight. Characteristics of meteorological drought (such as duration, severity, intensity, inter-arrival time) in a specific region can be assesses using drought indexes such as SPI or RDI. These indexes measure the drought on numerical scale that reflect unusually wet, normal and unusually dry periods. RDI can truly represent the water availability of a region because it based on the difference between precipitation and evapotranspiration while SPI depends only on precipitation (Marini et al., 2018). Some studies such as: Tsakiris et al., 2007, Merabti et al., 2017, Khalili et al., 2010, Marini et al., 2018, Zarch et al., 2011, Pashuardis and Michaelides, 2008, Surendran et al., 2019, Sobral et al., 2018 have compared the Standardized Precipitation Index (SPI) and the Reconnaissance Drought Index (RDI) in different locations. Local-scale comparisons have demonstrated that both indices exhibit similar performance in identifying and assessing the severity of dry and wet events in spite of the SPI relies on monthly precipitation (P), whereas RDI is based on the ratio of P to monthly potential evapotranspiration (PET).

Surendran et al., (2019) quantified complex natural phenomenon by deciles, SPI, RDI and Streamflow drought index SDI in Madurai region in India during the year 1901-2004 and they detected that the Streamflow drought index SDI gave a different trend than SPI or RDI and that SPI is better index than deciles. Marini et al., (2018) investigated the meteorological drought events in Apulia region using two drought indices (SPI and RDI) for the period 1960–2012 and they found that the east zone is drier than the west zone of Apulia. Khatiwada et al., (2019) explored dynamics of spatio-temporal variation of drought events across the Western Nepal by the different meteorological drought indixes (SPI, SPEI, RDI and PDSI) and hydrological drought indices (SPI and PDSI). Ramkar et al., (2018) dealt with temporal analysis of meteorological drought by RD, RDI, and SPI during the years 1981-2013 in the west-central part of India. Comparison of the RDI and SPI showed different results considering the severity and the period of drought event and results of RDI appeared to be slightly more accurate than SPI. They concluded that the agricultural area of Girna River is more vulnerable to drought. Mohamed et al., (2023) examined the long-term precipitation anomalies by RDI and SPI indices in Tunisia during the years 1958-2020 and found that drought conditions were similar in frequency, duration and severity. They stated that SPI-12 is better for planning and

management of water resources in Tunisia. Nagy et al., (2020) examined dry and wet periods from 1960 to 2015 using drought indices (SDI, SPI, RDI and SPEI) with a 12- month timescales. The findings revealed alternating dry and wet periods. Despite various in input indicators among the indices, common assessment periods were identified, particularly in the Poprad/Svit stations.
Due to simplicity calculation of RDI, same autors: Dastorani et al., (2011), Alemu et al., (2023), Ogunrinde et al., (2023), Ashraf et al., (2022), Zarch et al., (2015) and Akbari et al., (2016) made an assessment of future drought occurrence using climate models. Others authors examined the agricultural drought by RDI for instance: Tian et al., (2022), Vergoni et al., (2021), Abdelmalek and Nouiri (2020), Zarei et al., (2021).
The aim of this paper is an identification and quantification of severe precipitation anomalies over an annual time scale across eastern part of Slovakia for the last fifty-year time period using RDI and SPI.

Materials and methods

The monitored area is shown in Figure 1. It is presented by four synoptic stations; Bardejov (49°18'56"N, 21°12'44"E), Červený Kláštor (49°23'30"N, 20°24'19"E), Košice (48°42'58"N, 21°15'39"E), Spišské Vlachy (48°56'54"N, 20°47'38"E). The metropolis of eastern Slovakia is Košice while the total area of mentioned territory is 16 179 km^2 and with a population of 1.6 million. The northwest border with Poland is formed by the High Tatras mountain. The northern border is further formed by the lower mountain Spišská Magura and the very extensive Nizke Beskydy extending from the northwest of eastern Slovakia to northeast. The Vihorlat mountain rises above the town of Humenné. The Východoslovenská lowland stretches in southeastern part of territory. The Slovak Rudohorie, Slovak Karst and Slovak Paradise are located in the southwestern part of the territory. This territory is located in a temperate climate zone, whereas the area around Červený Kláštor is characterized by the highest average precipitation value and the area around Košice is characterized by the lowest average precipitation value. From the water management point of view, this territory (eastern, northern and western part of the territory) is classified as a moderately sensitive to a very sensitive territory (south-eastern Slovakia) to the occurrence of hydrological drought (MŽP SR, 2018). Values of monthly precipitation, minimum and maximum temperature were provided by Slovak Hydrometeorological Institute of Košice for a period of years 1972-2022 for presented stations.

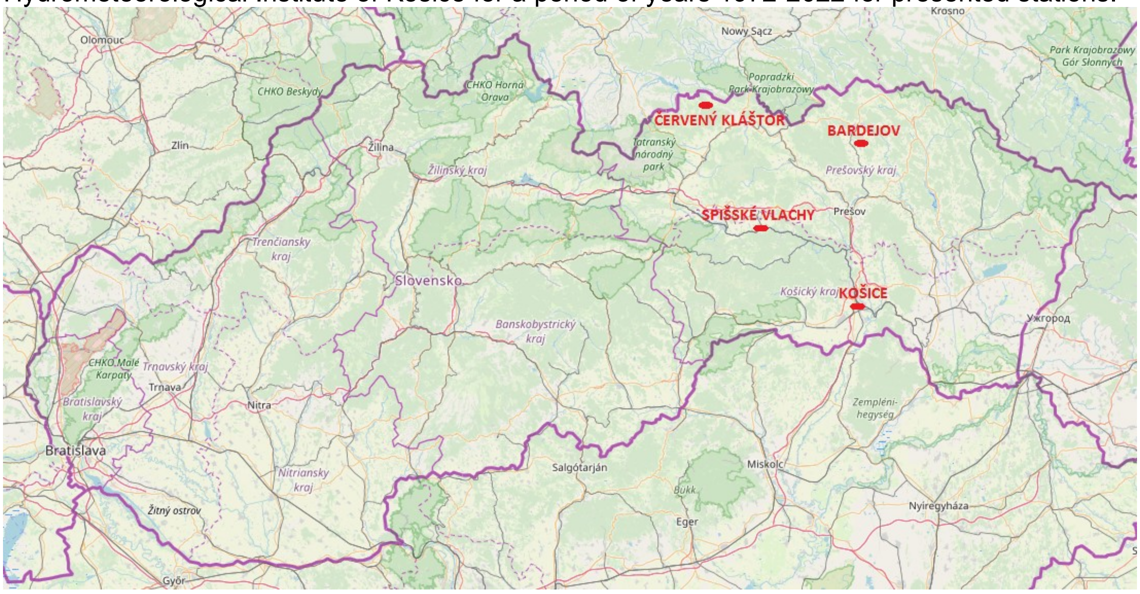

Fig. 1: Monitored area of eastern Slovakia

The methodology includes three steps. The first step involves completing statistical files. Monthly precipitation series, along with minimum and maximum temperatures series for a reference period are condensed into 12-month time scales. The second step consist of calculating the two drought indexes namely SPI and RDI in a DrinC program. The third step contain the determination of the main characteristics of severe meteorological drought at four meteorological stations.

In the context of drought management, it is crucial to categorize the risk of drought into distinct levels, as these categories play a significant role in assessing the severity of the drought. The classification of meteorological drought based on the Standardized Precipitation Index (SPI) or Reconnaissance drought index (RDI) is presented in Table 1, comprising eight distinct categories (Blain, 2012), (Sienz et al., 2012) (Zarch et al., 2011). This study specifically focuses on events classified as severe drought. The identification of the historical severe drought events spanning from 1972 to 2022 employed to RUN method (Yevjevich, 1967). Subsequently, the primary characteristics of drought, including duration, severity, number of drought events and average inter-arrival time were determined. A threshold drought level of (Z=-1.5) was utilized to detect the initiation of severe drought event. Consequently, if ($Z < -1.5$), drought conditions were recognized, and the duration of a drought (D_d) was defined as the period during which index values consistently remained below -1.5. The severity of a drought (S_d) was calculated as the cumulative value of the index throughout the drought period. The inter-arrival time (T_d) denoted the duration between two consecutive droughts (Madadgar et al., 2011).

Tab. 1: Classification of meteorological drought using index Z (SPI or RDI_{st})

Z intervals	Z classes	Probability events
≥2	extreme humidity	2,3%
1,5 to 1,99	high humidity	4,4%
1,0 to 1,49	mild humidity	9,2%
0,99 to - 0,99	almost normal humidity	68,2%
-1,0 to -1,49	moderate drought	9,2%
-1,5 to -1,99	severe drought	4,4%
≤-2	extreme drought	2,3%

Results

For the analysis of meteorological drought in the eastern part of Slovakia covering an area of 16 179 km^2, data spanning 50 years was utilized. The objective of this study was to examine the historical occurrence of severe drought, determine the average recurrence of prolonged meteorological drought, and assess the region's vulnerability to drought. Identification of prolonged meteorological drought events was based on the 12-month Standardized Precipitation Index (SPI) and the 12-month Reconnaissance Drought Index (RDI). The outcomes of the temporal analysis at the four stations are presented in Figures from 2 to 7. Figures 2 and 3 show the frequency of the severe drought event by SPI-12 and RDI-12 respectively at the four stations.

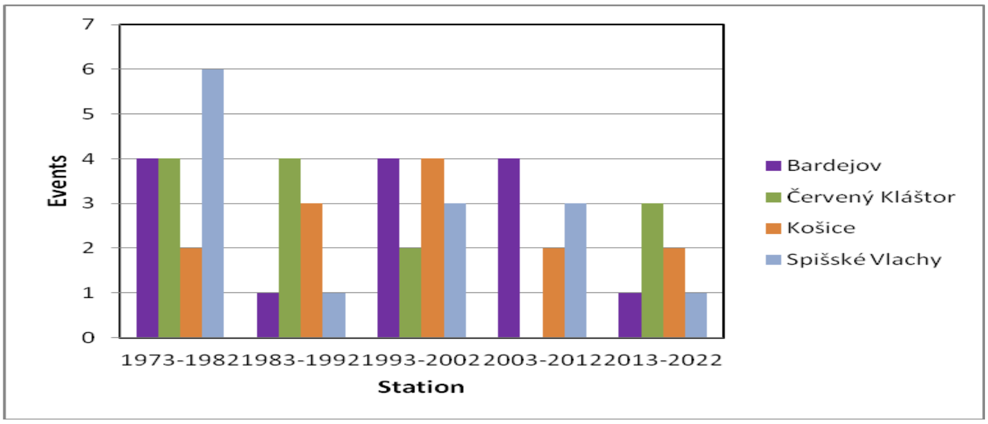

Fig. 2: Frequency of the severe drought event by SPI-12 at the four stations

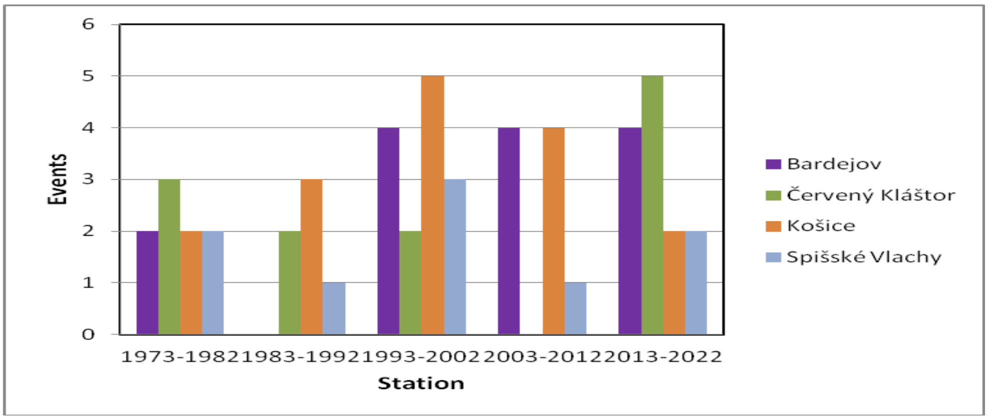

Fig. 3: Frequency of the severe drought event by RDI-12 at the four stations

The frequency analysis of severe drought identified by the indices is not completely identical. The results from the SPI-12 index show that the most severe decade was in 1973-1982 while the RDI-12 index was the period of 1993-2002. It is clear that the meteorological drought deepened in this decade also due to the influence of climatic factors. The Characterization of severe meteorological drought by SPI-12 and RDIst-12 are shown in Table 2.

Tab. 2: Characterization of severe meteorological drought by SPI-12 and RDI_{st}-12

Water meter station	**Events**		**Duration (months)**		**Cumulative severity**		**Inter-arrival time (year)**	
	SPI	RDI_{st}	SPI	RDI_{st}	SPI	RDI_{st}	SPI	RDI_{st}
Bardejov	14	14	24	26	-43.7	-47.8	3.45	3.45
Červený Kláštor	13	12	44	40	-75.5	-79.7	4.07	3.76
Košice	13	16	31	29	-56.8	-49.9	4.03	2.98
Spišské Vlachy	14	9	39	42	-70.8	-76.3	3.46	5.36

Comparison between RDI and SPI at the four stations for the period from 1972 to 2022 are shown in figures 4 to 7.

For RDI-12, a total of 14 episodes of severe drought were recorded at the Bardejov precipitation station with a total cumulative severity of –47.8 and total duration 26 months. In years: 1994, 2003 and 2022 were prolonged severe meteorological drought. The average drought return time at Bardejov station is 3.45 years. The severe episodes of drought lasted a short time (Figure 4). Sometimes histogram of RDI-12 is overestimate mainly in year 1978-79, 1980-81 and sometime curve of RDI-12 is underestimate mainly in year 2016-2018, 2019-2020 in confront of curve of SPI-12, but in a larger time scale the curve of RDI -12 is similar to curve of SPI-12 in Bardejov station. The number of severe drought episodes in Bardejov station turned out to be the same, even if with some differences in timing, the years with the same record of severe drought are 1974, 1982, 1993, 1994, 2003, 2011, 2016 and 2022.

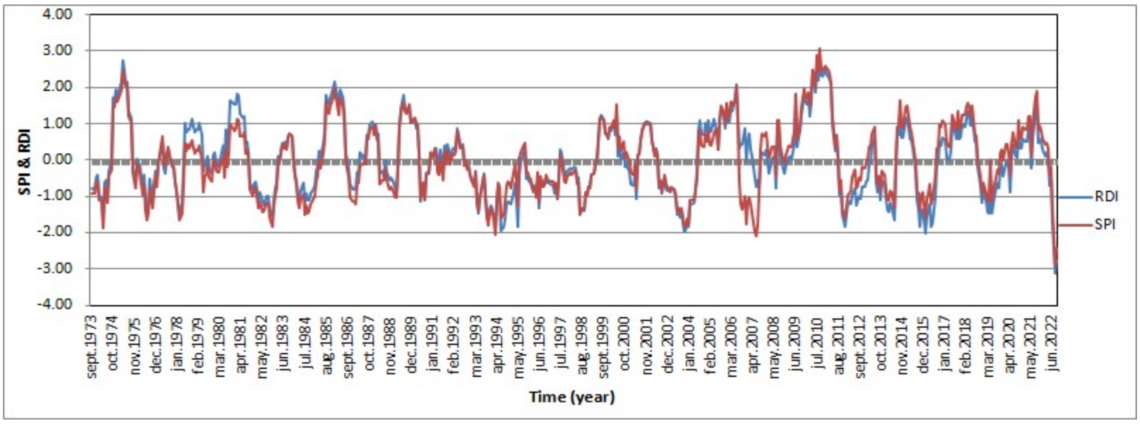

Fig. 4: Annual drought indexes at station Bardejov for the period (1972-2022).

For RDI-12, a total of 12 episodes of severe drought were recorded at the Červený Kláštor precipitation station with a total cumulative severity of –79.7 and total duration 40 months. In years: 1973, 1986, 1993, 1994, 2012, 2022 were prolonged severe meteorological drought. The average drought return time at Červený Kláštor station is 3.76 years. The severe episodes of drought lasted a short time (Figure 5). Sometimes histogram of RDI-12 is overestimate mainly in year 1978-81, 2004-05 and sometime curve of RDI-12 is underestimate mainly in year 1994-1995, 2012-2013, 2016-2020 in confront of curve of SPI-12, but in a larger time scale the curve of RDI-12 is similar to curve of SPI-12 in Červený Kláštor station. The number of severe drought episodes in Červený Kláštor station is different with small differences in timing; the years with the same record of severe drought are 1973, 1974, 1978, 1986, 1991, 1993, 1994, 2012, 2014 and 2022.

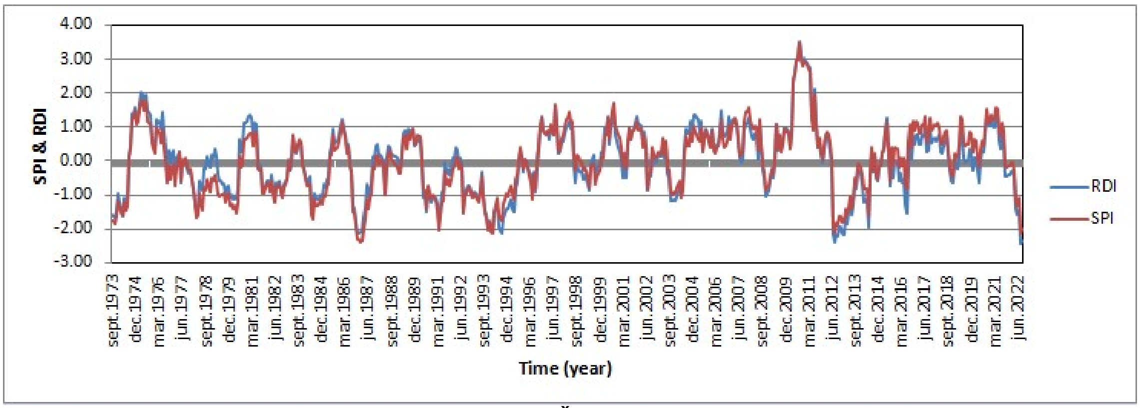

Fig. 5: Annual drought indexes at station Červený Kláštor for the period (1972-2022).

Košice precipitation station recorded a total of 16 severe drought episodes for RDI-12 accumulating to a severity -49.9 over 29 months. Prolonged meteorological drought occurred in 1973, 1986 and 1993. On average, the drought return time at Košice station is 2.97 years, mainly with short-lasting severe drought episodes (see Figure 6). The RDI-12 histogram occasionally overestimates especially in 1978, 1980 and 2005 while the RDI-12 curve underestimates in 2007-2008, 2011-2013 and 2015-2016 compared to the SPI-12 curve at Košice station. Notably, RDI-12 identifies more drought events than SPI-12, with shared severe drought records in 1977, 1986, 1990, 1991, 1993, 1994, 1995, 2007, 2018 and 2022.

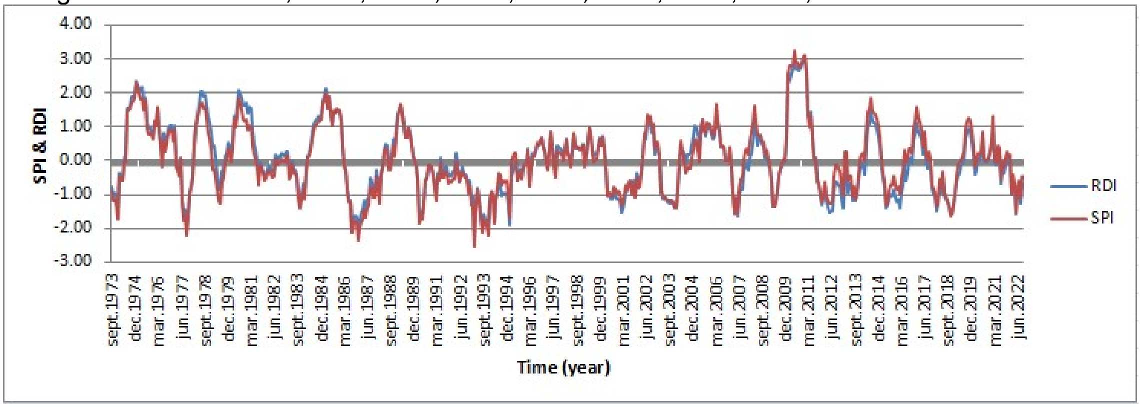

Fig. 6: Annual drought indexes at station Košice for the period (1972-2022).

Spišské Vlachy precipitation station recorded a total of 9 severe drought episodes from RDI-12, with a cumulative severity of -76.3 over 42 months. Prolonged severe meteorological drought occurred in the years 1974, 1986, 1993, 2011, 2015 and 2022. The average drought return time at the Spišské Vlachy station is 5.36 years. The severe drought episodes were generally of short duration as shown in Figure 7. Occasionally, the histogram of RDI-12 overestimates particularly in the year 1978-80, 1991-92, 1996-98 while sometime the curve of RDI-12 underestimates mainly in the years 2000-2001 compared to the curve SPI-12. However in a larger time scale the curve of RDI-12 is similar to the curve of SPI-12 at the Spišské Vlachy station. The number of severe drought episodes detected by RDI-12 is slightly less than SPI-12, with small differences. The years with the same record of severe drought are 1974, 1986, 1993, 1994, 2011, 2015 and 2022.

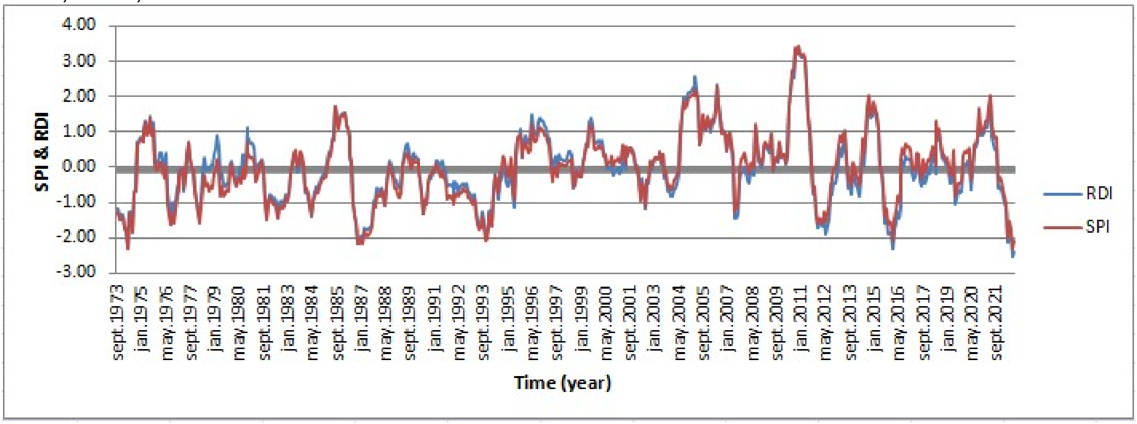

Fig. 7: Annual drought indexes at station Spišské Vlachy for the period (1972-2022).

Conclusion

Occurrence of drought in the area complicate the possibilities for recreation of visitors. The article presents the assessment of drought in eastern Slovakia. Drought constitutes a hydro-climatic risk at the regional level, and its adverse impacts may intensify due to climate change. In this study, we employed the Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI) to analyze drought conditions at four precipitation stations in the eastern part of Slovakia. Drought index approaches (SPI and RDI) were used to assess severe historical meteorological drought events during the period (1972-2022). The annual drought analysis revealed that the average return time for severe meteorological droughts varies between 3.45 to 5.36 years. More frequent severe droughts are identified in Košice station, and there is the smallest average return time. The results showed that the northern part of eastern Slovakia surrounding city Červený Kláštor is more vulnerable to drought because there are estimated events with the biggest cumulative severity and the longest duration. In the central part of the studied area in Spišske Vlachy, an almost annual event of severe meteorological drought occurred in October 1986, and the longest eleven-month event was detected in the northern part in the Červený Klaštor city. The years 1993, 1994 and 2022 represent severe years with extensive, severe and widespread occurrence of meteorological drought. The findings highlight the susceptibility of individual weather stations to the infrequent incidence of meteorological drought, providing valuable insights for improved coordination and management of this phenomenon when it occurs for purpose to minimize negative impact on animate and inanimate components of nature as well as human activities in the investigated area.

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Souhrn
Tato studie se zabývá dvěma indexy sucha: Standardizovaný srážkový index (SPI) a průzkumný index sucha (RDI) v časovém intervalu 1972-2022. Identifikace závažného meteorologického sucha pak byla zjištěna, pokud byla hodnota indexu menší než -1,5. Východní Slovensko se v posledních letech potýká s intenzivním meteorologickým suchem v důsledku klimatických změn a v budoucnu se bude vyskytovat častěji. Tato skutečnost zakládá důležitost analýzy a předpovědi meteorologického sucha na sledovaném území s cílem minimalizovat negativní dopad na faunu a flóru i životní prostředí.

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