DOI: 10.17707/AgricultForest.63.3.20

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SEVERITY, MAGNITUDE AND DURATION OF DROUGHTS IN BOSNIA AND HERZEGOVINA USING STANDARDIZED PRECIPITATION EVAPOTRANSPIRATION INDEX (SPEI)

SUMMARY

Drought in Bosnia and Herzegovina (B&H) is mostly analyzed using water deficit obtained from agro-hydrological balance; a ratio between precipitation or actual evapotranspiration (AET) to potential evapotranspiration (PET); and more recently using Standardized Precipitation Index (SPI).

The main objective of this research is to use the relatively new multiscalar drought index, Standardized Precipitation Evapotranspiration Index (SPEI) to analyze severity, magnitude, and duration of drought periods in B&H. SPEI is based on precipitation and evapotranspiration data and it has the advantage of combing multiscalar character with the capacity to include the effects of variability in atmospheric water demand on draught assessment. Evapotranspiration is calculated with Penman-Monteith method, the standard international procedure for computing reference or potential evapotranspiration (ET0).

In order to assess all four types of drought, SPEI is calculated for shorter (1, 3 and 6 months) and longer (12 and 24 months) time scales. Weather stations with long-term continuous climate data records were selected - 13 stations across B&H in total, from which the climate data for 50-year period (1961 – 2010) were collected. A crucial advantage of SPEI over other drought indices previously used in B&H and its use of potential evapotranspiration and multiscalar characteristics, enabling identification of different drought types.

By using Standardized Precipitation Evapotranspiration Index (SPEI) it was found that severity, magnitude and duration of drought periods in B&H vary depending on the location and time scale for which drought was calculated. Presence of more severe long lasting droughts in period after 1986 was found for all 13 analyzed locations across B&H.

Keywords: Bosnia and Herzegovina, drought, SPEI.

INTRODUCTION

Bosnia and Herzegovina (B&H) has experienced serious incidences of extreme weather events in the past two decades, causing severe economic losses. Based on available data and currently available climate projections, exposure to

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Notes: The authors declare that they have no conflicts of interest. Authorship Form signed online.

threats from climate change will continue to increase (Žurovec et al., 2015). In order to address properly the challenges represented by climate change and its effects, B&H should develop and implement a national climate change mitigation strategy and action plan, national Clean Development Mechanism strategy and take tangible steps to implement its international and regional commitments (Čadro, et al. 2012).

The annual average precipitation in B&H is about 1250 mm, which is higher than the European average of 1000 mm (Vlahinić, 2000), but significant spatial and time variation results in areas which experience heavy flooding in winter months and drought season in the summer. Drought in B&H is mostly analyzed using water deficit obtained from agro-hydrological balance; a ratio between precipitation or actual evapotranspiration (AET) to potential evapotranspiration (PET); and more recently using Standardized Precipitation Index (SPI) and self-calibrated Palmer Drought Severity Index (scPDSI).

Agricultural sector of B&H is highly sensitive to droughts due to its socio-economic relevance. Agriculture has to be protected not only from average droughts but from those occurring once in ten years (Vlahinić et al., 2001). Because of that, it is necessary to take into account the frequency of drought phenomena. In a study of frequency distribution of drought severity for eight localities, it was found that the strongest droughts have occurred in the Mostar area, where in 1952 a catastrophic drought with annual soil water deficiency of over 400 mm occurred. Very mild droughts or no droughts at all have been experienced in Bihać. The sequential order of decreasing drought once in ten years occurrence is as follows: Mostar > Bijeljina > Bosanski Brod > Tuzla > Sarajevo > Livno > Banja Luka > Bihać (Vlahinić, et al., 2001; INCBH, 2009). The average yield decrease as a result of drought is about 20%. Drought effect is most strongly expressed in the southern parts of B&H (Vlahinić, 2000). In the central part (Sarajevo) during the time period 1961–2010, 98 (16.4%) months had drought character, and the last decade (2001-2010) is the driest, with the 24 dry months (Žurovec et al., 2011). Research showed yield reduction for most important crops (e.g. tobacco, pepper, maize, soybean, potato, alfalfa) in the northern part of B&H (Žurovec et al., 2010). For this area, it was found that as a result of climate change, dry periods that last for a longer period of time occur more frequently. These results indicate the urgent need to start with climate change adaptation, otherwise, agriculture of the area and therefore the people engaged in it will face significant negative consequences (Žurovec, et al., 2015).

During the last decades, B&H experienced several droughts in the years 2000, 2003, 2007. This produced some severe consequences: In August 2000, B&H suffered the worst drought in 120 years, where about 60% of the agricultural production was affected, resulting in extreme food insecurity. During the summer of 2003, some regions were hit by drought, which caused around €200 million in damages of agricultural output and affected close to 200,000 people. In the summer of 2007, extremely high temperatures and the resulting drought destroyed more than 40% of the agricultural production and caused forest fires, which affected about 250 hectares of land (Hodžić et al., 2013).

The severity, magnitude and drought duration may be quantified using a drought index. A drought index integrates all meteorological, hydrological and agricultural information typically into a number and gives a comprehensible big picture on drought conditions for decision making (Narasimhan and Srinisvasan, 2005).

Most studies related to drought analysis and monitoring systems worldwide have been conducted using either the Palmer drought severity index (PDSI; Palmer 1965), or the standardized precipitation index (SPI; McKee et al. 1993) (Vicente-Serrano et al., 2010).

The PDSI is based on water balance concept that includes precipitation and potential evapotranspiration (PET or ETo) data. This index was improved by development of the self-calibrated PDSI (sc-PDSI; Wells et al. 2004), but the main shortcoming has not been resolved. This relates to its fixed temporal scale and an autoregressive characteristic (Guttman, 1998).

The main criticism of the SPI is that its calculation is based only on precipitation data. The index does not consider other variables that can influence droughts, such as temperature, evapotranspiration, wind speed and soil water holding capacity. Therefore, a new drought index - the standardized precipitation evapotranspiration index (SPEI) based on precipitation and ETo has been proposed by Vicente-Serrano et al. (2010). The SPEI combines the sensitivity of PDSI to changes in evaporation demand with the simplicity of calculation and the multi-temporal nature of the SPI.

The main objective of this research is to use the Standardized Precipitation Evapotranspiration Index to analyze severity, magnitude, and duration of drought periods in B&H. A crucial advantage of SPEI over other drought indices previously used in B&H is its use of potential evapotranspiration and multiscalar characteristics, enabling identification of different drought types.

MATERIAL AND METHODS

In order to assess meteorological, agricultural and hydrological drought, SPEI is calculated for shorter (1, 3 and 6 months) and longer (12 and 24 months) time scales. SPEI1 represents short-term meteorological drought, while SPEI3 represent the drought impact, which influences soil moisture content and agriculture production. Six months SPEI (SPEI6) is correlated with stream flows, SPEI12, and SPEI24 with ground water and dam storages. Except drought conditions, SPEI can also show severity of wet spell, and this paper is focused only on severely (index value from -1.5 to -1.99) and extreme dry (index value ≤ -2.00) months.

Weather stations (WS) with long-term continuous climate data records were selected - 13 stations across B&H in total (Table 1), from which the monthly climate data (air temperature, precipitation, relative humidity, solar radiation and wind speed) for 50-year period (1961 – 2010) or 600 months were collected.

Table 1: Geographic position of used weather stations (WS)

WS	Banja L.	Bihać	Bugojno	Butmir	Doboj	Livno	Mostar	Prijedor	Sanski M.	Sarajevo	Sokolac	Tuzla	Zenica
Longitude	17° 13'	15° 51'	17° 27'	18° 20'	18° 05'	17° 01'	17° 48'	16° 44'	16° 40'	18° 26'	18° 47'	18° 42'	17° 56'
Latitude	44° 47'	44° 49'	44° 04'	43° 49'	44° 44'	43° 49'	43° 21'	44° 59'	44° 45'	43° 52'	43° 56'	44° 33'	44° 12'
Altitude	160	246	564	518	165	724	70	137	158	630	872	305	344

The SPEI was calculated based on the monthly difference between precipitation and ETo using the Package 'SPEI' in R statistical software developed by Beguería and Vicente-Serrano (2015). ETo for 13 WS was calculated with Penman-Monteith equation (Allen et al. 1998) using FAO EToCalc software.

The number of severely and extreme drought months (1961-2010) for SPEI3 calculated for 13 WS was converted to a regular grid using spatial interpolation method which helps to identify drought prone areas, severity and duration. For this study, the inverse distance weighted method (IDW) was used and drought map was prepared by ArcGIS 10.2 software.

RESULTS AND DISCUSSION

To determine severity and magnitude of drought events the number of dry months (SPEI < -1.5) for 13 WS was calculated (Table 2). In total, 600 months for the time period 1961 – 2010 was included in calculation of SPEI for 1, 3, 6, 12 and 24 month time scale.

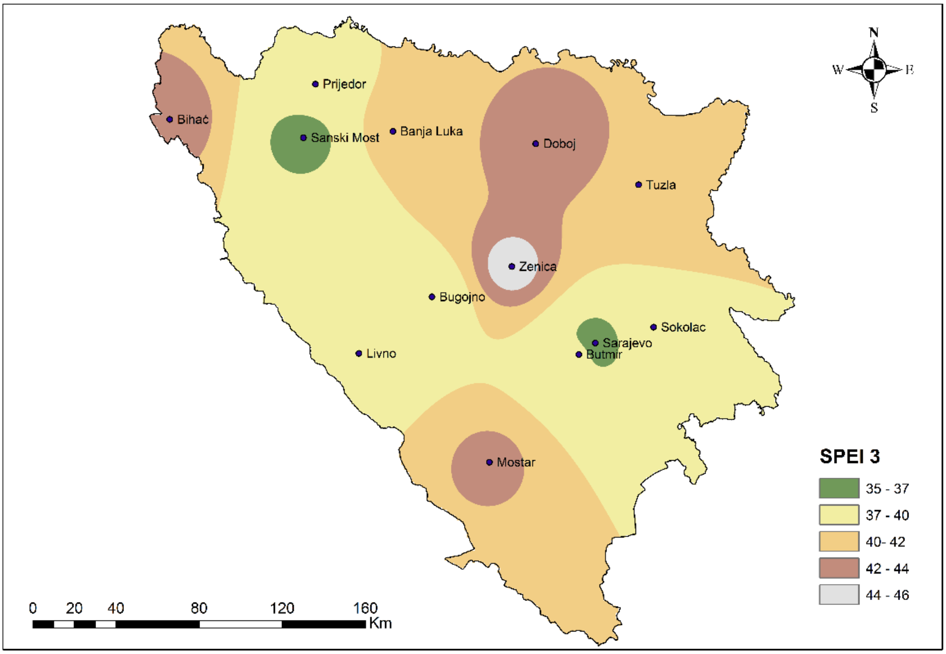
Table 2: The occurrence number and percentage of severely and extreme dry months

WS	$SPEI_1$		$SPEI_3$		$SPEI_6$		$SPEI_{12}$		$SPEI_{24}$	
	No.	%	No.	%	No.	%	No.	%	No.	%
Banja Luka	40	6.67	41	6.86	41	6.89	45	7.64	46	7.97
Bihać	36	6.00	44	7.36	38	6.39	39	6.62	39	6.76
Bugojno	36	6.00	37	6.19	**45**	**7.56**	**53**	**9.00**	33	5.72
Butmir	37	6.17	38	6.35	41	6.89	**36**	**6.11**	**27**	**4.68**
Doboj	36	6.00	44	7.36	**34**	**5.71**	37	6.28	41	7.11
Livno	39	6.50	38	6.35	36	6.05	37	6.28	35	6.07
Mostar	**32**	**5.33**	43	7.19	42	7.06	41	6.96	36	6.24
Prijedor	**41**	**6.83**	40	6.69	**45**	**7.56**	49	8.32	28	4.85
Sanski Most	39	6.50	**35**	**5.85**	37	6.22	38	6.45	48	8.32
Sarajevo	37	6.17	**35**	**5.85**	35	5.88	45	7.64	44	7.63
Sokolac	40	6.67	40	6.69	41	6.89	42	7.13	41	7.11
Tuzla	40	6.67	42	7.02	44	7.39	38	6.45	36	6.24
Zenica	40	6.67	**46**	**7.69**	41	6.89	38	6.45	**54**	**9.36**

For $SPEI_1$, which is considered as meteorological drought, the highest number of dry months is in Prijedor: 41, while Mostar has the lowest number: 32. In relation to 600 analyzed months, severely or extreme meteorological drought in B&H occurs in 5.33 - 6.83 % of them. The sequential order of decreasing number of dry months in analyzed time period is as follows: Prijedor > Banja Luka > Sokolac > Tuzla > Zenica > Livno > Sanski Most > Butmir > Sarajevo > Bihać > Bugojno > Doboj > Mostar.

Number of extreme drought events at specific location can show susceptibility to the certain type of drought. For drought affecting soil moisture content or agriculture ($SPEI_3$) the highest number of dry months is in Zenica: 46, while Sanski Most and Sarajevo have the lowest number: 35 (Table 2).

The spatial representation of severely and extreme $SPEI_3$ drought months number in B&H (Picture 1) shows that most vulnerable areas to agricultural drought extend from northeast to south of the country including region of Bihać. Less vulnerable areas are located on higher altitudes (Dinaric Mountains) from Sarajevo to Sanski Most. Severely or extreme agricultural drought in B&H occurs in 5.85 - 7.69 % of the analyzed months.



Picture 1: Number of severely and extreme $SPEI_3$ drought months in B&H, 1961-2010

For the $SPEI_6$, the highest number of dry months is in Bugojno and Prijedor - 45. Severely or extreme drought for $SPEI_6$ in B&H occurs in 5.71 - 7.56 % of the analyzed months. The sequential order of decreasing number of $SPEI_6$ dry months is as follows: Bugojno > Prijedor > Tuzla > Mostar > Banja

Luka > Butmir > Sokolac > Zenica > Bihać > Sanski Most > Livno > Sarajevo > Doboj.

Hydrological drought can be shown through longer time series of SPEI. For $SPEI_{12}$ the highest number of dry months is in Bugojno: 53, while Butmir has the lowest number 36 (Table 2). Severely or extreme drought $SPEI_{12}$ in B&H occurs in 6.11 - 9.00 % of the analyzed months. The order of decreasing number of $SPEI_{12}$ dry months in analyzed time period is as follows: Bugojno > Prijedor > Banja Luka > Sarajevo > Sokolac > Mostar > Bihać > Sanski Most > Tuzla > Zenica > Doboj > Livno > Butmir.

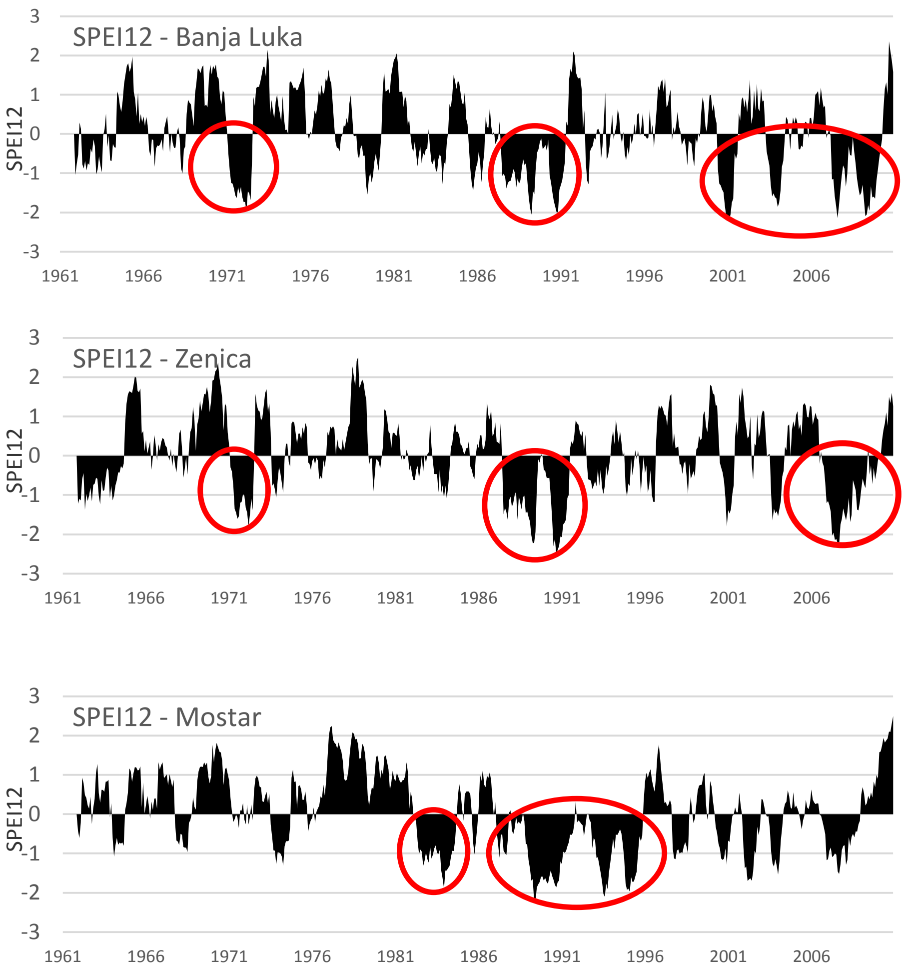


Figure 1: $SPEI_{12}$ for Banja Luka, Zenica and Mostar, 1961-2010

The comparison between severity, magnitude and duration of drought period for the long term time scale ($SPEI_{12}$) in Banja Luka, Zenica and Mostar is showed in figure 1. Chosen WS with their locations can represent North (Banja Luka), Central (Zenica) and South (Mostar) parts of B&H. Presence of more severe and long lasting droughts in period after 1986 was found for all the analyzed locations.

For Banja Luka, $SPEI_{12}$ values can be grouped into tree long lasting drought periods. First, from February 1971 until July 1972 (18 months); second, from June 1987 until March 1991 (47 months). Third, in the last decade (2001 – 2010), four short but severe drought period were determined: June 2000 – August 2001; May 2003 – May 2004; April 2007 – March 2008 and; September 2008 – February 2010. The highest $SPEI_{12}$ value for this location is -2.16, and it happened in February 2001.

Compared to Banja Luka, Zenica has similar severity and duration of drought periods. For the same first drought period, in seventies, drought magnitude was lower in Zenica. Second long drought period lasted like in Banja Luka for 47 months, but with higher severity, especially in period June 1990 – March 1991. Significant drought of the last decade started in November 2006 and lasted for 30 months. The highest $SPEI_{12}$ value for this location is -2.52, determined for September 1990.

Mostar, compared to other two locations, had two long lasting drought periods: first lasted for 28 months, from May 1982 until August 1984 and; second started in February 1987 and with small period of near 0 values of $SPEI_{12}$ (in 1988 and 1991) lasted for almost 8 years. The highest $SPEI_{12}$ value for Mostar is -2.52, determined for June 1989.

For $SPEI_{24}$ the highest number of dry months is in Zenica: 54, while Butmir has the lowest number: 27 (Table 2). Severely or extreme drought $SPEI_{24}$ in B&H occurs in 4.68 - 9.36 % of the analyzed months. For the long-term $SPEI_{24}$ larger differences in the number of dry months between locations were found.

The order of decreasing number of $SPEI_{24}$ dry months in analyzed time period is as follows: Zenica > Sanski Most > Banja Luka > Sarajevo > Doboj > Sokolac > Bihać > Mosta > Tuzla > Livno > Bugojno > Prijedor > Butmir.

CONCLUSIONS

By using Standardized Precipitation Evapotranspiration Index (SPEI) it was found that severity, magnitude and duration of drought periods in B&H vary depending on the location and time scale for which drought was calculated.

The most vulnerable area to meteorological drought is the northern part of B&H. From 600 analyzed months (1961 – 2010) 6.83 % were severely and extremely dry.

The most vulnerable areas to drought affecting soil moisture content or agriculture (SPEI3) extend from northeast to south of the country including region of Bihać. Less vulnerable areas are located in the parts of the country with the higher altitude (Dinaric Mountains) extending from Sarajevo to Sanski Most.

Most affected areas by hydrological drought according to SPEI6 and SPEI12 are Bugojno (7.56 – 9.00 % of severely and extremely dry months) and Prijedor (7.56 – 8.32 % of severely and extremely dry months), while according to SPEI24 Zenica with 9.36 % of severely and extremely dry months.

Presence of more severe long lasting droughts in period after 1986 was found for all 13 analyzed locations across B&H.

Analysis like this can help decision-makers to set priorities for water resource planning in B&H, but in future more detailed SPEI research is required.

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