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Evaluation of drought in Bosnia and Herzegovina during the period 1956–2022

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Abstract— The issue of drought is treated as an important natural phenomenon that often has a negative impact on both the livelihoods of the population and environmental protection. Many parts of the world have been affected by catastrophic droughts in the past, leading to prolonged periods of famine and disease among local populations. According to the definition provided by the Intergovernmental Panel on Climate Change in 2014 (IPCC), drought can be assessed as a potential hazard and challenge depending on the evaluation of its impact on the population and its economic activities. The aim of this study is to determine drought periods in Bosnia and Herzegovina and to highlight their consequences. For the purpose of analysis, available data on average monthly precipitation from 12 meteorological stations in Bosnia and Herzegovina from 1956 to 2022 were used. The Standardized Precipitation Index (SPI-1 and SPI-3) was used to determine meteorological drought, including its intensity, frequency, and duration. Based on the results obtained, a relatively uniform frequency of drought was observed across the seasons. On the other hand, extreme droughts were most pronounced in winter and spring months. The maximum duration of drought was recorded in Zenica from November 1989 to October 1990.

Key-words: drought, precipitation, Standardized Precipitation Index, climate change, Bosnia and Herzegovina

1. Introduction

In recent decades, there has been an increase in the occurrence of extreme weather events in many countries worldwide, such as cold and heat waves, floods, fires, droughts, and others. Drought is one of the natural phenomena that has had pronounced negative effects on human society as a whole (*Heim*, 2002; *Zhou* and *Xu*, 2024). It is one of the most destructive natural phenomena globally, considering its long duration, wide-ranging impact, and high frequency (*Mishra* and *Singh,* 2010; *Vogt et al*., 2011; *Vicente-Serrano et al*., 2013; *Lai et al*., 2019; *Wang et al*., 2024). It negatively affects agricultural yields, contributes to soil degradation, leads to the extinction of plant and animal species, while in some parts of the world it is a direct cause of famine and disease (*Mouillot et al*., 2002; *Mishra* and *Singh*, 2010).

Historical data on precipitation and drought indices suggest increased aridity since 1950 in many terrestrial regions on Earth (*Dai*, 2011. 2013). Drought, as a periodic phenomenon, is most commonly caused by natural factors such as lack or insufficient amount of precipitation, low air humidity, and high air temperatures (*Djabeu,* 2017; *Eslamain* and *Eslamain,* 2017), exacerbated by anthropogenic factors such as excessive water consumption, land use, and land management practices (*Wilhite et al*., 2000). Meteorological drought is a monthly or yearly period with precipitation below normal values, often accompanied by above-average temperatures. It precedes and also triggers other types of drought, such as hydrological and agricultural droughts (*Heim*, 2002; *Dai*, 2011).

McMahon and *Diaz Arenas* (1982) define drought as a prolonged period of abnormally dry weather caused by a lack of precipitation that results in serious hydrological imbalance. According to *Anđelković* and *Živković* (2007), drought periods are considered unfavorable phenomena when they last longer than one month.

Dry areas cover 41% of the world's land surfaces (*White* and *Nackoney*, 2003; *Huang et al*., 2015; 2017), and they are home to approximately 2.5 million people (*Mortimore*, 2009). These areas are extremely sensitive to degradation caused by global warming and anthropogenic activities due to the low fertility of dry soils (*Scheffer et al*., 2001; *Rietkerk et al*., 2004; *Maestre et al.*, 2013; *Huang et al*., 2015; *Li et al*., 2016; *Zhou et al.*, 2016). Studies on drylands worldwide have been the focus of many international scientific research projects such as the Global Land Project (GLP), Integrated Land-Ecosystem-Atmosphere Processes Study (iLEAPS), and Global Water System Project (GWSP) (*Fu* and *De Vries*, 2006).

Many authors have pointed out the increased frequency of drought periods caused by decreased precipitation and increased air temperatures in Southeast Europe (*Anagnostopoulou et al.,* 2003; *Tsakiris* and *Vangelis*, 2005; *Anđelković* and *Živković*, 2007; *Koleva* and *Aleksandrov*, 2008; *Reiser* and *Kutiel*, 2008; *Kalamaras et al*., 2010; *Stricevic et al*., 2011; *Gočić* and *Trajković*, 2013; 2014;

Tošić and *Unkašević*, 2013; *Popova et al.,* 2015; *Trnka et al*., 2016; *Spinoni et al*., 2017; *Janačova et al*., 2018; *Jingtao*, 2019; *Hološ* and *Šurda*, 2021; *Stoyanova* and *Nikolova*, 2022). However, there is a lack of studies specifically addressing the issue of drought in Bosnia and Herzegovina, although there are quantitative and qualitative climatological studies dealing with changes in air temperatures and precipitation (*Trbić et al.,* 2017; *Popov et al*., 2018; 2019; *Papić et al*., 2020; *Gnjato et al*., 2021, *Bačević et al*., 2022), which can serve as a basis for more concrete research on drought periods.

This paper consists of the following subsequent sections: 1) introductory section; 2) overview of the study area; 3) methodology and data sources; 4) findings and discussion; and 5) concluding remarks.

2. Study area

Bosnia and Herzegovina is located in Southeast Europe and shares borders with Croatia, Serbia, and Montenegro (*Fig. 1*). It is situated between 45°16'08" N, 17°13'11" E in the north (municipality of Kozarska Dubica) and 42°33'00" N, 18°32'24" E in the south (city of Trebinje), as well as 44°03'00" N, 19°37'41" E in the east (municipality of Bratunac) and 44°49'30" N, 15°44'00" E in the west (city of Bihać). In the southern part, through a narrow corridor of 21.2 km, it has an outlet to the Adriatic Sea (municipality of Neum).

Table 1. Meteorological stations in Bosnia and Herzegovina

Station No.	**Station location**	**Altitude**	**Latitude**	**Longitude**
1	Banja Luka	153 m	44°47′08″ N	17°13′11″ E
2	Bileća	443 m	42°53′04″ N	18°27′29″ E
3	Bugojno	562 m	44°03′43″ N	17°27′02″ E
4	Doboj	146 m	44°44′17″ N	18°06′16″ E
5	Ivan Sedlo	967 m	43°45′04″ N	18°02′10″ E
6	Livno	724 m	43°49′22″ N	17°00′04″ E
7	Mostar	99 m	43°20′53″ N	17°47′38″ E
8	Sanski Most	158 m	44°46′12″ N	16°40′25″ E
9	Sarajevo	630 m	43°52′04″ N	18°25′22″ E
10	Sokolac	872 m	43°57′14″ N	18°49′26″ E
11	Tuzla	305 m	44°32′31″ N	18°41′06″ E
12	Zenica	344 m	44°12′07″ N	17°54′01″ E

Fig. 1. Geographical position of Bosnia and Herzegovina with landmarks of the analyzed meteorological stations.

The climate of Bosnia and Herzegovina is diverse, influenced by various climatic factors. The Adriatic Sea significantly affects the climate, particularly during the colder periods of the year, by releasing a large amount of heat, thus tempering extreme winter temperatures. The relief, altitude, distribution of mountain ranges, plateaus, basins, and karst fields significantly modify the climate of Bosnia and Herzegovina. The Dinaric Mountains, in particular, exert a pronounced climatic influence as they act as a natural barrier, preventing the penetration of cold air masses from the north and warm air masses from the south. Through karst basins and valleys of major rivers, continental influences from the north and Mediterranean influences from the south penetrate deeper into the interior. Soil composition, vegetation, and snow cover also influence the character of climatic elements, thereby modifying the climate of specific locations. Cyclonic activity and numerous local influences also contribute to the climate (*Marković*, 1972; *Rodić*, 1975; *Drešković* and *Mirić,* 2014; *Bajić* and *Trbić*, 2016).

On the territory of Bosnia and Herzegovina, three main types of climate are prevalent: continental and moderately continental, mountainous and mountainous-valley, and Mediterranean and modified Mediterranean climates. Continental climate is found in the northern part of the country, Mediterranean in the south, and the area between these two climate regions is characterized by high mountains, plateaus, and valleys, where, depending on the altitude, mountainous climate predominates.

3. Data and methods

3.1. Data

The study determined drought periods in the research area from 1956 to 2022. Precipitation data from 12 meteorological stations (MS) were utilized, which were published in the Statistical Yearbooks of the Statistical Office of the Republic of Srpska and the Federal Hydrometeorological Institute of Bosnia and Herzegovina. Most meteorological stations lack data, primarily from the period of the civil war (1991–1995). An exception is the meteorological station in Mostar, where continuous measurements are available throughout the analyzed period. The percentage of missing data for other stations is as follows: MS Sarajevo 1.5%, MS Sanski Most 1.7%, MS Tuzla 3.1%, MS Zenica 3.7%, MS Bugojno 4.6%, MS Banja Luka, MS Bileća, and MS Livno 5.9%, MS Sokolac and MS Doboj 7.4%, and MS Ivan Sedlo 8.3%. Accordingly, missing data were supplemented using interpolation methods due to justified reasons (*Kasam et al*., 2014; *Kilibarda et al*., 2015).

From *Table 1*, which displays the mathematical-geographical coordinates of meteorological stations and their relative altitudes, it is evident that the selected meteorological stations are situated at varying elevations. The lowest relative altitude is found at the MS Mostar (99 m), while the highest is at Ivan Sedlo (967 m), indicating a diversity in climate conditions.

3.2. Methods

To determine meteorological drought in the study, the Standardized Precipitation Index (SPI) (*McKee et al*., 1993) was utilized. It was calculated using data on average monthly precipitation for the period 1956–2022. SPI values were obtained using RStudio (Version R4.3.3). The World Meteorological Organization (WMO) recommends this index as a universal drought analysis tool, and it is frequently used in scientific studies (*Kim et al.,* 2009; *Mendez* and *Magana*, 2010; Hayes et al., 2011; Stricevic et al., 2011; Spinoni et al., 2014; Labudova et al., 2016; *Šudra et al*., 2020; *Hološ* and *Šurda,* 2021; *Stoyanova* and *Nikolova*, 2022; *Amiri* and *Gocic*, 2023; *Erkol et al*., 2024; *Zhou* and *Hu*, 2024). Generally, indices based on precipitation data are more widely accepted by the scientific community, as precipitation is the main factor contributing to the occurrence, development, and duration of droughts (*Mahmoudi et al*., 2019).

Using SPI as an indicator, a functional and quantitative definition of drought can be established for each time period. In addition to its applicability to various time series, it can provide early drought warning and assist in assessing drought intensity. SPI values correspond to standardized sets of precipitation values transformed into a gamma distribution. The occurrence of drought for a given time period is defined as a period in which SPI is continuously negative and when SPI reaches a value of -1.0 or less. According to *McKee et al*. (1993), drought intensity is arbitrarily defined for SPI values in the following categories:

Table 2. Classification of droughts according to SPI values

SPI values	**Drought category**
0 to -0.99	mild drought
-1.00 to -1.49	moderate drought
-1.5 to -1.99	severe drought
≤ -2.00	extreme drought

Source: *McKee et al.,* 1993

Using the provided categorization, we determined a drought period as when SPI ≤ -1, while extreme drought occurs when SPI ≤ -2. For determining meteorological drought, we utilized short-term SPI values for 1 and 3 months (SPI-1 and SPI-3), as opposed to agricultural and hydrological droughts, which typically employ SPI-6 and SPI-12 values (Svodoba et al., 2012; *Stoyanova* and *Nikolova*, 2022; *Wang et al.,* 2022).

We utilized SPI-1 values to determine the duration, magnitude, and intensity of drought. The onset of drought is defined as the period when the SPI-1 value is less than or equal to -1.0, while the drought ends when SPI-1 reaches 0 or a positive value. According to *McKee et al.* (1993), the drought magnitude (DM) represents the sum of all mentioned months (from -1 to 0) and is calculated using the formula:

$$DM \equiv -\left(\sum_{j-1}^{x} \mathrm{SPI}_{ij}\right),$$

where *j* represents the first month in which SPI-1 is less than or equal to -1.0, and *x* is the last consecutive month with a negative SPI-1 value. Based on the obtained drought magnitude values, the average drought intensity (ADI) can be calculated, representing the ratio between the magnitude (DM) and the duration of drought (D) (*McKee et al*., 1995; *Bonaccorso et al.,* 2003; *Stoyanova* and *Nikolova*, 2022). It is calculated using the formula:

$$ADI \equiv \frac{DM}{D}.$$

SPI-3 values were used to determine seasonal droughts. Accordingly, SPI-3 values were extracted for each season. Spring was calculated using total precipitation for March, April, and May; summer for June, July, and August; autumn for September, October, and November; and finally, winter for the months of December, January, and February.

4. Results and discussion

4.1. Duration, magnitude, and average drought intensity based on SPI-1 values

Drought as a phenomenon significantly impacts various economic sectors, with agriculture often being the first to suffer due to its dependence on soil moisture content, which can decrease rapidly during a drought period. If the duration of precipitation deficit extends, then other sectors reliant on available water resources will also be affected (*Table 3*).

Table 3. Duration, magnitude, and average drought intensity in Bosnia and Herzegovina from 1956 to 2022

Meteorological stations (MS)	Start month	End month	D	Lowest value of SPI-1	DM	ADI
Banja Luka	October 2019	April 2020	7	-4.93	6.33	-0.90
Bileća	January 2000	June 2000	6	-5.43	6.82	-1.13
Bugojno	November 1989	September 1990	11	-4.60	11.13	-1.01
Doboj	March 2011	November 2011	9	-4.55	11.02	-1.22
Ivan Sedlo	June 1990	January 1991	8	-4.83	3.97	-0.49
Livno	May 1962	October 1962	6	-4.11	7.81	-1.30
Mostar	January 1993	May 1993	5	-4.78	9.53	-1.90
Sanski Most	June 1988	March 1989	9	-4.33	8.29	-0.92
Sarajevo	December 1989	August 1990	9	-4.31	8.59	-0.95
Sokolac	September 1956	March 1957	7	-5.44	7.88	-1.12
Tuzla	May 1962	October 1962	6	-4.53	5.85	-0.97
Zenica	November 1989	October 1990	12	-4.31	13.80	-1.15

The duration of drought at the observed stations in Bosnia and Herzegovina varies, which is expected given the different climatic characteristics. The maximum duration of drought in the observed period was 12 months at the meteorological station Zenica from November 1989 to October 1990 (*Table 3*).

The magnitude of this event was 13.80, with an average drought intensity of -1.15. The minimum duration of drought was 5 months, recorded from January to May 1993 at MS Mostar. Although the drought lasted for 5 months, the magnitude of this event was very high at 9.53, resulting in the most pronounced average drought intensity (-1.90).

The occurrence of extreme drought was recorded at most observed stations in the years 1957 (9 stations), 1963 (9 stations), 1969 (8 stations), 1989 (9 stations), 2007 (9 stations), 2012-2013 (all stations), 2017 (10 stations), and 2021–2022 (8 stations). Multi-year periods without drought occurrence at most stations were observed in the years 1958–1960, 1976–1978, 2004–2006, and 2008–2010 (*Fig. 2*).

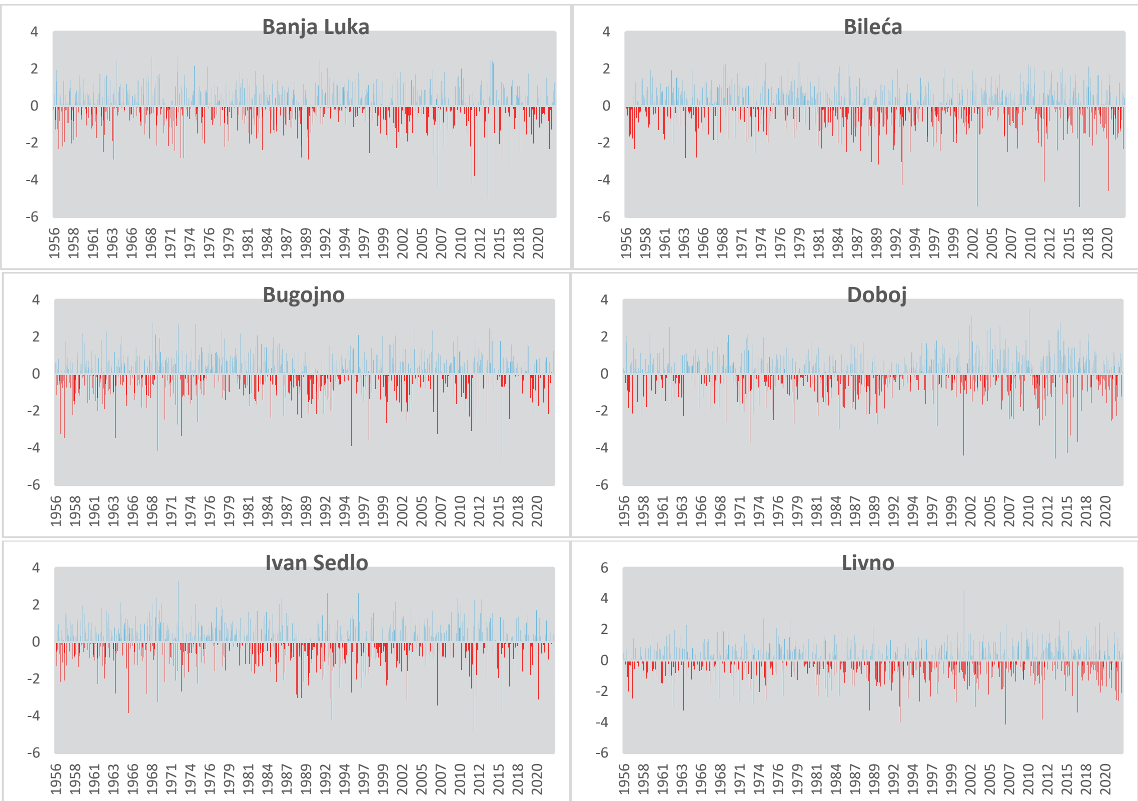
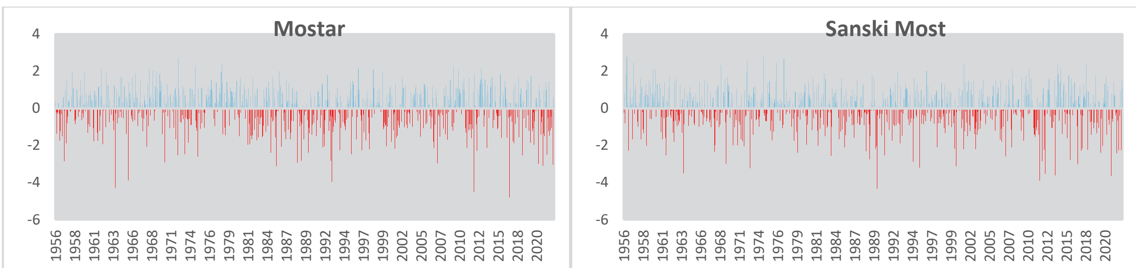


Fig. 2. SPI-1 values at 12 meteorological stations in Bosnia and Herzegovina.



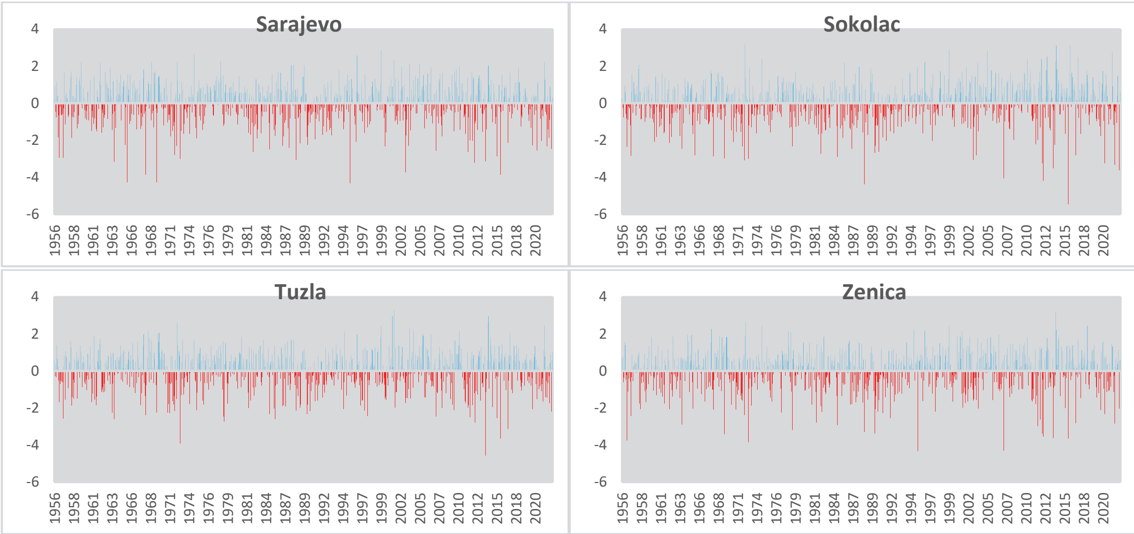


Fig. 2 continued.

4.2. Drought frequency according to SPI-3 values

Analysis of drought results obtained based on SPI-3 values for all 12 observed stations in Bosnia and Herzegovina indicates a relatively uniform frequency of droughts and extreme droughts across the seasons (*Table 4, Fig 3*). The frequency of drought was highest in the summer period (13.55%), while it was lowest in the winter period (12.93%). The frequency of extreme drought was most pronounced in winter (2.98%), and least pronounced in autumn (2.07%).

Table 4. Frequency of drought in Bosnia and Herzegovina from 1956 to 2022 by seasons

	Season	**Spring**		**Summer**		**Autumn**		**Winter**	
MS	**Drought**	**No. of months**	**%**	**No. of months**	**%**	**No. of months**	**%**	**No. of months**	**%**
Banja Luka	Dry	26	12.93	29	14.42	29	14.42	28	13.93
	Extremely dry	6	2.98	3	1.49	4	1.99	5	2.48
Bileća	Dry	26	12.93	27	13.43	24	11.94	23	11.44
	Extremely dry	5	2.48	5	2.48	5	2.48	10	4.97
Bugojno	Dry	30	14.92	21	10.44	30	14.92	22	10.94
	Extremely dry	5	2.48	8	3.98	6	2.98	6	2.98
Doboj	Dry	28	13.93	24	11.94	26	12.93	27	13.43
	Extremely dry	3	1.49	2	0.99	5	2.48	5	2.48
Ivan Sedlo	Dry	29	14.42	27	13.43	25	12.43	25	12.43
	Extremely dry	3	1.49	3	1.49	4	1.99	6	2.98
Livno	Dry	35	17.41	30	14.92	21	10.44	23	11.44
	Extremely dry	2	0.99	3	1.49	1	0.49	8	3.98
Mostar	Dry	28	13.93	30	14.92	25	12.43	28	13.93
	Extremely dry	4	1.99	4	1.99	4	1.99	9	4.47
Sanski Most	Dry	18	8.95	26	12.93	25	12.43	31	15.42
	Extremely dry	10	4.97	5	2.48	4	1.99	5	2.48
Sarajevo	Dry	25	12.43	28	13.93	27	13.43	28	13.93
	Extremely dry	7	3.48	4	1.99	4	1.99	3	1.49
Sokolac	Dry	24	11.94	24	11.94	27	13.43	27	13.43
	Extremely dry	6	2.98	2	0.99	5	2.48	5	2.48
Tuzla	Dry	26	12.93	31	15.42	29	14.42	24	11.94
	Extremely dry	6	2.98	7	3.48	3	1.49	4	1.99
Zenica	Dry	28	13.93	30	14.92	28	13.93	26	12.93
	Extremely dry	7	3.48	8	3.98	5	2.48	6	2.98
Total	Dry	323	13.39	327	13.55	316	13.1	312	12.93
	Extremely dry	64	2.65	51	2.11	50	2.07	72	2.98

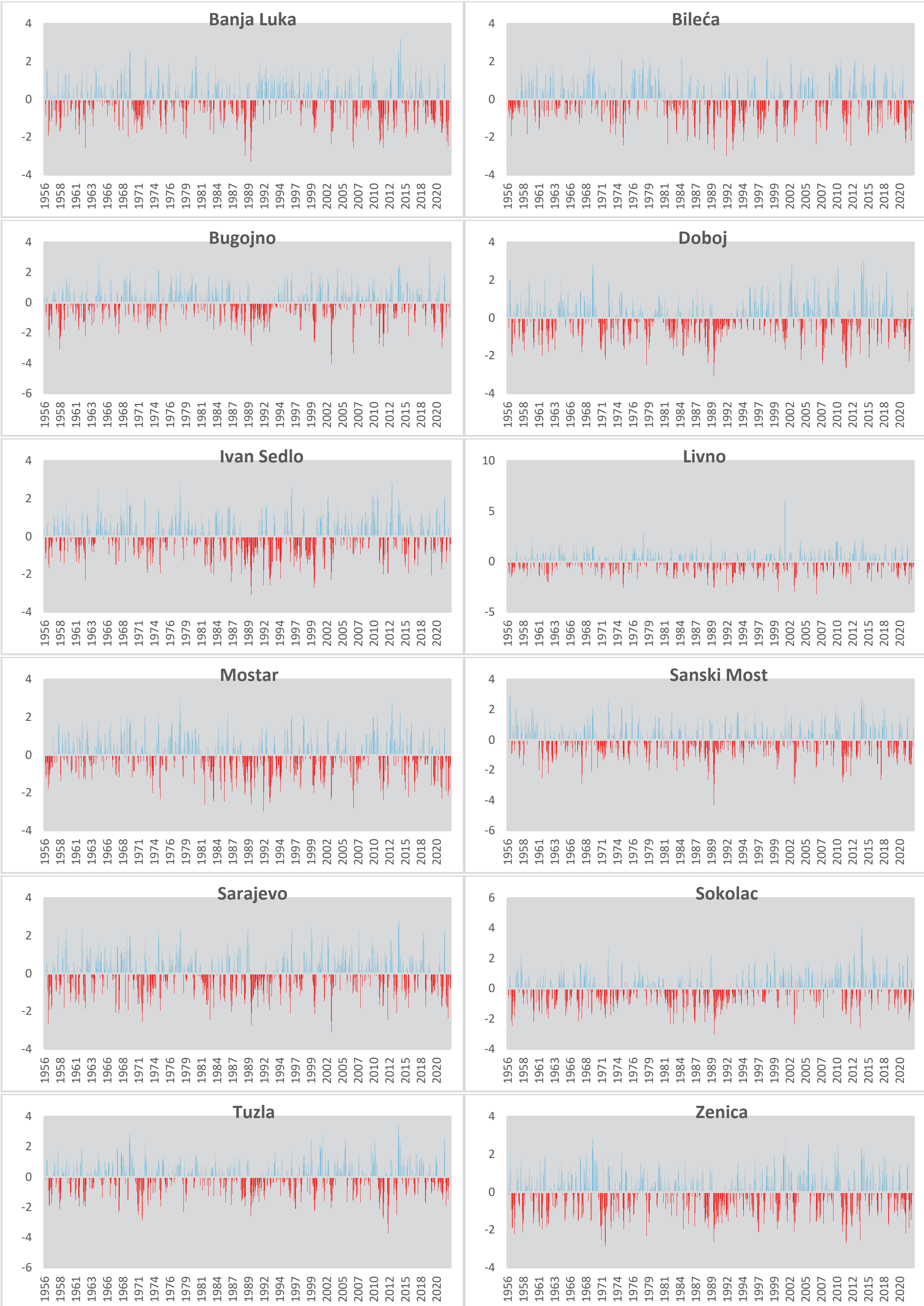


Fig. 3. SPI-3 values at 12 meteorological stations in Bosnia and Herzegovina.

Expectedly, the frequencies of drought vary across seasons when observing individual meteorological stations. The highest number of drought months in spring was recorded in Livno, totaling 35 (17.41%), while the lowest was in Sanski Most with 18 (8.95%). The most pronounced drought in the summer period was observed in Tuzla with 31 drought months (15.42%), while the least pronounced was in Bugojno with 21 drought months (10.44%). The highest number of drought months in autumn was recorded in Bugojno, totaling 30 (14.92%), and the lowest in Livno with 21 (10.44%). Winter saw the most pronounced drought in Sanski Most with 31 drought months (15.42%), while the least pronounced was in Bileća and Livno with 23 drought months each (11.44%).

The most extremely dry spring months were recorded in Sanski Most, totaling 10 (4.97%), summer months in Bugojno and Zenica, totaling 8 (3.98%), autumn months in Bugojno, totaling 6 (2.98%), and winter months in Mostar, totaling 9 (4.47%). In contrast, Livno has the least extremely dry spring months, totaling 2 (0.99%), Sokolac summer months, totaling 2 (0.99%), Livno autumn months 1 (0.49%), and Sarajevo winter months, totaling 3 (1.49%).

5. Conclusion

Meteorological drought occurs when below-average amounts of precipitation are recorded over an extended period, resulting in reduced moisture in the soil and atmosphere. It can significantly impact crop yields, reduce livestock numbers, increase the risk of wildfires, degrade soil, and disrupt ecosystems.

The study analyzed available data on average monthly precipitation from 12 meteorological stations in the territory of Bosnia and Herzegovina from 1956 to 2022. By using the Standardized Precipitation Index (SPI) as an indicator, we identified drought periods and their characteristics. We observed a relatively uniform frequency of droughts across the seasons, with the most pronounced extreme droughts occurring in winter and spring months. The maximum duration of drought was recorded in Zenica from November 1989 to October 1990. The longest periods of extreme drought in most stations were observed in 1957, 1963, 1969, 1989, 2007, 2012–2013, 2017, and 2021-2022.

In conclusion, our research highlights the crucial importance of understanding drought dynamics for efficient water resource management, adapting to climate change, and efforts to reduce disaster risks in Bosnia and Herzegovina. Although drought is a common occurrence in Bosnia and Herzegovina, a drought management strategy has not yet been developed in the country. This study can serve as a basis for future research focusing on assessing the risks and hazards of drought.

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