Original scientific paper
Journal of Central European Agriculture, 2024, 25(2), p.531-541

DOI: /10.5513/JCEA01/25.2.4183

Assessing the impact of climate change on extreme hydrological events in Bosnia and Herzegovina using SPEI

Sabrija ČADRO[1] (✉), Monika MARKOVIĆ[2], Adna HADŽIĆ[1], Adnan HADŽIĆ[1], Ognjen ŽUROVEC[3]

[1] University of Sarajevo, Faculty of Agriculture and Food Science, Zmaja od Bosne 8, 71000 Sarajevo, Bosnia and Hercegovina

[2] Josip Juraj Strossmayer University of Osijek, Faculty of Agrobiotechnical Sciences, Vladimira Preloga 1, 31000, Osijek, Croatia

[3] Teagasc, Environment Soils and Land Use Department, Johnstown Castle, Oak Park, Carlow R93 XE12Wexford, Ireland

✉ Corresponding author: s.cadro@ppf.unsa.ba

Received: November 20, 2023; accepted: April 8, 2024

ABSTRACT

Average monthly air temperatures in Bosnia and Herzegovina (BiH) exhibit a notable rise during summer, ranging from 0.4 to 0.8 °C per decade, while precipitation experiences a significant decrease of up to 8 mm per decade. Climate models, across various RCP scenarios, project an increase in air temperature, that is most pronounced in the summer season. Additionally, there is a projected frequency and intensity of heavy precipitation during autumn. In BiH, agricultural production faces substantial risks, including droughts, spring and autumn frosts, hail, and floods. Recent years have witnessed extreme hydrological events, notably the 2012 drought and the 2014 floods. Strategic documents highlight the critical importance of addressing floods and droughts for agriculture, as well as their implications for the environment, households, and industry. To assess the severity of extreme hydrological events and their impact on agriculture, with a specific emphasis on autumn and summer in Bosnia and Herzegovina, average and peak values of the Standardized precipitation evapotranspiration index (SPEI) were calculated separately for the periods 1961–1990 and 1991–2020, focusing on October and August. Compared to the reference climatic period the current climate is characterized by shifts between intense wet and dry periods, with very few years exhibiting stable and expected weather conditions. Identified as extremely wet and flood-prone years, $SPEI_{2\ October}$ values for 1974 (2.42), 1996 (2.13), 2001 (2.24), and 2014 (2.05) stand out, with only one extremely dry year in 1985 (-2.21). $SPEI_{2\ August}$ indicates extremely dry years, notably 2012 (-2.35) and 2017 (-2.25).

Keywords: drought, flood, agriculture, wetness, dryness, drought index

INTRODUCTION

Due to climate change, extreme hydrological events (EHE), especially floods and droughts are generally predicted to become more frequent and damaging in Europe (Forzieri et al., 2016).

This holds for Bosnia and Herzegovina (BiH) as well. Droughts and floods have attracted substantial attention from researchers due to their profound impact on various aspects of human life, including agriculture and socioeconomic development (Mohammed et al., 2022). On a global scale, during the last decade (2010 – 2020), regions highly vulnerable to floods and droughts experienced a 15 times higher human mortality compared to regions with very low vulnerability (IPCC, 2023).

The analysis of meteorological data shows a continuous rise in mean annual temperature across BiH, with a particularly notable increase in the last 30 years.

Regarding precipitation, there are no significant changes on an annual basis over the entire country, but more pronounced seasonal variations are present (Čadro et al., 2023; FNC, 2021).

Trends in average monthly air temperatures in BiH show the greatest increase during the summer months (June - July – August), ranging from 0.4 to 0.8 °C per decade depending on the location (Popov et al., 2019; Popov et al., 2018). During the summer months, air temperatures were higher by 1.6 °C in the period from 1991 to 2016, compared to the period from 1961 to 1990 (Čadro et al., 2019a). Additionally, while there are no significant changes in annual precipitation, a reduction in its quantity is observed during the summer months, ranging from 0.3 to 8.2 mm per decade (Popov et al., 2019; Popov et al., 2017). The current amount of precipitation in August is lower by 12 mm compared to the period from 1961 to 1990 (Čadro et al., 2019a). On the other hand, this difference, with an equal amount throughout the year, manifests during the autumn, specifically in September and October, when there is an increase in precipitation from 2.1 to 12.4 mm per decade (Popov et al., 2017).

Across the entire territory of BiH, climate models for various Representative Concentration Pathway (RCP) scenarios consistently indicate a sustained rise in air temperature, with the most significant increase occurring during the June-July-August (JJA) season. Notably, this period also experiences the greatest precipitation loss (FNC, 2021). Also, the projected increase in frequency and intensity of heavy precipitation will increase rain-generated local flooding (IPCC, 2023).

In the context of BiH conditions, characterized by low adaptive capacity and the significance of the agricultural sector (Zurovec and Vedeld, 2019; Žurovec et al., 2017), this situation is anticipated to lead to water scarcity across multiple interconnected sectors and crop production losses. These challenges arise from heat and dry conditions, aligning with the extreme key risks defined by the IPCC. In BiH agricultural production, major risks are droughts, spring frosts, autumn frosts, hail, and floods (Zurovec and Vedeld, 2019). BiH faced several EHE, notably the 2012 drought and the 2014 floods (TNC, 2016). In general, according to important reports in BiH, significant droughts occurred in 2000, 2003, 2007, 2011, 2012, 2015, and 2018 (Čadro et al., 2017; Čaušević et al., 2020; NAP, 2021; PSP-BiH, 2023; UNDP, 2020), while catastrophic floods occurred in June 2001, April 2004, and May and August 2014 (NAP, 2021; WBG, 2021; WBIF, 2019).

A drought index quantifies severity, magnitude, and duration, integrating meteorological, hydrological, and agricultural data for decision-making (Bezdan et al., 2019; Mohammed et al., 2022). The Palmer drought severity index - PSDI (Palmer, 1965) and the Standardized precipitation index – SPI (McKee et al., 1993), as well as the Standardized precipitation evapotranspiration index SPEI (Vicente-Serrano et al., 2010), are commonly used globally for drought analysis and monitoring. Drought analysis in BiH primarily involves assessing water deficit, computed through the agro-hydrological balance. This balance considers the ratio of actual evapotranspiration to potential or reference evapotranspiration (Čadro et al., 2020; Čadro et al., 2019b).

Additionally, the Standardized Precipitation Index (SPI) has been increasingly used for this purpose in recent times (Ducic et al., 2015). Žurovec and Čadro (2011) suggested using SPI for drought monitoring in BiH. The correlation between yield reduction and $SPI_{3\ August}$ has demonstrated statistical significance in Tuzla and Bijeljina. Depending on the crop (tobacco, maize, soybean, pepper, potato, alfalfa), the correlation coefficient (r) ranged from -0.77 to -0.89, indicating a strong to very strong correlation relationship. The Agrometeorology section, utilizing data from BiH hydrometeorological services, includes a drought monitor or soil moisture assessment based on the SPI for 1, 3, 6, and 12 months. Based on the calculation of $SPEI_3$ it was determined that the region most vulnerable to agricultural drought stretches from the northeast to the southern parts of BiH, including areas like Bihać. Less vulnerable areas are situated in higher-altitude regions, such as the Dinaric Mountains, extending from Sarajevo to Sanski Most (Čadro et al., 2017).

Climate change in BiH is manifesting both positive and negative effects. Extended growing seasons are proving favorable for winter crops, while increased temperatures and water scarcity pose threats to spring crops. The cultivation areas for fruits and vineyards are expanding due to milder winters. Nevertheless, a high risk of reduced yields and lower quality for pasture and forage looms can be attributed to the increased occurrence of extreme weather events (TNC, 2016).

The primary challenge in the BiH agricultural sector is its low productivity, rooted in small-scale, subsistence-oriented farming with limited adoption of advanced agricultural technologies like drainage systems, irrigation techniques, or smart agriculture solutions, the cropping system is exceptionally susceptible to climate changes (Žurovec et al., 2015). Despite this, there has been an increase in overall maize grain production, reaching its peak in 2020 at 1,426,400 tons, as well as an increase in grape production from 14,200 tons in 2000 to 44,700 tons in 2020 (ASBH, 2023).

The BiH government is committed to diverse climate change adaptation measures, including improved water resource management, investments in modern irrigation, and the upgrade of irrigation-drainage systems, suitable for current and predicted climates (FNC, 2021; MAWFFiB, 2022). Many strategic documents emphasize that addressing floods and droughts is crucial for agriculture and stable crop yields, as well as other sectors such as the environment, households, and industry (NAP, 2021; TNC, 2016; UNECE, 2018).

Considering that agricultural drought, characterized by an extended period of insufficient soil moisture (Bezdan et al., 2019), substantially affects crop growth and yield, especially given Bosnia and Herzegovina's increased vulnerability to climate change and the occurrence of extreme hydrological events (EHE), it is crucial to comprehend the frequency of such events. This understanding forms a foundational step towards implementing more effective adaptation measures.

The primary objective of this study is to utilize the Standardized Precipitation Evapotranspiration Index (SPEI) for a comprehensive analysis of the severity of extreme hydrological events (floods and droughts) and their implications for agriculture in the context of climate change. Research concentrates on specific time scales and periods, considering two climate periods: the reference climatic period (1961 – 1990) and the current state of the climate (1991 – 2020), with a particular emphasis on significant changes in temperature and precipitation during the summer and autumn periods in BiH.

MATERIAL AND METHODS

To analyse extreme hydrological events (EHE) using the Standardized Precipitation Evapotranspiration Index (SPEI) across diverse agro-climatic locations, six research locations were chosen in BiH: Bihać, Tuzla, Sanski Most, Sarajevo, Livno, and Mostar (Figure 1, Table 1).

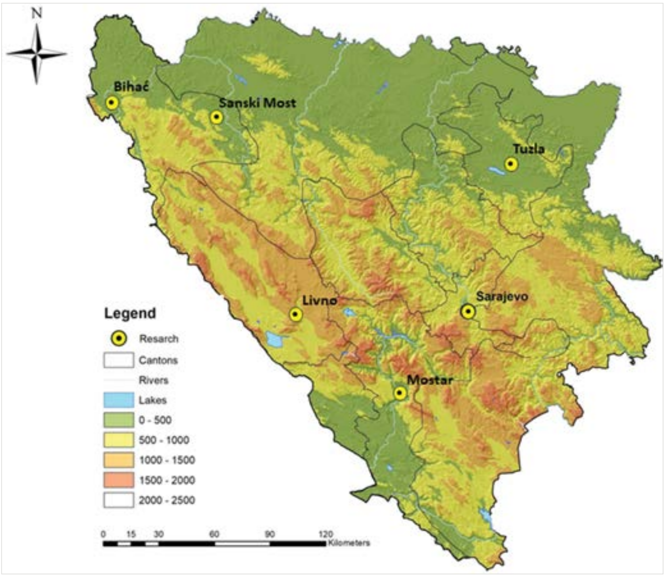

Figure 1. Topography and locations of selected research locations in Bosnia and Herzegovina

Table 1. Basic geographic and climatic attributes of the research locations for the period 1961 - 2020

Research locations	°E	°N	Altitude (m)	P (mm)	T_{mean} (°C)	T_{max} (°C)	T_{min} (°C)	ET_0 (mm)	Köppen–Geiger
Bihać	15°51'	44°48'	246	1346	11.14	16.56	6.07	785	Cfb x"s
Tuzla	18°41'	44°32'	305	909	10.51	16.84	5.46	749	Cfb x"s
Sanski Most	16°40'	44°46'	158	1042	10.64	17.05	5.19	777	Cfb x"s
Sarajevo	18°25'	43°52'	630	939	10.05	15.67	5.33	784	Cfb x"s
Mostar	17°47'	43°20'	99	1482	15.09	20.47	10.53	1084	Csa sx"
Livno	17°00'	43°49'	724	1153	9.51	15.77	3.61	805	Cfb x"s

Note: °E – longitude; °N – latitude; P – precipitation; T_{mean} – mean air temperature; T_{max} – mean maximum air temperature; T_{min} – mean minimum air temperature; Csa sx" – Mediterranean climate; Cfb x"s – temperate warm and humid climates

Each of these locations is equipped with a weather station that has recorded continuous long-term climate data. These data, spanning from 1961 to 2020, were sourced from the Federal Hydro-Meteorological Institute of BiH. To evaluate the influence of climate change on EHE patterns, the analysis period is divided into two sections: 1961 - 1990, recognized as the "reference climatic period," and 1991 - 2020, identified as the "current state of the climate". The basic geographic and climatic attributes of the research locations, derived from all collected climate data (1961 – 2020) are given in Table 1.

Based on the Köppen–Geiger climate classification (Geiger, 1961), all research locations belong to the category of temperate warm and humid climates (Cfb x"s). Mostar is an exception, as the only station characterized by a Mediterranean climate (Csa sx"). Consequently, Mostar exhibits the highest average annual precipitation of 1482 mm and the highest temperatures, with an annual mean temperature of 15.09 °C. Despite belonging to the same climate type, other locations display distinct climatic attributes. Tuzla and Sarajevo, for instance, have the lowest annual precipitation of 909 mm and 939 mm, respectively. Among these locations, Bihać stands out with the highest average annual precipitation of 1346 mm. Additionally, Bihać has the highest mean air temperature of 11.14 °C, while Livno records the lowest air temperature (Tmean 9.51 °C). The lower temperatures in Livno can be attributed to its altitude of 724 m.

In this research, the Standardized Precipitation Evapotranspiration Index (SPEI) developed by Vicente-Serrano et al. (2010) was used to assess wet/dry and EHE conditions in BiH. The SPEI shares a similar conceptual framework with the Standardized Precipitation Index (SPI). However, instead of focusing solely on precipitation (P), it considers a climatic water balance (precipitation minus potential or reference evapotranspiration) calculated over various timescales, representing distinct types of droughts (meteorological, agricultural, hydrological, and socioeconomic).

To calculate SPEI, the first monthly reference evapotranspiration (ET_0) using the Penman-Monteith (FAO56 PM) method (Allen et al., 1998) was determined. This calculation was performed using the software tool SRCLET (2021). ET_0 was calculated according to Allen et al. (1998) equation:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean} + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where ET_0 is the reference evapotranspiration (mm/day), R_n the net radiation at the crop surface (MJ/m^2/day), G the soil heat flux density (MJ/m^2/day), T_{mean} the mean daily air temperature at 2 m height (°C), u_2 the wind speed at 2 m height (m/s), e_s the saturation vapor pressure (kPa), ea the actual vapor pressure (kPa), e_s - e_a the saturation vapor pressure deficit (kPa), Δ the slope of the vapor pressure curve (kPa/°C) and γ is the psychrometric constant (kPa/°C).

The computation was done using basic climate parameters (air temperature, air humidity, solar radiation, and wind speed), however, since solar radiation (R_s) data was unavailable for Rn calculation, insolation data (n) were used and R_s was calculated using Ångström (1924) as proposed in Allen et al. (1998) equation:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a$$

where R_a is the extraterrestrial radiation (MJ/m²/day), N is the maximum possible duration of sunshine or daylight hours (h), a_s is the regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0) and $a_s + b_s$ is the fraction of extraterrestrial radiation reaching the earth on clear days (n = N). Values of a_s = 0.25 and b_s = 0.5 were used (Allen et al., 1998).

SPEI was calculated using the package "SPEI" in R statistical software. The calculation was done for shorter 2-month ($SPEI_2$) time scales, representing short-term wet or dry events that influence soil moisture content and agricultural production. $SPEI_2$ serves as a measure of agricultural drought and, in this study, will also be used to measure extremely wet periods leading to floods. SPEI can have both positive and negative values. Positive values indicate a wet period, while negative values indicate a dry one. (McKee et al., 1993; Vicente-Serrano et al., 2010). $SPEI_2$ was divided into eight categories from extremely wet to extremely dry (Table 2), based on the SPI categories provided by McKee et al. (1993).

Table 2. Dryness and wetness categories based on SPEI values

Category	Range
Extremely wet	2.00 ≤ SPEI
Very wet	1.50 ≤ SPEI < 2.00
Moderately wet	1.00 ≤ SPEI < 1.50
Mild wet	0 < SPEI < 1.00
Mild dry	-1.00 < SPEI < 0
Moderately dry	-1.50 < SPEI ≤ -1.00
Severely dry	-2.00 < SPEI ≤ -1.50
Extremely dry	SPEI ≤ -2.00

The maximum (peak) positive (indicating wetness) and negative (indicating dryness) $SPEI_2$ values for a given month represent the period of maximum moisture/drought intensity (Čadro et al., 2017; McKee et al., 1993).

To analyse the impact of EHE on agriculture, $SPEI_{2\ October}$ (including September and October) and $SPEI_{2\ August}$ (including months of July and August) were calculated. These two periods were chosen because they represent periods with the most significant changes in air temperature and precipitation levels for BiH.

To illustrate our findings, we applied the #ShowYourStripes (Hawkins, 2023) principle, or Drought Stripes, wherein the intensity of the blue colour signifies the intensity of the wet period (positive values of $SPEI_2$), while the intensity of the red colour corresponds to the intensity of the dry period (negative values of $SPEI_2$).

RESULTS AND DISCUSSION

To evaluate the severity of Extreme Hydrological Events (EHE) and their implications for agriculture, with a specific focus on changes during fall ($SPEI_{2\ October}$) and summer ($SPEI_{2\ August}$) in BiH, the average and peak values of $SPEI_2$ were calculated. These values are presented separately for the periods 1961-1990 and 1991-2020.

This approach is used to assess the influence of climate change on the occurrence of EHE. Additionally, the examination of peak values identifies specific years with high intensity of wetness or dryness, signaling a high potential for floods or droughts.

Table 3 presents the calculations for $SPEI_{2\ October}$ during the periods 1961-1990 and 1991-2020 across all six research locations (Bihać, Tuzla, Sanski Most, Sarajevo, Livno, and Mostar).

Analysis of the wet periods indicates that the average $SPEI_{2\ October}$ (Table 3) during the period 1961-1990 is lowest in Tuzla and Sanski Most at 0.48, indicating a low intensity of excessive wetness, while the highest is in Sarajevo (0.75), where this variation within the wet periods is more pronounced with more intense rainfall.

Table 3. The average and peak values of $SPEI_{2\ October}$ in the period 1961 -1990, and 1991 – 2020

Location			Bihać	Tuzla	Sarajevo	Sanski Most	Mostar	Livno	BiH
WET	1961 - 1990	Average	0.57	0.48	0.75	0.48	0.73	0.68	0.61
		Max	2.16 1974	1.32 1974	1.98 1974	2.10 1974	2.10 1974	2.42 1974	2.42 1974
	1991 - 2020	Average	0.92	1.01	0.90	1.03	0.76	0.86	0.91
		Max	2.05 2014	2.24 2001	2.13 1996	1.92 2014	1.98 1998	1.78 1996	2.24 2001
DRY	1961 - 1990	Average	-0.79	-0.96	-0.82	-0.73	-0.85	-0.96	-0.85
		Max	-2.10 1985	-1.68 1985	-2.04 1985	-2.21 1985	-1.82 1986	-2.07 1985	-2.21 1985
	1991 - 2020	Average	-0.78	-0.74	-0.70	-0.70	-0.82	-0.65	-0.73
		Max	-1.89 2006	-1.77 2011	-1.81 2018	-1.97 2006	-1.75 2011	-1.50 2011	-1.97 2006

The average for BiH is 0.61. In this period, the peak value of $SPEI_{2\ October}$ reaches 2.42 (Extremely wet) and occurs in 1974 in Livno. For all locations, 1974 is the year with the highest values.

The total precipitation in the year 1974 does not suggest a particularly wet year because the values do not deviate much from the annual average (Table 1). However, depending on the location, between September and October of 1974, 21% to 43% of all precipitation for that year occurred. As a result, this EHE from 1974 also corresponds to record river levels (Sava and Drina) and unprecedented floods in northern BiH (Brilly et al., 2015).

In the period from 1991 to 2020, there is an increase in the risk of large amounts of precipitation, with an average for BiH of 0.91. This increase is most intense at the locations that had a low intensity of excessive wetness until then, which are Tuzla and Sanski Most, where the current average $SPEI_{2\ October}$ under wet conditions is around 1.00. In the current climate state, over the last 30 years, the peak value of 2.24 occurred in Tuzla in 2001. Except that, extremely wet October was recorded in Sarajevo 1996 (2.13) and Bihać 2014 (2.05).

During the dry years of the period 1961-1990, for $SPEI_{2\ October}$ (Table 3), the lowest average value was recorded in Sanski Most at -0.73, the highest value in Tuzla and Livno at -0.96, and the average for BiH was -0.85. The most intense drought occurred in 1985 when the $SPEI_{2\ October}$ value in Sanski Most was -2.21 (Extremely dry). During the period 1991-2020, the drought value decreased, averaging -0.73 for BiH, with the highest in Mostar (-0.82) and the lowest in Livno (-0.65). The maximum dryness value of -1.97 (Very dry) was recorded in Sanski Most in 2006.

To provide a more detailed analysis of these changes for $SPEI_{2\ October}$, Figure 2 shows the number of years divided into specific categories (Table 2) of wetness and dryness as an average for BiH.

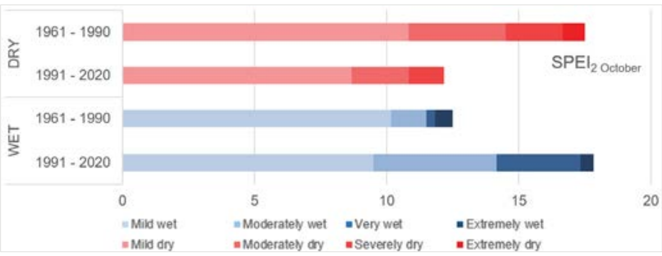

Figure 2. The average number of years categorized under specific conditions for $SPEI_{2\ October}$ in Bosnia and Herzegovina

In Figure 2 we can observe that considering SPEI$_{2\ October}$, wet periods dominate over dry ones. Additionally, during the period from 1991 to 2020, the number of wet years increased from 13 to 18, while the number of dry years decreased from 18 to 12. The biggest reduction is observed in "very dry" and “extremely dry” years, while, on the other hand, there has been an increase in the number of "moderately wet" and "very wet" years.

For a better visualization of the conditions for all years in the period from 1961 to 2020, Drought Stripes for SPEI$_{2\ October}$ is displayed in Figure 3 for all research locations: Bihać, Tuzla, Sanski Most, Sarajevo, Livno, and Mostar. The intensity of the blue colour indicates the intensity of the wet year, while the intensity of the red colour corresponds to the intensity of the dry year.

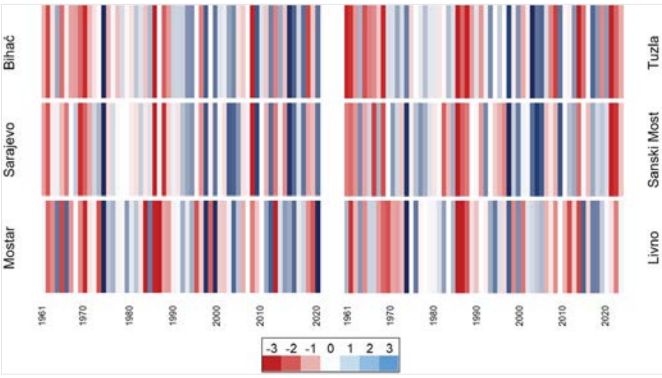

Figure 3. Drought stripes for SPEI$_{2\ October}$ - Bihać, Tuzla, Sanski Most, Sarajevo, Livno, and Mostar

Initially, a predominantly dry period from 1961 to 1973 is evident at all research locations. Following the exceptionally flood-prone year of 1974, a stable phase without EHE, during which SPEI$_{2\ October}$ very rarely exceeds 1, lasting until 1984. Following that, there are 3 to 5 very dry Octobers, marking the beginning of the last 30 years of the analysed period characterized by frequent shifts between more intense wet and dry periods. Particularly noteworthy are three wet Octobers in 2001, 2002, and 2003, as well as droughts in Tuzla and Sarajevo during 2018 and 2019.

Based on identified trends in autumn precipitation (Popov et al., 2017) and RCP regional climate model predictions forecasting a continuation of such trends until 2100 (FNC, 2021), along with the projected increase in the frequency and intensity of heavy precipitation (IPCC, 2023), the findings suggest an increase in flood susceptibility during fall months (September and October) in BiH, with a particular emphasis on the region of Tuzla. This is important from the perspective of agriculture and environmental protection because the increased rainfall during the autumn significantly impacts various activities: the vegetation period is prolonged, the harvesting window is shortened, crops ripen more slowly, diseases develop more easily, soil preparation for winter crops is difficult, the lack of vegetation can cause erosion, landslides, and soil structure degradation and floods become more frequent due to faster water circulation.

Table 4 summarises the results for SPEI$_{2\ August}$ in the periods 1961-1990 and 1991-2020 across all six research locations (Bihać, Tuzla, Sanski Most, Sarajevo, Livno, and Mostar).

If we now observe the moisture condition in August, focusing primarily on wet Augusts, the average value for SPEI$_{2\ August}$ during the period 1961 - 1990 is the lowest in Sanski Most at 0.87 and the highest in Bihać at 1.07. It is interesting to note that in the climatic reference period (1961-1990), August was wetter than October. In this period, the peak value of SPEI$_{2\ August}$ reached 2.38 (Extremely wet) and occurred in 1972 in Sanski Most. For many locations (Tuzla, Sarajevo, Sanski Most, and Mostar), the year 1972 stands out with the highest values. The exceptions are Bihać and Livno, where 1976 recorded the highest values.

For the current state of the climate (1991 – 2020), in August, there was a reduction in EHE related to wet conditions and floods. The average SPEI for August in BiH is reduced to 0.71, with the highest reduction observed in Bihać and Livno (0.71). The peak value of 2.13 occurred in Tuzla in 2005. Apart from that, there are no extremely wet Augusts.

Dry events in the period 1961-1990, for SPEI$_{2\ August}$ (Table 4), are least pronounced in Bihać with average values of only -0.50, while the highest value is in Sanski Most at -0.87, and the average for BiH was -0.67.

Table 4. The average and peak values of SPEI$_{2\ August}$ in the period 1961 -1990, and 1991 – 2020

Location			Bihać	Tuzla	Sarajevo	Sanski Most	Mostar	Livno	BiH
WET	1961 - 1990	Average	1.07	0.89	0.92	0.87	0.93	0.92	0.93
		Max	2.12 1976	2.29 1972	2.00 1972	2.38 1972	2.20 1972	1.90 1976	2.38 1972
	1991 - 2020	Average	0.71	0.80	0.81	0.75	0.79	0.71	0.71
		Max	1.77 2005	2.13 2005	1.74 2006	1.59 2014	1.84 2014	1.78 2014	2.13 2005
DRY	1961 - 1990	Average	-0.50	-0.64	-0.77	-0.87	-0.61	-0.61	-0.67
		Max	-1.12 1985	-1.73 1988	-1.45 1965	-1.58 1988	-1.79 1987	-1.27 1990	-1.79 1987
	1991 - 2020	Average	-1.01	-0.82	-0.82	-0.87	-0.96	-0.98	-0.91
		Max	-2.25 2017	-2.35 2012	-1.91 2012	-1.96 2012	-2.15 2012	-2.04 2012	-2.35 2012

These results indicate that during the period 1961 - 1990, August in BiH had a wet character, with wet periods dominating.

The most intense drought, classified as a very dry event, occurred in August 1987, with a peak value in Mostar of -1.79. At other locations, peak droughts occurred in 1965, 1985, 1987, 1988, and 1990. Different years for different locations imply that droughts were local with a small spatial extent.

During the period 1991-2020, the drought value increases, and August becomes a dry month. The average value of SPEI$_{2\ August}$ for BiH reaches -0.91, with the highest in Bihać (-1.01) and the lowest in Sarajevo and Tuzla (-0.82). The peak value, indicating an extremely dry August, was recorded in 2012 at Tuzla at -2.35. Except for that, extremely dry Augusts were recorded in 2017 at Bihać (-2.25), and 2012 at Mostar (-2.15) and Livno (-2.04).

The drought of 2012 is well-documented; this high-severity drought reduced yields of vegetables and grain crops by 70% (NAP, 2021; UNDP, 2020). It, along with the floods of 2014, served as a turning point in raising awareness about the necessary implementation of climate change adaptation measures in BiH.

Figure 4, based on SPEI$_{2\ August}$, shows the number of years divided into specific categories (Table 2) of wetness and dryness, averaged for BiH.

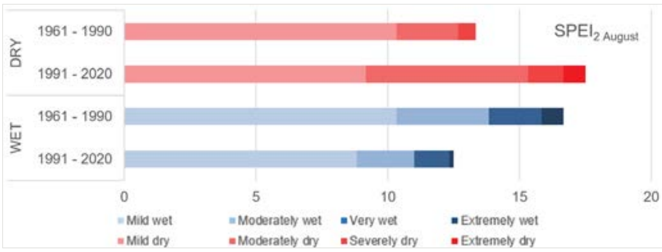

Figure 4. The average number of years categorized under specific conditions for SPEI2 $_{August}$ in BiH

Here we can more clearly observe the change in August, a transition from a month dominated by wet conditions to a month with more dry events. During the period from 1991 to 2020, the number of wet years decreased from 17 to 13, while the number of dry years increased from 13 to 18. The biggest increase is observed in "moderately dry" and “extremely dry” years.

Figure 4 contains Drought stripes for SPEI$_{2\ August}$ for all six research locations.

Drought in August was almost non-existent until 1987 (Figure 5). SPEI$_{2\ August}$ values rarely exceed -1, and if they do, it is mostly localized, as in Sarajevo in 1965 (-1.45) or

Tuzla in 1971 (-1.57). On the other hand, this period is quite wet, especially evident in 1968, 1969, 1972, 1976, and 1989. The period from 1978 to 1986 represents normal conditions and stable weather. After 1990, wet Augusts continued to occur, as seen in 2002, 2005, 2006, or 2014. However, most other years with SPEI values over -1 indicate increased dryness.

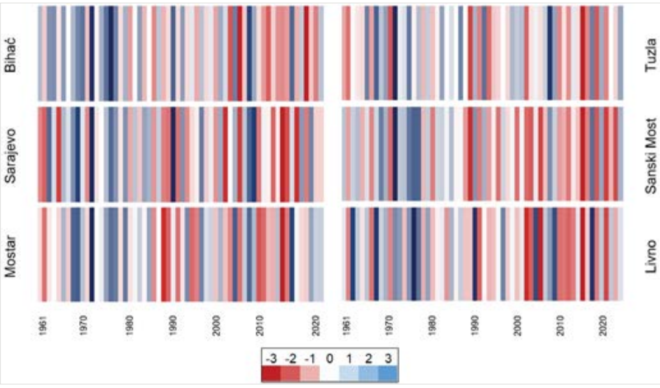

Figure 5. Drought stripes for $SPEI_{2\ August}$ - Bihać, Tuzla, Sanski Most, Sarajevo, Livno, and Mostar

Hence, drought in August is becoming increasingly frequent, with rare years witnessing expected precipitation levels (2016 and 2020). Considering the trends in temperature and precipitation during the summer months (Popov et al., 2018; TNC, 2016), revealing higher temperatures and a significant reduction in precipitation (Trbic et al., 2022), it can be concluded that this drought trend will persist and intensify. Considering that August is the month when most crops in BiH are in full development and fruit-forming stage, an adequate water supply is crucial for agricultural production during this period. These findings, coupled with the low level of implementation of climate change adaptation measures in BiH, highlight the urgent need for proactive measures and the practical application of adaptive strategies in Bosnian agriculture.

A similar situation is observed in other countries of the Western Balkan region. In Serbia, data analysis indicates a higher frequency and greater extent of droughts in the last several decades, showing an overall trend toward drier conditions. This trend is particularly noticeable in July and August. The occurrence of both extreme and severe drought events in Serbia has doubled in frequency in recent decades (Djurdjević et al., 2024). The eastern continental and agricultural regions of Croatia are increasingly susceptible to intensifying drought events, with a notable expansion of areas affected by drought in recent years (Santos et al., 2023). These results agree with the results of other researchers at the European level (Dukat et al., 2022; Oikonomou et al., 2020).

BiH can apply various agricultural adaptation measures, including sustainable water management, new irrigation systems, improved drainage, resilient farming methods, early planting, and smart agriculture practices (NAP, 2021; Playán et al., 2024; TNC, 2016; Trbic et al., 2018; UNDP, 2013, 2020; WBG, 2021). However, prioritization based on regional and crop significance is crucial for effective implementation in response to climate change.

CONCLUSIONS

Considering the rising air temperatures, most pronounced during summer months, along with reduced precipitation and increased intensity of precipitation during autumn, the utilization of the short-term 2-month SPEI was employed to determine occurrences of Extreme Hydrological Events (EHE) in October and August in BiH.

In the period from 1991 to 2020, compared to the earlier period (1961 - 1990), there is an increase in humidity in October, especially in the number of "moderately wet" and "very wet" years. This period is also characterized by shifts between intense wet and dry periods, with very few years exhibiting stable and expected weather conditions. Identified as extremely wet, and consequently flood-prone years, are 1974 (2.42), 1996 (2.13), 2001 (2.24), and 2014 (2.05), with only one extremely dry year in 1985 (-2.21).

In comparison to October, August shows opposite trends. Until 1990, August was more humid than dry; however, after 1990, this month adopts a drier character that becomes more pronounced over time. Earlier droughts in August were of lower intensity and smaller spatial extent, while in current climate conditions, we can observe that August is almost every year ranging from moderately to extremely dry and covers a wide area, sometimes even the entire BiH. The current climate state is characterized by a shift between dry and wet periods without a stable weather period with expected precipitation levels. Identified as extremely dry years are 2012 (-2.35) and 2017 (-2.25).

The findings highlight an urgent need for adaptive measures in Bosnian agriculture. Bosnia and Herzegovina supports strategies like improved water management and resilient farming, but prioritizing by region and crop is crucial for effective climate change response.

ACKNOWLEDGEMENTS

This research was done with the support of the Erasmus + Programme of the European Union, as part of the Jean Monnet project "Modern techniques to ensure environmental sustainability in Eastern Europe" (MEET). Project Reference: 621118-EPP-1-2020-1-BA-EPPJMO-MODULE.

REFERENCES

Allen, R. G., Pereira, L., Raes, D., Smith, M. (1998) Crop evapotranspiration: Guidelines for computing crop water requirements. Rome: United Nations FAO.

Ångström (1924) Solar and terrestrial radiation. Quaterly Journal of Royal Meteorological Society, 50, 121-125.

ASBH (2023) Agency for statistics of Bosnia and Herzegovina - agriculture. Available at: https://bhas.gov.ba/Calendar/Category/23?lang=bs# [Accessed 15 November 2023].

Bezdan, J., Bezdan, A., Blagojevic, B., Mesaros, M., Pejic, B., Vranesevic, M., Nikolic-Doric, E. (2019) SPEI-Based Approach to agricultural drought monitoring in Vojvodina Region. Water, 11 (7). DOI: https://doi.org/10.3390/w11071481

Brilly, M., Šraj, M., Zabret, K., Primožič, M., Vihar, A., Vidmar, A. (2015) Impact of climate change on flooding in the Bosnia and Sava river basin. Paper presented at the Simpozij Upravljanje rizicima od poplava i ublažavanje njihovih štetnih posljedica, Sarajevo (in Bosnian).

Čadro, S., Marković, M., Kaloper, S. E., Ravlić, M., Žurovec, J. (2020) Soil water balance response to climate Change in Posavina Region. AgriConf 2019. IFMBE Proceedings, 78. DOI: https://doi.org/10.1007/978-3-030-40049-1_2

Čadro, S., Škaljić, S., Rakita, N., Žurovec, J. (2019a) A modern hardware and software solutions for corn irrigation. Paper presented at the 4th International Symposium Agricultural Engineering ISAE 2019, Belgrade.

Čadro, S., Uzunovic, M., Cherni-Čadro, S., Žurovec, J. (2019b) Changes in the water balance of Bosnia and Herzegovina as a result of climate change. Agriculture and Forestry, 65 (3). DOI: https://doi.org/10.17707/AgricultForest.65.3.02

Čadro, S., Uzunović, M., Marković, M., Žurovec, O., Gocić, M. (2023) Climate change impacts on water balance components in Bosnia and Herzegovina and Croatia. Agriculture and Forestry, 69 (2), 101-116. DOI: https://doi.org/10.17707/AgricultForest.69.2.08

Čadro, S., Žurovec, J., Cherni-Čadro, S. (2017) Severity, Magnitude and Duration of Droughts in Bosnia and Herzegovina Using Standardized Precipitation Evapotranspiration Index (SPEI). Agriculture and Forestry, 63(3), 199-206. DOI: https://doi.org/10.17707/AgricultForest.63.3.20

Čaušević, A., Beslik, S., Hadžić, F., Griffin, R. (2020) Bosnia and Herzegovina, the impact and risks of climate change. Sarajevo: Multi, Damira Hadžibeganovića 115.

Djurdjević, V., Stosic, B., Tošić, M., Lazić, I., Putniković, S., Stosic, T., Tošić, I. (2024) Analysis of recent trends and spatiotemporal changes of droughts over Serbia using high-resolution gridded data. Atmospheric Research, 304. DOI: https://doi.org/10.1016/j.atmosres.2024.107376

Ducic, V., Ivanovic, R., Mihajlovic, J., Gnjato, R., Trbic, G., Curcic, N. B. (2015) Dendroindication of Drought in Rogatica Region (Eastern Bosnia). Archives of Biological Sciences, 67 (1), 201-211. DOI: https://doi.org/10.2298/Abs141114025d

Dukat, P., Bednorz, E., Ziemblinska, K., Urbaniak, M. (2022) Trends in drought occurrence and severity at mid-latitude European stations (1951-2015) estimated using standardized precipitation (SPI) and precipitation and evapotranspiration (SPEI) indices. Meteorology and Atmospheric Physics, 134 (1). DOI: https://doi.org/10.1007/s00703-022-00858-w

FNC (2021) Fourth National Communication of Bosnia and Herzegovina Under the United Nations Framework Convention on Climate Change, UNDP.

Forzieri, G., Feyen, L., Russo, S., Vousdoukas, M., Alfieri, L., Outten, S., Cid, A. (2016) Multi-hazard assessment in Europe under climate change. Climatic Change, 137 (1-2), 105-119. DOI: https://doi.org/10.1007/s10584-016-1661-x

Geiger, R. (1961) Überarbeitete Neuausgabe von Geiger, R.: KöppenGeiger Klima der Erde., (Wandkarte 1:16 Mill.). – KlettPerthes. (in German)

Hawkins, E. (2023) #ShowYourStripes. Available at: https://showyourstripes.info/ [Accessed 15 November 2023]

IPCC (2023) Climate Change 2023: Synthesis Report. Geneva, Switzerland. DOI: https://doi.org/10.59327/IPCC/AR6-9789291691647

MAWFFiB (2022) Agriculture and Rural Development Strategy for the Federation of Bosnia and Herzegovina 2021 – 2027. UNDP. Sarajevo: Federal Ministry of Agriculture, Water Management and Forestry.

McKee, T. B., Doesken, N. J., Kleist, J. (1993) The Reletionship of Droughts Frequency and Duration to Time Scales. Eighth Conference on Applied Climatology, 17-22 January, Anaheim, California.

Mohammed, S., Alsafadi, K., Enaruvbe, G. O., Bashir, B., Elbeltagi, A., Széles, A., Harsanyi, E. (2022) Assessing the impacts of agricultural drought (SPI/SPEI) on maize and wheat yields across Hungary. Scientific Reports, 12 (1). DOI: https://doi.org/10.1038/s41598-022-12799-w

NAP (2021) Bosnia and Herzegovina National Adaptation Plan – NAP with proposed measures. Sarajevo: UNDP.

Oikonomou, P. D., Karavitis, C. A., Tsesmelis, D. E., Kolokytha, E., Maia, R. (2020) Drought characteristics assessment in Europe over the Past 50 years. Water Resources Management, 34 (15), 4757-4772. DOI: https://doi.org/10.1007/s11269-020-02688-0

Palmer, W. C. (1965) Meteorological drought. Washington: U.S. Department of Commerce.

Playán, E., Cerekovic, N., Markovic, M., Vasko, Z., Vekic, M., Mujcinovic, A., Zapata, N. (2024) A roadmap to consolidate research and innovation in agricultural water management in Bosnia and Herzegovina. Agricultural Water Management, 293. DOI: https://doi.org/10.1016/j.agwat.2024.108699

Popov, T., Gnjato, S., Gnjato, R. (2019) Recent climate change in Bosnia and Herzegovina. Paper presented at the Материалы Международной научно-практической конференции Географическая наука Узбекистана и России, г. Ташкент, Республика Узбекистан.

Popov, T., Gnjato, S., Trbic, G., Ivanisevic, M. (2018) Recent trends in extreme temperature indices in Bosnia and Herzegovina. Carpathian Journal of Earth and Environmental Sciences, 13 (1), 211-224. DOI: https://doi.org/10.26471/cjees/2018/013/019

Popov, T., Gnjato, S., Trbić, G., Ivanišević, M. (2017) Trends in extreme daily precipitation indices in Bosnia and Herzegovina. Collection of Papers - Faculty of Geography at the University of Belgrade, 65(1). DOI: https://doi.org/10.5937/zrgfub1765005P

PSP-BiH (2023) Pressures on nature in BiH (third draft assessment) (Vol. 4). Sarajevo: University of Sarajevo, Faculty of Science.

Santos, J. F., Tadic, L., Portela, M. M., Espinosa, L. A., Brlekovic, T. (2023) Drought characterization in Croatia using E-OBS gridded data. Water, 15(21). DOI: https://doi.org/10.3390/w15213806

SRCLET (2021) Available at: https://meet.motherlandia.org/srclet/ [Accessed 15 November 2023]

TNC (2016) Third National Communication and second biennial update report on greenhouse gas emissions of Bosnia and Herzegovina under the United Nations Framework Convention on Climate Change (UNDP Ed.). Sarajevo: UNDP.

Trbic, G., Bajic, D., Djurdjevic, V., Ducic, V., Cupac, R., Markez, Đ., Popov , T. (2018) Limits to adaptation on climate change in Bosnia and Herzegovina: insights and experiences. Climate Change Management. Springer, 245–259. DOI: https://doi.org/10.1007/978-3-319-64599-5_14

Trbic, G., Popov, T., Djurdjevic, V., Milunovic, I., Dejanovic, T., Gnjato, S., Ivanisevic, M. (2022) Climate change in Bosnia and Herzegovina according to climate scenario RCP8.5 and possible impact on fruit production. Atmosphere, 13(1). DOI: https://doi.org/10.3390/atmos13010001

UNDP. (2013) Climate change adaptation and low-emission development strategy for Bosnia and Herzegovina. UNDP, Sarajevo.

UNDP (2020) The 2020-2030 Climate change adaptation and low emission development strategy for Bosnia and Herzegovina. Sarajevo.

UNECE (2018) Bosnia and Herzegovina environmental performance reviews - Third review. New York and Geneva.

Vicente-Serrano, S. M., Beguería, S., López-Moreno, J. I. (2010) A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. Journal of Climate, 23(7), 1696-1718. DOI: https://doi.org/10.1175/2009jcli2909.1

WBG (2021) Climate risk profile: Bosnia and Herzegovina (t. W. B. Group Ed.). Washington, DC: the World Bank Group.

WBIF (2019) Flood hazard and flood risk maps project in BiH climate change working paper: the Western Balkans Investment Framework.

Zurovec, O., Vedeld, P. O. (2019) Rural livelihoods and climate change adaptation in laggard transitional economies - A case from Bosnia and Herzegovina, Sustainability.

Žurovec, J., Čadro, S. (2011) The relationship between standardized precipitation index and yield reduction of significant agricultural crops in northeastern Bosnia. Paper presented at the 22nd International Scientific-Expert Conference on Agriculture and Food Industry, Sarajevo.

Žurovec, O., Čadro, S., Sitaula, B. K. (2017) Quantitative assessment of vulnerability to climate change in rural municipalities of Bosnia and Herzegovina. Sustainability, 9 (1208), 18. DOI: https://doi.org/10.3390/su9071208

Žurovec, O., Vedeld, P. O., Sitaula, B. K. (2015) Agricultural sector of Bosnia and Herzegovina and climate change—challenges and opportunities. Agriculture, 5 (2), 245-266. DOI: https://doi.org/10.3390/agriculture5020245