An assessment of historical short-time precipitation deficiency in eastern Slovakia and northern Serbia according to the SPI-3

Tatiana SOĽÁKOVÁ, Martina ZELEŇÁKOVÁ, Hany ABD-ELHAMID, Milan GOCIC, Helena HLAVATÁ, Peter BUJANSKÝ, Miroslav GARAJ

Short-term precipitation deficiency is one of the primary causes of agricultural drought, which can have far-reaching consequences on various aspects such as society, environment, and the economy. This complex natural phenomenon attracts more attention due to changes in precipitation pattern. The use of the SPI-3 index for the quantitative measure of precipitation anomalies over a three-month period across the eastern part of Slovakia and the northern part of Serbia is a valuable approach in understanding and managing drought conditions in these countries with different climate conditions. The SPI-3 can be highly beneficial for the farmers, policymakers, and water resource managers when it comes to making informed decisions about irrigation, crop selection and water allocation during drought events. In northern Serbia and eastern Slovakia, the extreme precipitation anomalies often occur during the autumn season. Predicting extreme rainfall anomalies, especially during the growing season, is highly justified and essential for effective natural risk management in agriculture-dependent countries. The average inter-arrival time of an extreme precipitation deficit is in the north of Serbia ranges from 3.1 to 5.1 years, while in the east of Slovakia it ranges from 3.2 to 5.9 years.

KEY WORDS: precipitation deficiency, agricultural drought, SPI, Slovakia, Serbia

Introduction

Agricultural drought is a natural phenomenon that occurs when there is a prolonged deficiency in precipitation or insufficient soil moisture to support crop growth. Drought indices like SPI (Standardized Precipitation Index), SPEI (Standardized Precipitation Evapotranspiration Index) and PDSI (Palmer Drought Severity Index) are crucial tools for characterizing and quantifying agricultural drought. These indices provide valuable information for assessing the severity, duration and spatial extent of drought conditions, in addition to effective drought monitoring and management (McKee et al., 1993; Vincente-Serrano et al., 2010; Palmer, 1965). The European Drought Observatory (EDO) is a useful resource for monitoring and assessing drought conditions in Europe. It utilizes various drought indices to identify drought expansion in European regions as well as to apply adaptation strategies to mitigate future economic losses due to drought. It is essential for governments, businesses, and communities to work together to address this issue and minimize the economic consequences of drought in the EU. Nowadays, the prediction for a future next ten years is that the economic consequences will be 9.68 billion EUR (CGTN, 2023). The analysis of short-term rainfall anomalies and their effects on the environment have been studied throughout Europe by a number of researchers (e.g. Mohammed et al. (2022) in Hungary, Vergni et al. (2021) in Italy, Popova et al. (2014) in Bulgaria, Potop et al. (2010) in Czech Republic, Pandžić et al. (2022) in Croatia Labedzki (2007) or Kubíak-Wójcicka et al. (2023) in Poland, Kobulinckzy et al. (2023) in Romania and Slovenia Payab and Türker (2019) in Cyprus, Tiqkas et al. (2019) in Greece, Kubíak-Wójcicka et al. (2021) in Slovakia. Also, some researchers have studied soil moisture deficiency in Slovakia. Vido et al. (2019) examined precipitation and evapotranspiration anomalies using SPEI in Arborétem Mlyňany. Kišš et al. (2021) observed the occurrence of physical drought in Nitra River basin. Takáč et al. (2015) investigated agricultural drought events in Danube lowland using Daisy model. Zuzulova and Vido (2018) tested the correlation relationship between normalized difference vegetation index NDVI and Palmer drought severity index PDSI during the time period of 2000–2014 in twelve cities. Portela et al. (2015) calculated three-month standardized precipitation index in whole Slovak country during the reference period 1981–2013. For instance, the following authors addressed the issue of meteorological drought in Slovakia: Škvareninová et al. (2018), Soľáková et al. (2022), Almkiael et al. (2023). Mimić et al. (2022) and Strievic et al. (2011) studied soil moisture deficiency and its consequence on agriculture.
yields and proposed new methodology for early warning system in northern Serbia. Mimić et al. (2022) studied a level of moisture stress in maize and sunflower yields during the summer in Vojvodina province. Mimić et al. (2022) stated that maize was the most sensitive to drought. Striević et al. (2011) presented their authentic methodology, which they tested at 9 meteorological stations located at northern Serbia. Northern Serbia is an area with high agricultural production thanks also the USAID project, which supported unemployed people to set up greenhouses for growing crops especially higher-value crops such as peppers, lettuce, tomatoes and cucumbers (USAID, 2023). The main aim of this study is to compare the short-term deficiency of precipitation using SPI-3 index and predict future drought in different study areas in Slovakia and Serbia.

Material and methods

Eastern Slovakia and northern Serbia (see Fig. 1) have a temperate continental climate with cold winters and hot and humid summers. East Slovakia lowland is the most important region for agriculture in Slovakia and also northern Serbia is an area with high agriculture production too. Eastern Slovakia is represented by five synoptic stations located in Bardejov, Humenné, Ždiar, Medzev a Spišské Vlachy. Mentioned stations lie on the territory of sub-basins: Dunajec and Poprad, Bodrog, Bodva, Hornad with land area 14494 km², of which 47.13% is agricultural land. Northern Serbia is represented by five synoptic stations located in Kikinda, Zrenjanin, Sombor, Palić and Novi Sad. These stations belong to the Tisza sub-basin, covering 10057 km² in Serbia, with agricultural land making up 86.47% of the total area. Values of monthly precipitation are provided by Hydrometeorological Institute of Serbia and Slovak Hydrometeorological Institute of Košice for the time period (1972–2019). All selected rain gauge stations had complete data on total rainfall for the analyzed time interval. The agricultural area occupies a smaller area in the territory of eastern Slovakia than in the territory of northern Serbia. In the territory of eastern Slovakia mainly; wheat, barley and maize are grown while in the territory of northern Serbia, mainly; peppers, lettuce, tomatoes and cucumbers are grown (MINZP, 2023; Interreg 2023). Extreme short-term precipitation deficit in vegetation period is one of the primary causes of agricultural drought, which can lead to deficiency of soil water content and can result in social, environmental and especially economic problems. For the analysis of extreme short-term precipitation deficit we calculated three-month standardized precipitation index (SPI-3). Computation of the SPI-3 involves fitting a gamma probability density function to obtain cumulative distribution function of three months precipitation totals.

![Fig. 1. Studied areas in Slovakia and northern Serbia.](image-url)
for a given month for a selected rain gauge station. The cumulative distribution function of gamma function is then transformed to the standard normal random variable, which represents the value of the SPI. These mathematical operations were performed in the DrInC program. Then, based on SPI values, we can classify periods into several categories: extremely wet (SPI>2), very wet (SPI between 1.5 and 1.99), moderately wet (SPI between 1.0 and 1.49), near normal (SPI between -0.99 and 0.99), moderately dry (SPI between -1 and -1.49), very dry (SPI between -1.5 and -1.99), extremely dry (SPI<2) (McKee et al., 1993). In this study we examined the main characteristics of short-time drought conditions such as duration, severity and intensity in eastern Slovakia and northern Serbia. We identified extreme short-time precipitation deficiency during the period (1972–2019).

**Results and discussion**

For the five stations in the eastern part of Slovakia, the analysis of short-term precipitation deficits for the time period (1972–2019) is shown in the Table 1 and Fig. 2. An assessment of short-term precipitation anomalies for the five stations in the northern part of Serbia is presented in Table 2 and Fig. 3. An extreme short-term precipitation deficit was identified by 3-month SPI, which can be expected in an average of 3.2 to 5.9 years. In Fig. 2 and Fig. 3 is a extreme short-term precipitation deficiency marked by red colour.

**Table 1.** Characterization of episodes with extreme short-term deficiency of precipitation by SPI-3 in eastern Slovakia

<table>
<thead>
<tr>
<th>Station</th>
<th>Number of events</th>
<th>Duration</th>
<th>Cumulative severity</th>
<th>Cumulative intensity</th>
<th>Average Inter-arrival time [years]</th>
<th>Years of extreme drought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bardejov</td>
<td>12</td>
<td>17</td>
<td>-42.4</td>
<td>-29.3</td>
<td>3.7</td>
<td>1973, 1975, 1977</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2012, 2014</td>
</tr>
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<td></td>
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<td>2014, 2016, 2017</td>
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<td>2015</td>
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<td></td>
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<td></td>
<td>2015</td>
</tr>
</tbody>
</table>
Fig. 2. SPI-3 of five selected stations in eastern Slovakia.

Table 2. Characterization of episodes with extreme short-time deficiency of precipitation by SPI-3 in northern Serbia

<table>
<thead>
<tr>
<th>Station</th>
<th>Number of events</th>
<th>Duration</th>
<th>Cumulative severity</th>
<th>Cumulative intensity</th>
<th>Average Inter-arrival time [years]</th>
<th>Years of extreme drought</th>
</tr>
</thead>
</table>
In total, events with severe insufficient short-term precipitation totals for a five synoptic stations in eastern Slovakia during the years 1972–2019 are 52 with a total duration of 67 months, cumulative severity of -154.3. The most vulnerable year of extreme drought was 1987 in this country, because extreme meteorological drought was recorded in several observed stations based on intensity, severity and duration. Extreme short-term precipitation deficits in eastern Slovakia were recorded especially in the autumn. The longest three-month extreme precipitation deficit was recorded in Ždiar station.

In both observed countries, extreme precipitation deficits most often occur in the autumn period when they do not affect agricultural activity than much. The territory of northern Serbia is more sensitive to the occurrence of extreme precipitation deficits.
Based on the Fig. 4 the duration of these events over 47-year time period ranges from 9 to 20 months, while these events lasted the longest at the Palič station. This station has the greatest cumulative severity and intensity (see the Fig. 5 and Fig. 6). In Medzev and Palič stations, we and expect more frequent occurrence of extreme short-term precipitation deficits.

**Fig. 4.** Duration of extreme precipitation deficiency in eastern Slovakia and in northern Serbia.

**Fig. 5.** Cumulative severity of extreme precipitation deficiency in eastern Slovakia and in northern Serbia.
Fig. 6. Cumulative intensity of extreme precipitation deficiency in eastern Slovakia and in northern Serbia.

Fig. 7. Average inter-arrival time of extreme short-time precipitation deficiency in eastern Slovakia and in northern Serbia.

**Conclusion**

Extreme short-term precipitation deficiency mainly in vegetation season can have significant implications for food production and water resources in northern Serbia and in eastern Slovakia. The sixth report of Intergovernmental Panel on Climate Change pointed out that soil moisture will be decrease more than 25% in
analyzed countries (Mimić et al., 2022). Due to their high agricultural production, the countries of the study area are becoming more and more sensitive to persistent precipitation deficits, rising temperatures and increasing evapotranspiration and therefore monitoring, predicting and implementing irrigation systems helps to avoid economical losses in agriculture. By calculating SPI-3 in the studied area, we estimate the occurrence of extreme precipitation deficits on average every 3 to 5 years from the beginning of the last such event.

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Innovative approaches to the assessment and management of drought risk due to climate change – Inovative prístupy k hodnoteniu a riadeniu rizika suchu v dôsledku zmeny klimy.

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