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RECENT TRENDS IN EXTREME TEMPERATURE INDICES IN BOSNIA AND HERZEGOVINA

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Abstract: The study investigates trends in extreme temperature indices in Bosnia and Herzegovina. A collection of daily minimum and maximum temperature time series from four meteorological stations was selected for the calculation of 18 indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI). Trends in warm and cold extreme temperature indices during 1961–2015 periods were calculated using the RClimDex (1.0) software. Given the results, the significant warming trend is present all over Bosnia and Herzegovina. Tmax and Tmin exhibit a warming tendency during the observed period. Warm temperature extremes significantly increased, whereas cold temperature extremes showed a downward trend. In general, the warm temperature indices show stronger warming trends than those negative associated with cold temperature indices. The highest trend values were obtained for the increase in frequency and intensity of warm temperature extremes: TXx, TNn, TN90p, TX90p, WSDI, SU and TR30. The warming trend was most prominent in summer, then in winter and spring. A significant positive/negative correlation between East-Atlantic pattern and warm/cold temperature indices was determined over the entire territory of Bosnia and Herzegovina throughout the year. Winter and spring extreme temperature indices were also significantly related to the North Atlantic Oscillation index and Arctic Oscillation index, respectively.

Key words: extreme temperatures, indices, trend, climate change, Bosnia and Herzegovina.

1. INTRODUCTION

Unequivocal global warming of the climate system in the second half of the 20th century which has not been observed in recent decades and centuries (IPCC, 2014) is a result of widespread changes in mean temperatures as well as changes in frequency, intensity, and duration of extreme climate events. Studies on temperature extremes at different spatial scales, ranging from the local and regional to the global ones, indicated trends consistent with the global warming.

Global scale studies on extreme temperature indices showed that the changes were generally as expected in a warming world: warm temperature extremes increased, whereas cold temperature extremes showed a downward trend (Alexander et al., 2006; Donat et al., 2013; Morak et al., 2013). Alexander et al., (2006) found that over 70% of the global land area showed a significant decrease (increase) in the annual occurrence of cold (warm) nights. Daytime temperature extremes showed reduction in the number of cold days (TN90p) and an increased frequency of warm days (TX90p) (Donat et al., 2013). Hemispherically averaged numbers of warm days and nights have showed an increase in the range of approximately 7–9 days since the 1970s, whereas the frequency of cold days and nights decreased for approximately 5–6 days (Morak et al., 2013). Changes in all these percentile-based indices have occurred around the mid 1970s which corresponds with changes in mean global temperature (Alexander et al., 2006). The absolute temperature indices (TNn, TNx, TXn and TXx) have showed an upward trend in the second half of the 20th century (Alexander et al., 2006; Donat et al., 2013). The warming is generally stronger for the coldest than for the warmest values (Donat et al., 2013). Globally averaged, TNn has increased per about 3°C in the past 60 years, whereas TNx and TXx increased about 1°C over much of Europe, Asia, and northeastern North America (Donat et al., 2013). In many parts of the world, intra-annual extreme temperature range (ETR) showed a statistically significant decline during this period (Frich et al., 2002; Alexander et al., 2006). Almost 40 % of the land area showed a significant decrease in DTR, consistent with minimum temperatures warming faster than maximum temperatures (Alexander et al., 2006). The upward temperature trend resulted in a lengthening of the thermal growing season that had been observed in most parts of the Northern Hemisphere mid-latitudes (Frich et al., 2002). The changes in the threshold-based indices also suggest that warming of the climate system is globally present. The annual occurrence of frost days and ice days has decreased over the second half of the 20th century. Conversely, trends in the annual occurrence of tropical nights and summer days were positive and significant in a number of regions of the world (Alexander et al., 2006; Frich et al., 2002). During this period, the occurrence of warm (cold) spells significantly increased (decreased) for 8(4) days per decade (Donat et al., 2013). Results of these global analyses that determined increase in warm temperature extremes and decrease in cold temperature extremes were confirmed by numerous regional and local studies in vast majority of world regions. Since the beginning of the 20th century, the frequency of cold extremes (e. g. ice days, frost days and the cold spell duration index) in North and South America decreased, whereas warm extremes (e. g. warm nights and summer days) showed increasing tendency (Peterson et al., 2008; Brown et al., 2010; Skansi et al., 2013). Over the past 4−5 decades, an increase (decrease) in warm (cold) extremes was determined and confirmed by all temperature indices: percentile-based indices, annual maximum and minimum value of the daily annual temperature and also fixed threshold-based indices in various regions of Africa, e. g. in Morocco (Filahi et al., 2016), Nigeria (Abatan et al., 2016), the West African Sahel region (Mouhamed et al., 2013) and South Africa (Kruger & Sekele, 2013). Similar patterns of change in extreme temperature indices were determined in most parts of Indo-Pacific region – e.g. over the South Asia (Sheikh et al., 2015), China (Yu & Li, 2015), Australia and New Zealand (Caloiero, 2017). Higher frequency and greater amplitude of warm extremes and rarer occurrence of cold extremes were also detected in Europe (Chen et al., 2015). Globally observed trends in extreme temperature indices have been analyzed and confirmed at the continental level (Klein Tank & Können, 2003; Andrade et al., 2012; Chen et al., 2015). Avereged over Europe, TN10p and TX10p decreased 2.1 days per decade and 1.3 days per decade, respectively, whereas TN90p and TX90p increased 2.5 days per decade and 2.1 days per decade, respectively, during the 1946−1999 periods (Klein Tank & Können, 2003). The average annual number of FD declined for -1.7 days per decade, whereas SU displayed upward trend in the range of 0.8 days per decade (Klein Tank & Können, 2003). The upward regional maximum and minimum temperatures and increase in the frequency of warm extremes and decrease in cold ones have been detected during the second half of the 20th century and the beginning of the 21st century over the Carpathian Basin (Bartholy & Pongrácz, 2007; Lakatos et al., 2016), Iberian Peninsula (Fonseca et al., 2016), Apennine Peninsula (Fioravanti et al., 2016), Alps (Brugnara et al., 2016;), Scandinavia (Kivinen et al., 2017). National and local scale studies in Romania (Dumitrescu et al., 2015), Greece (Kioutsioukis et al., 2010), Spain (El Kenawy et al., 2011), Portugal (Espirito Santo et al., 2014), Austria (Nemec et al., 2013) and other countries detected similar trends in extreme temperatures. The regional temperature of Southeast Europe has also become warmer during the second half of the 20th century. The present 1991–2020 periods will be 0.5–1.0°C warmer than the reference 1961–1990 periods and the warming will continue in the future decades (Cheval et al., 2017). The increase in warm temperature extremes and decrease in cold ones were reported by previous studies in this part of Europe where Bosnia and Herzegovina is located (Unkašević & Tošić, 2013; Malinovic-Milicevic et al., 2016; Branković et al., 2013; Burić et al., 2015).

This study represents a continuation of the research on climate change in Bosnia and Herzegovina. Previous studies on mean temperatures (Trbić et al., 2017) already found that a warming trend was present all over this territory. However, this area has been so far poorly investigated in terms of trends in climate extremes. The main goal of this study is to analyze trends in daily maximum and minimum temperatures in Bosnia and Herzegovina using 18 extreme temperature indices (representing both warm and cold extremes). Given the existing gap in the knowledge about extreme climate events patterns of change, this study aims to reveal novel informations about the extreme temperatures variability over the Bosnia and Herzegovina territory during the 1961−2015 periods.

2. DATA AND METHODS

2.1. Study area

The study area is the territory of the Bosnia and Herzegovina, which is a continental country located in Southeast Europe. The smaller, northern part of the country covers Peripannonian region characterized by moderate continental climate (continental in the extreme northeast) with the average annual temperature 10−11°C. Going southward, the hills gradually turn into Dinaric Mountains. Mountain climate is characterized by annual temperatures in the range of 5−10°C (at highest mountain peaks below 5°C). The Herzegovina region in the south is subjected to the Mediterranean (Adriatic) influences. The lower parts of the region are the warmest area with average annual temperatures about 14°C. Maximum and minimum temperature recorded in Bosnia and Herzegovina were 43.1°C (in August 2007) and -32.2°C (in January 1963), respectively. The occurrence of extremely high temperatures in Bosnia and Herzegovina is a consequenceinfluence of the influence of very warm air masses originating in the Sahara region, while cold temperature extremes occur under the influence of Siberian anticyclone and cold polar air masses.

2.2. Data sources

The analysis of trends in extreme temperature indices during the 1961–2015 periods was carried out using climatological data set of daily maximum and minimum temperatures from 4 meteorological stations in Bosnia and Herzegovina: Banjaluka (BL), Doboj (DB), Sarajevo (SA) and Mostar (MO). Data were provided by the Federal Hydrometeorological Institute Sarajevo and the Republic Hydrometeorological Service of the Republic of Srpska. Metadata analysis showed that the locations of the meteorological stations did not change throughout the observed period and that measurements were performed using the same type of instruments without a break (only at DB station there were short interruptions in measurements during the war period 1992–1996).

2.3. Methodology

The recent extreme temperatures variability in Bosnia and Herzegovina has been determined by trends in annual and seasonal mean daily maximum (Tmax) and minimum (Tmin) temperatures and by trends in warm and cold extreme temperature indices. A set of 16 temperature indices that describe both cold and warm extremes was selected (Table 1) from the list of 27 core climate change indices (available at http://etccdi.pacificclimate.org/list_27_ indices.shtm). The indexes were defined by the joint CCL/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI). In addition, two more indices have also been analyzed – extreme temperature range (ETR) index (defined as in Frich et al., (2002) and Alexander et al., (2006)) and tropical days (defined as annual count of days when TX > 30°C). The selected indices can be divided into 5 categories (Alexander et al., 2006):

1. Percentile-based indices that sample the coldest and warmest deciles for both maximum and minimum temperatures (TN10p, TX10p, TN90p and TX90p). The 1961–1990 periods was set as the base period for determining the frequency distribution for the this indices.
2. Absolute indices that represent maximum or minimum values within a year (TNx, TNn,TXx and TXn).
3. Threshold-based indices defined as the number of days on which a temperature value falls above or below a fixed threshold (FD, ID, SU, TR20 and TR30).
4. Duration-based indices defined as periods of excessive warmth and cold or in the case of growing season length periods of mildness (WSDI, CSDI and GSL).
5. Extremes variability indices including DTR and ETR.

The indices were calculated using RClimDex (1.0) (Zhang & Yang, 2004). Before calculations, the data quality control procedure in RClimDex was also performed. Outliers in daily maximum and minimum temperatures (defined as values outside a range of four standard deviations of the climatological mean value for the day) were also identified and then manually checked. Although the definitions of the percentile-based temperature indices in RClimDex were calculated in percent, the units were converted into days for easier understanding. RClimDex provides that one of the indices has a user-dependent threshold which we have chosen to be tropical days (TR30). Trends have been analyzed by stations individually and then the trend for the whole territory of Bosnia and Herzegovina has been calculated. To detect possible significant trends, averaged data series of extreme temperature indices for Bosnia and Herzegovina were subjected to the nonparametric Mann-Kendall test. Trend magnitude (change per unit time) was determined by the Sen's nonparametric estimator of slope. The statistical significance of the observed trends was defined at the 99.9%, 99%, 95% and 90% level. The nonparametric Kolmogorov–Smirnov test, that quantifies a distance between the empirical distribution functions of two samples, was used to compare probability distributions of extreme temperature indices between 1961–1990 and 1991–2015 periods. Calculations were made in XLSTAT Version 2014.5.03.

Table 1. Definitions of the indices used in the study

Index	Descriptive name	Definition	Units
Indices of warm temperature extremes			
TXx	Maximum value of daily maximum temperature	Annual maximum value of daily maximum temp	°C
TXn	Minimum value of daily maximum temperature	Annual minimum value of daily maximum temp	°C
TX90p	Warm days	Number of days when TX > 90th percentile	days
TN90p	Warm nights	Number of days when TN > 90th percentile	days
SU	Number of summer days	Annual count of days when TX > 25°C	days
TR30	Number of tropical days	Annual count of days when TX > 30°C	days
TR20	Number of tropical nights	Annual count of days when TN > 20°C	days
WSDI	Warm spell duration index	Annual count of days with at least 6 consecutive days when TX > 90th percentile	days
Indices of cold temperature extremes			
TNn	Minimum value of daily minimum temperature	Annual minimum value of daily minimum temp	°C
TNx	Maximum value of daily minimum temperature	Annual maximum value of daily minimum temp	°C
TX10p	Cold days	Number of days when TX < 10th percentile	days
TN10p	Cold nights	Number of days when TN < 10th percentile	days
FD	Number of frost days	Annual count of days when TN < 0°C	days
ID	Number of icing days	Annual count of days when TX < 0°C	days
CSDI	Cold spell duration index	Annual count of days with at least 6 consecutive days when TN < 10th percentile	days
Indices of extremes variability			
GSL	Growing season length	Annual (1st Jan to 31st Dec in Northern Hemisphere) count between first span of at least 6 days with daily mean temperature TG > 5°C and first span after July 1st of 6 days with TG < 5°C.	days
DTR	Daily temperature range	Monthly mean difference between TX and TN	°C
ETR	Intra-annual extreme temperature range	Difference between the highest temperature observation of any given calendar year and the lowest temperature reading of the same calendar year	°C

In order to describe the relationship between the observed trends in extreme temperature indices in Bosnia and Herzegovina and the large-scale atmospheric circulations (Barnston & Livezey, 1987), two primary modes of atmospheric circulation variability over the North Atlantic that impact seasonal temperature over Europe – the North Atlantic Oscillation (NAO) and the East-Atlantic (EA) pattern – were analyzed. In addition, the influence of the Arctic Oscillation (AO) was also evaluated. Data on teleconnection patterns indices were collected from NOAA Climate Prediction Center (available at http://www.cpc.ncep.noaa.gov/ data/teledoc/ telecontents.shtml). To assess and quantify the relation between analyzed extreme temperature indices and the large-scale circulation patterns, the Pearson correlation coefficient was used. The coefficients were calculated on annual or seasonal levels for state averaged temperature indices. The statistical significance of the determined correlations was defined at the same statistical levels as for trend slopes.

3. RESULTS

Decadal trends in annual and seasonal Tmax and Tmin in Bosnia and Herzegovina are shown in Table 2 and Figure 1. Significant positive trends in Tmax and Tmin in the 1961–2015 periods were present troughout the year (except for Tmax in autumn). The annual Tmax has significantly increased by 0.5°C (0.3–0.6°C) per decade and the annual Tmin by 0.4°C (0.3–0.5°C) per decade. Although climate system warming was apparent in all seasons, the trend was most prominent in summer (0.5–0.7°C per decade for Tmax and 0.4–0.6°C per decade for Tmin) and then in winter and spring, whereas in autumn only a slight temperature increase has been observed.

Table 2. Decadal trends in annual and seasonal Tmax and Tmin in Bosnia and Herzegovina in 1961–2015 (°C per decade)

Station	Tmax					Tmin				
	Winter	Spring	Summer	Autumn	Year	Winter	Spring	Summer	Autumn	Year
BL	0.6^b	0.6^a	0.7^a	0.3^b	0.6^a	0.5^a	0.4^a	0.6^a	0.4^a	0.5^a
DB	0.6^b	0.5^b	0.5^a	0.2	0.4^a	0.4^c	0.2^c	0.4^a	0.2	0.3^a
SA	0.4^c	0.4^b	0.7^a	0.2	0.4^a	0.4^b	0.2^b	0.4^a	0.2^c	0.3^a
MO	0.2^c	0.3^b	0.6^a	0.1	0.3^a	0.2^c	0.3^a	0.5^a	0.2^c	0.3^a
BIH	0.5^b	0.4^a	0.6^a	0.2	0.5^a	0.4^b	0.3^a	0.5^a	0.2^a	0.4^a

Statistical significance at the 99.9 % (^{a}), 99 % (^{b}), 95 % (^{c}) and 90 % (^{d}) level

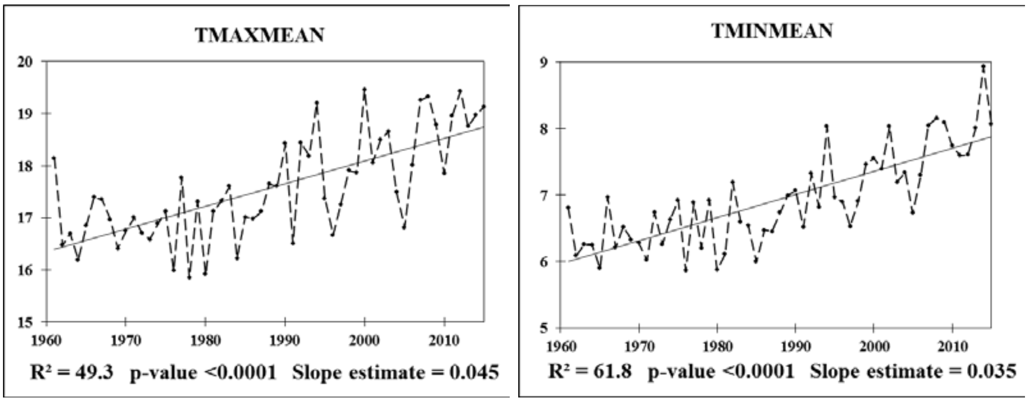

Figure 1. Linear trends in annual Tmax and Tmin in Bosnia and Herzegovina in 1961–2015

The obtained results (Table 3 and Figure 2) show that there are general positive trends associated with indices of warm temperature extremes, whereas cold temperature extremes indices show a downward trend. Both trends indicate climate system warming present over the entire territory of Bosnia and Herzegovina. In general, the warm temperature indices show stronger warming trends that are more significant than the negative ones associated with cold temperature indices. There are statistically significant trends for most stations in all temperature indices that indicate warming, with the exception of the indices associated with warming of minimum daily maximum and minimum temperatures (TXn and TNn) and CSDI.

The absolute temperature indices trend analysis shows that the estimated positive trends in maximum values of daily maximum and minimum temperatures TXx and TNx over the entire territory of Bosnia and Herzegovina were high and significant – 0.7°C (0.5–0.8°C) per decade and 0.5°C (0.4–0.6°C) per decade, respectively. Conversly, upward trends in minimum values of daily maximum and minimum temperatures were less pronounced, particularly for TXn. Trends in TNn (0.4–0.6°C per decade) were only partially significant, whereas TXn trends (0.3°C per decade) were insignificant over the entire study area.

Higher increase in TXx than in TNn has resulted in ETR insignificant increase in the range of 0.1–0.3°C per decade. DTR showed very low positive trend (0.1°C per decade) that was only partially significant. Upward trends in Tmax and Tmin have led to extension of the growing season length. GSL has been steadily increasing during the observed period by the rate of 5.2 (2.8–8.9) days per decade.

Table 3. Decadal trends in extreme temperature indices in Bosnia and Herzegovina in 1961–2015

Index	TXx	TXn	TNx	TNn	ETR	DTR	GSL	WSDI	CSDI
BL	0.7^a	0.3	0.6^a	0.5	0.3	0.1	8.9^a	7.1^a	-0.9^d
DB	0.6^b	0.2	0.4^a	0.6	-0.1	0.1^c	5.3^c	5.8^a	-0.7
SA	0.8^a	0.3	0.5^c	0.5^d	0.3	0.1^c	2.8	6.4^a	-0.3
MO	0.5^a	0.3	0.6^a	0.4^c	0.1	0.1	3.3^a	7.1^a	-0.8
Index	TX10p	TX90p	TN10p	TN90p	FD	ID	SU	TR30	TR20
BL	-4.5^a	11.8^a	-6.0^a	13.8^a	-5.6^a	-2.6^a	7.7^a	7.1^a	0.9^a
DB	-4.4^a	8.8^a	-4.1^a	8.6^a	-2.8^c	-2.1^b	5.2^a	5.1^a	0.5^a
SA	-3.1^a	9.6^a	-4.4^a	8.2^a	-3.4^b	-2.5^a	6.2^a	6.1^a	0.2^c
MO	-3.3^a	9.5^a	-4.2^a	9.8^a	-2.0^b	-0.3	3.2^b	5.4^a	5.7^a

Statistical significance at the 99.9 % (^{a}), 99 % (^{b}), 95 % (^{c}) and 90 % (^{d}) level

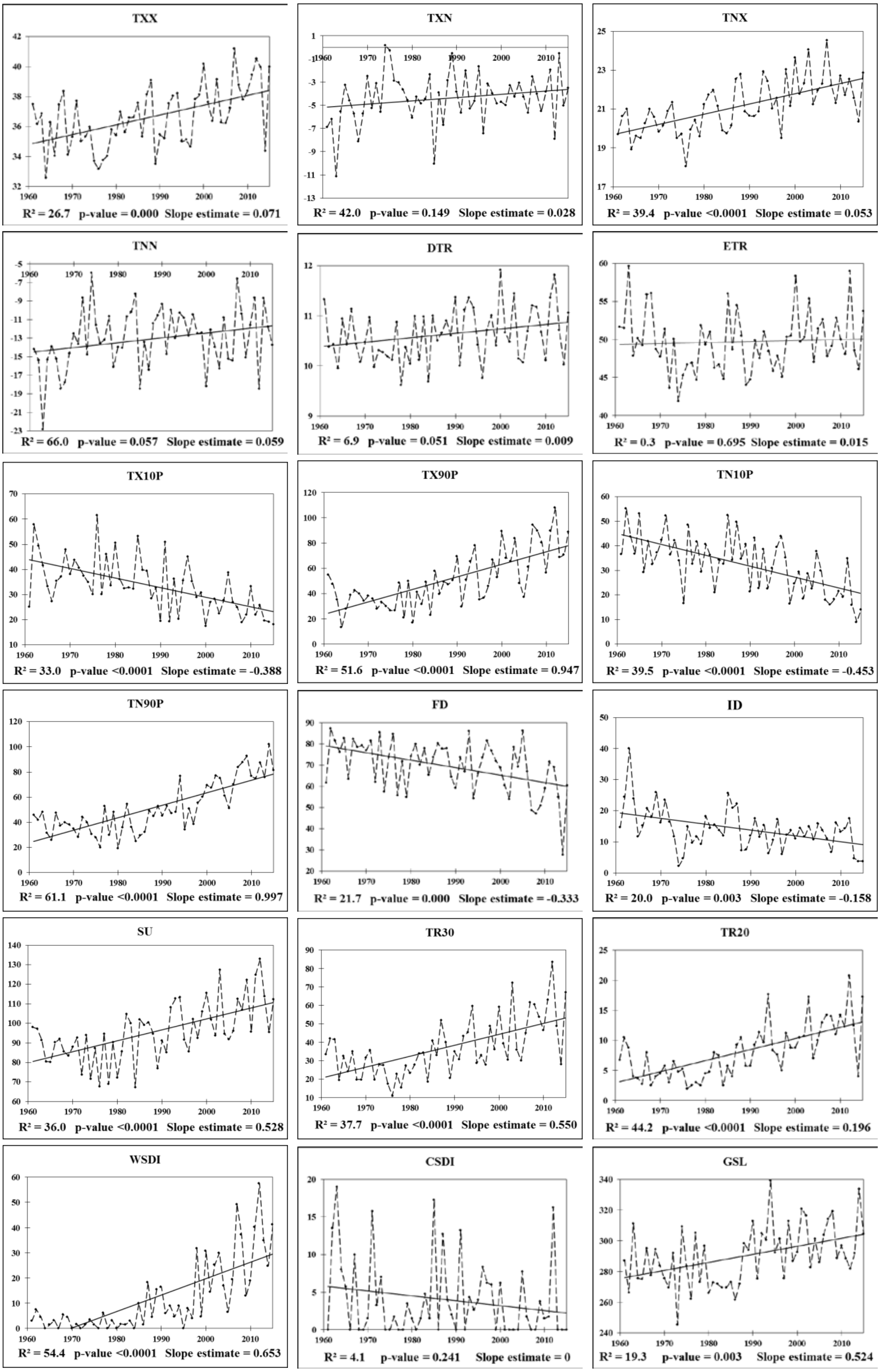

Figure 2. Linear trend in extreme temperature indices in Bosnia and Herzegovina in 1961–2015

The positive/negative trends in warm/cold days and nights also indicate climate system warming in Bosnia and Herzegovina. The number of TN10p and TX10p has been reduced by 4.5 (4.1–6.0) and 3.9 (3.1–4.5) days per decade, respectively, whereas the increase in number of TN90p and TX90p was much higher – 10.0 (8.2–13.8) and 9.5 (8.8–11.8) days per decade, respectively.

The analysis of percentile-based indices showed that the nighttime temperatures increase was greater than the daytime temperatures. In general, increase in number of TN90p has been higher than in TX90p, whereas decline in number of TN10p has been higher than in TX10p.

Table 4 shows that highest increase (decrease) in warm (cold) days and nights occurred in summer season. Thus, the aforementioned indicates stronger warming in this part of year than in winter.

Table 4. Decadal trends in seasonal percentile-based indices in Bosnia and Herzegovina in 1961–2015 (days per decade)

Index	Winter	Spring	Summer	Autumn
TX10p	-1.1[c]	-0.9[c]	-1.3[a]	-0.3
TX90p	1.2[b]	1.8[b]	4.7[a]	1.3[c]
TN10p	-0.7[d]	-1.0[a]	-1.7[a]	-0.5
TN90p	1.5[b]	1.6[a]	4.8[a]	1.5[b]

Statistical significance at the 99.9 % ([a]), 99 % ([b]), 95 % ([c]) and 90 % ([d]) level

Consistent with climate system warming were also the observed trends in threshold-based temperature indices – the significant downward trends in FD and ID and the significant upward trends in SU, TR30 and TR20. The annual FD and ID declined for 3.3 (2.0–5.6) and 1.6 (0.3–2.6) days per decade, respectively. The increase in warm threshold-based temperature indices SU, TR30 and TR20 has been much more prominent – 5.3 (3.2–7.7), 4.8 (5.1–7.1) and 2.0 (0.2–5.7) days per decade, respectively. During the observed period, the prominent and significant positive trends in WSDI were found at all analyzed stations. WSDI increased by 6.5 (5.8–7.1) days per decade. Conversely, only a slight negative trend was determined for CSDI (0.3-0.9 days per decade) over the entire territory.

4. DISCUSSION

Much of the world (Alexander et al., 2006; Frich et al., 2002; Donat et al. 2013), including Europe (at continental level) (Klein Tank & Können, 2003), reports greater warming in Tmin than in the Tmax. For example, in Southeastern part of the United States the higher positive trends were generally observed in minimum temperature-related indices, including TR20, TNx and TN90p (Powell & Keim, 2015). In South America, the largest warming rates during the 1950–2010 periods also showed indices derived from minimum temperatures (e. g. TR20 4.68 days per decade, TN10p -1.77 days per decade and TX10p -0.61 days per decade), whereas maximum temperature indices demonstrated lower warming rates (e. g. TN90p 1.54 days per decade, SU 1.26 days per decade, TXn 0.20°C per decade) (Skansi et al., 2013). Trends in minimum temperature extremes in China were also more rapid than trends in maximum temperature extremes (Yu & Li, 2015). However, in Bosnia and Herzegovina changes in maximum temperatures were higher than in minimum temperatures. This follows the results of other studies carried out for Southeast Europe region (Malinovic-Milicevic et al., 2016; Branković et al., 2013; Burić et al., 2015). The maximum temperatures in Serbia and Croatia were exposed to the greater changes (with the highest frequency of trends in the range of 0.3−0.4°C per decade), than minimum temperatures which mostly increased 0.2−0.3°C per decade (Branković et al., 2013; Malinovic-Milicevic et al., 2016). Higher trend values for maximum temperatures were also determined in Italy (Fioravanti et al., 2016) and Spain (El Kenawy et al., 2011).

Further, significant positive trends in maximum values of daily maximum and minimum temperatures were recorded over the entire territory of Bosnia and Herzegovina, particularly prominent for TXx. Recent studies on detection and attribution of climate change have shown that human influence (clearly separable from the response to natural-only forcings) have increased the probability of many extremely warm seasonal temperatures and reduced the probability of extremely cold seasonal temperatures in many parts of the world (Stott et al., 2016; Kim et al., 2016). This external influences are estimated to have resulted in large changes in the likelihood of extreme annual maximum and minimum daily temperatures − globally, waiting period for extreme annual TNn and TXn events that were expected to recur once every 20 years in the 1960s are now estimated to exceed 35 and 30 years, respectively; in contrast, waiting periods for TNx and TXx have decreased to fewer than 10 and 15 years, respectively (Zwiers et al., 2011).

Global analysis of the percentile-based indices showed that the changes were most pronounced in the number of TN10p, then in the frequency of TN90p, whereas the least was in the frequency of TX90p (Morak et al., 2013). Results for Europe have shown that these trends tend to be more significant for the monthly number of TX90p than for the

TN10p, which means that daytime temperatures are undergoing a stronger warming (Andrade et al., 2012). Daytime temperature extremes TN90p and TX90p showed particularly strong trends in the last quarter of the 20th century (11.3 days per decade and 10.9 days per decade, respectively) (Klein Tank & Können, 2003) that contribute much more to the climate system warming than the decreases in cold extremes. The decadal trend for TN90p in Europe of 11.3 implies almost a doubling of the annual number of warm nights and shortened their return period from 10 to 6 days (Klein Tank & Können, 2003). The greatest changes in Bosnia and Herzegovina have also been reported for TN90p (increase up to 13.8 days per decade) and TX90p (increase up to 11.8 days per decade) and then for TN10p. Decrease rates for TN10p and TX10p were considerably lower. Similar patterns of change in percentile-based indices were found for other regions of Europe and world. The significant increase (decrease) in the annual occurrence of warm (cold) nights was detected at 74 % (26 %) of the stations in Greece (Kioutsioukis et al., 2010). In Italy, TN90p and TX90p have shown upward trends since the early 1980s, with positive mean anomalies since 1985. In Croatia, the most prominent increases were found in the number of TN90p (8−12 days per decade) and TX90p (6−10 days per decade) (Branković et al., 2013). In Austria, both TN and TX indices have also showed significant trends at almost all stations, with an increasing number of warm nights (days) and a decreasing number of cold nights (days) (Nemec et al., 2013). In China, the occurrence of TN90p and TX90p increased 2.17 days per decade and 0.97 days per decade, respectively, whereas TN10p and TXx decreased 1.80 days per decade and 0.86 days per decade, respectively, during the past 52 years (Yu & Li, 2015). In the Carpathian basin the strongest change occurred in the annual occurrence of warm nights which increased by about 44 days during the 1960−2010 periods (Lakatos et al., 2016).
Both trends in threshold-based temperature indices in Bosnia and Herzegovina – the upward trends in warm temperature indices and the downward trends in cold temperature indices are consistent with those trends observed globally (Alexander et al., 2006; Frich et al., 2002), in Europe – at continental level (Klein Tank & Können, 2003) and in its various regions (Branković et al., 2013; Burić et al., 2015; Lakatos et al., 2016; Fioravanti et al., 2016; El Kenawy et al., 2011). However, it should be noted that positive trends in the warm temperature indices (SU 5.28 days per decade, TR30 5.50 days per decade and TR20 5.7 days per decade – in Mostar, the only region where they are frequent) were much more pronounced than negative trends in cold temperature indices (FD -3.3 days per decade and ID -1.58 days per decade). This is also consistent with previous studies' findings. In the Carpathian Basin ID and FD displayed decreasing trend in the range of -1.8 days per decade and -2.5 days per decade, respectively, whereas increase in SU was more prominent (3.7 days per decade) (Lakatos et al., 2016). At most stations in Croatia, the increase of the number of SU was in the range of 2−8 days per decade, whereas decline in FD, were smaller in magnitude (mostly up to 2 days per decade) (Branković et al., 2013). In Italy, the average annual number of SU has been above the 1961–1990 averages over the last 30 years (except in a few years), as well as the number of TR20 (displays positive anomalies since 1982 with the exception of 1984 and 1996) (Fioravanti et al., 2016). TR20 displayed a significant positive trend at 65% of the stations in Greece, resulting in a notable increase of the upper bound of its distribution (Kioutsioukis et al., 2010). FD frequency decreased over the northeastern United States by 2.1 days per decade, with the strongest decreases over last part of the 20th century (Brown et al., 2010).

Significantly longer heat wave duration has been observed in this part of Europe (Frich et al., 2002). There were 11 intense and long-lasting heat waves between 1950 and 2015 in Europe, most of which occurred after 2000 (in 2003, 2006, 2007, 2010, 2014 and 2015) (Russo et al., 2015). Christidis et al., (2015) found that after the more extreme threshold observed in 2003, events that would occur twice a century in the early 2000s are now expected to occur twice a decade. Prominent and significant positive trends in WSDI and insignificant negative trends in CSDI over the entire territory suggest that the periods of extremely hot weather last longer, while the periods of extremely cold weather are shortened. The annual number of CSDI declined from 5.8 days and 3.3 days during the first two decades, to 3.5 days and 2.7 days during the last two decades. In the same period, the annual number of WSDI rapidly increased, from 2.0 days and 3.0 days up to 17.3 days and 33.7 days. It can be concluded that the warming trend was more related to increase in frequency of WSDI than to annual reduction in CSDI. The highest WSDI values were recorded in years with intense and long-lasting heat waves – 2007 and 2012. This is in line with findings of other studies in this region. For example, the most severe heat wave in Serbia (Belgrade) was recorded in July 2007 (Unkašević & Tošić, 2009), whereas the longest heat wave occurred during summer 2012 (Unkašević & Tošić, 2015). The Southeast Europe region also experienced an intense heat wave in 2015 (the heat event started at the end of July and persisted till the first ten days of August) (Russo et al., 2015). The significant increase in the frequency and duration of heat waves was also found in other European regions, particularly in the Mediterranean region (Espirito Santo et al., 2014; Fioravanti et al., 2016; El Kenawy et al., 2011; Fonseca et al., 2016). At low-elevation sites in the southern Alps number of hot days in summer and duration of heat waves have more than tripled (the estimated trends were in the range of 6.8 ± 0.9 days per century and 2.7 ± 0.4 days per century, respectively) (Brugnara et al., 2016). In the Carpathian basin WSDI displayed upward trend in the range of 4.1 days per decade (Lakatos et al., 2016).

Based on the foregoing, the estimated positive trends in extreme temperature indices in Bosnia and Herzegovina were more pronounced then negative ones. In general, changes are more prevalent in warm temperature extremes than in cold ones. The highest trend values in Bosnia and Herzegovina were precisely detected for the following warm temperature indices: TXx (0.71°C per decade), TN90p (9.97 days per decade), TX90p (9.47 days per decade), WSDI (6.53 days per decade), SU (5.28 days per decade) and TR30 (5.50 days per decade). This findings can be largely explained by higher increase found in the Tmax during the last 5–6 decades. Previous studies in several parts of Europe have found similar patterns of change (Malinovic-Milicevic et al., 2016; Unkašević & Tošić, 2013; Branković et al., 2013; Burić et al., 2015; Bartholy & Pongrácz, 2007; El Kenawy et al., 2011; Fonseca et al., 2016; Fioravanti et al., 2016; Brugnara et al., 2016). For example, more prominent changes in warm extremes than in cold ones were determined over the Iberian Peninsula, e. g. in Northeastern Spain − TN90p 3.3 days per decade, TX90p 2.7 days per decade, TR20 0.6 days per decade and TXx 0.27°C per decade (El Kenawy et al., 2011; Fonseca et al., 2016). The strongest positive trends (higher than 6 days per decade) in the Carpathian Basin were also detected for the annual numbers of TR30, SU, TX90p, TN90p and HWDI (Bartholy & Pongrácz, 2007).

Trends in all extreme temperature indices became stronger in last quarter of the 20th century and particularly since the beginning of the 21st century. The highest values in warm indices and lowest values in cold indices were recorded during the hottest years in the observed period. For example, the extremely low values of cold temperature indices in Banjaluka were recorded in the hottest year. In 2014 there were only 20 TX10p, 2 TN10p, 34 FD, 4 ID and without a single CSDI. Contrary, in 2012 (2007), one of the warmest years with occurrence of the intense heat wave, there were even 106 (104) TX90p, 109 (103) TN90p, 132 (115) SU, 88 (62) TR30, 10 (6) TR20 and 43 (58) WSDI. The maximum (minimum) frequency of warm (cold) temperature indices was recorded in hottest years with the occurrence of intense and long-lasting heat waves – in 2000, 2003, 2007, 2008, 2011, 2012, 2013 and 2015.

Global scale studies have shown that during the 20th century significant shifts in the extreme temperature indices probability distribution have occurred over the Northern Hemisphere midlatitudes associated with the warming trend (Alexander et al., 2006). The Kolmogorov–Smirnov test results (not shown) confirm that the distributions of extreme temperature indices in Bosnia and Herzegovina in the 1991–2015 periods are statistically different compared to the standard climatological period (1961–1990), except for TXn, TNn, CSDI and DTR. As expected due to a warming trend, the mean values of cold temperature indices distributions from 1961–1990 to 1991–2015 shifted to the left. Corresponding shift to the right in the mean values of warm temperature indices distributions was also observed. Similar was observed at global scale − the distributions of both Tmax and Tmin have significantly shifted towards higher values in the 1981–2010 periods compared to the 1951–1980 (Donat & Alexander, 2012).

Although a comprehensive research on the relations between large-scale circulation patterns and the extreme temperature trends is beyond the scope of this study, some basic correlation analyses were performed. Previous studies showed that positive temperature anomalies in many regions of Europe (including part of the continent where Bosnia and Herzegovina is located) were associated with the EA pattern (Rust et al., 2015). The positive phase of the EA pattern is associated with above-average surface temperatures in Europe throughout the year (Rust et al., 2015). Significant positive correlation with mean seasonal and annual temperatures in Bosnia and Herzegovina has been previously determined in research Trbić et al., (2017). The EA pattern in its positive phase triggers important warm advections over Europe (driven by southwesterly flows) that prevent the occurrence of extremely cold events (Andrade et al., 2012). Table 5 shows that there is a significant correlation with extreme temperature indices. The EA pattern index (EAI) shows strong and significant positive (negative) correlation with all warm (cold) temperature extreme indices in Bosnia and Herzegovina (except for TNn and TXn).

Although significant correlation coefficients between EAI and Tmax and Tmin were found throughout the year, the strongest correlations were determined for summer and winter seasons (Table 6). The analysis of seasonal percentile-based indices showed similar patterns during the year (Table 7).

Climate variability in Europe is also strongly dictated by NAO, especially during winter season (Hurrell et al., 2003). In winter, during positive NAO phase, the warmer maritime air masses are advected to Europe by stronger-than-average westerlies over the middle latitudes associated with low pressure anomalies over the region of the Icelandic low and anomalously high pressures across the subtropical Atlantic (Rust et al., 2015; Hurrell et al., 2003). Studies showed that the persistent and exceptionally strong positive NAO index (NAOI) since the early 1980s accounted for a substantial part of the observed warming over Europe in winter (Hurrell & Van Loon, 1997). The NAO in its positive phase, is clearly unfavourable (favourable) to cold night (warm day) occurrences in this part of Europe (Andrade et al., 2012). Correlation coefficients between annual NOAI and extreme temperature indices in Bosnia and Herzegovina are shown in Table 8. The significant positive correlation between NAOI and Tmax and Tmin (insignificant for TX90p and TN90p) was determined in Bosnia and Herzegovina in winter. In this season, a significant negative correlation was also found for TX10p and TN10p occurrence.

Table 5. Pearson correlation coefficient between annual EAI and extreme temperature indices in Bosnia and Herzegovina in the 1961–2015 periods

Index	r	Index	r	Index	r	Index	r
Tmax	0.672^a	TNx	0.561^a	FD	-0.517^a	WSDI	0.587^a
Tmin	0.700^a	TX10p	-0.656^a	ID	-0.353^b	CSDI	-0.294^c
TXx	0.439^a	TX90p	0.662^a	SU	0.572^a	DTR	0.319^c
TNn	0.066	TN10p	-0.589^a	TR30	0.533^a	ETR	0.172
TXn	0.015	TN90p	0.723^a	TR20	0.535^a	GSL	0.447^a

Statistical significance at the 99.9 % (^{a}), 99 % (^{b}), 95 % (^{c}) and 90 % (^{d}) level

Table 6. Pearson correlation coefficient between seasonal teleconnection patterns and Tmax and Tmin in Bosnia and Herzegovina in the 1961–2015 periods

Index	Tmax				Tmin			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
EA	0.650^a	0.479^a	0.647^a	0.512^a	0.606^a	0.445^a	0.663^a	0.503^a
NAO	0.392^b	0.160	-0.454^a	-0.141	0.270^c	0.156	-0.376^b	-0.114
EAWR	0.002	0.153	-0.353^b	-0.216	-0.175	0.127	-0.402^b	-0.273^c
AO	0.263^d	0.435^a	-0.191	0.078	0.075	0.389^b	-0.074	-0.133

Statistical significance at the 99.9 % (^{a}), 99 % (^{b}), 95 % (^{c}) and 90 % (^{d}) level

Table 7. Pearson correlation coefficient between seasonal teleconnection patterns and percentile-based temperature indices in Bosnia and Herzegovina in the 1961–2015 periods

Index	TX10p				TX90p			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
EA	-0.469^a	-0.482^a	-0.548^a	-0.542^a	0.609^a	0.409^b	0.649^a	0.400^b
NAO	-0.414^b	-0.008	0.318^c	0.121	0.210	0.204	-0.510^a	-0.093
AO	-0.308^c	-0.274^c	0.212	0.002	0.162	0.388^b	-0.205	0.209
Index	**TN10p**				**TN90p**			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
EA	-0.500^a	-0.318^c	-0.503^a	-0.486^a	0.579^a	0.517^a	0.684^a	0.433^a
NAO	-0.320^c	-0.078	0.209	0.084	0.024	0.091	-0.438^a	-0.092
AO	-0.183	-0.312^c	0.151	0.151	-0.103	0.396^c	-0.062	-0.075

Statistical significance at the 99.9 % (^{a}), 99 % (^{b}), 95 % (^{c}) and 90 % (^{d}) level

Table 8. Pearson correlation coefficient between annual NOAI and extreme temperature indices in Bosnia and Herzegovina in the 1961–2015 periods

Index	r	Index	r	Index	r	Index	r
Tmax	0.146	TNx	-0.064	FD	-0.126	WSDI	-0.049
Tmin	0.125	TX10p	-0.204	ID	-0.287^c	CSDI	-0.213
TXx	-0.080	TX90p	0.041	SU	0.023	DTR	0.105
TNn	0.421^a	TN10p	-0.179	TR30	-0.038	ETR	-0.390^b
TXn	0.398^b	TN90p	-0.029	TR20	-0.038	GSL	0.031

Statistical significance at the 99.9 % (^{a}), 99 % (^{b}), 95 % (^{c}) and 90 % (^{d}) level

Studies have demonstrated that during the period of instrumental measurements (since the mid-19th century), sea surface temperatures in North Atlantic showed two 65–80 years cycles with a 0.4°C temperature range between extremes of positive/warm and negative/cool phases referred to as the Atlantic Multidecadal Oscillation (AMO) (Gray et al., 2004). The AMO that is positively correlated with the global mean annual surface land temperature (Muller et al., 2013) has been in its warm phase since 1995. Since 1990s, the temperature increase also becomes more pronounced both globally and in Bosnia and Herzegovina (Trbić et al., 2017). Table 9 shows that correlation between AMO index (AMOI) and warm temperature extreme indices is positive and significant. The strongest correlation is found for TN90p, WSDI, TR20, TNx and TX90p. The negative correlation with cold temperature extreme indices is mainly insignificant, except for TX10p and TN10p. Table 10 shows that throughout the year links are the strongest in summer and autumn.

In addition to the links with the primary modes of atmospheric circulation variability over the North Atlantic, the significant relation to the Arctic Oscillation (AO) was also determined − positive for Tmax, Tmin, TNn, TXn, DTR, TX90p, SU, TR30, TR20 and WSDI, and for TX10p, TN10p and ID (Table 11). The links are particularly pronounced and significant in spring and partially in winter.

5. CONCLUSION

This study addresses the issue of changes in frequency, intensity, and duration of extreme temperature events in Bosnia and Herzegovina. Based on daily minimum and maximum temperature time series 18 extreme temperature indices recommended by the ETCCDI were calculated for 1961–2015 periods using the RClimDex (1.0) software.

The main conclusions of this study are as follows:

– The obtained results indicate that the entire territory of Bosnia and Herzegovina is characterized by prominent warming trend. The results showed a positive trends in both the maximum and the minimum temperatures throughout the year (particularly in summer). The increase in Tmax was being somewhat more pronounced.

Table 9. Pearson correlation coefficient between annual AMOI and extreme temperature indices in Bosnia and Herzegovina in the 1961–2015 periods

Index	r	Index	r	Index	r	Index	r
Tmax	0.470[a]	TNx	0.570[a]	FD	-0.192	WSDI	0.608[a]
Tmin	0.492[a]	TX10p	-0.394[b]	ID	-0.062	CSDI	-0.041
TXx	0.437[a]	TX90p	0.538[a]	SU	0.455[a]	DTR	0.223
TNn	-0.115	TN10p	-0.342[c]	TR30	0.523[a]	ETR	0.321[c]
TXn	-0.096	TN90p	0.619[a]	TR20	0.594[d]	GSL	0.318[c]

Statistical significance at the 99.9 % ([a]), 99 % ([b]), 95 % ([c]) and 90 % ([d]) level

Table 10. Pearson correlation coefficient between seasonal AMOI and extreme temperature indices in Bosnia and Herzegovina in the 1961–2015 periods

Index	Winter	Spring	Summer	Autumn
Tmax	0.015	0.119	0.494[a]	0.312[c]
Tmin	-0.007	0.124	0.621[a]	0.413[b]
TX10p	0.125	-0.076	-0.342[c]	-0.288[c]
TX90p	0.103	0.112	0.537[a]	0.388[b]
TN10p	0.112	-0.038	-0.447[a]	-0.336[c]
TN90p	0.12	0.247[d]	0.685[a]	0.427[a]

Statistical significance at the 99.9 % ([a]), 99 % ([b]), 95 % ([c]) and 90 % ([d]) level

Table 11. Pearson correlation coefficient between annual AOI and extreme temperature indices in Bosnia and Herzegovina in the 1961–2015 periods

Index	r	Index	r	Index	r	Index	r
Tmax	0.389[b]	TNx	0.129	FD0	-0.141	WSDI	0.225[d]
Tmin	0.289[c]	TX10p	-0.401[b]	ID0	-0.365[b]	CSDI	-0.167
TXx	0.097	TX90p	0.296[c]	SU25	0.235[d]	DTR	0.341[c]
TNn	0.343[b]	TN10p	-0.319[c]	TR30	0.196[a]	ETR	-0.234[d]
TXn	0.365[b]	TN90p	0.187	TR20	0.267[c]	GSL	0.159

Statistical significance at the 99.9 % ([a]), 99 % ([b]), 95 % ([c]) and 90 % ([d]) level

- The trend analysis of the extreme temperature indices suggests that there has been a significant increase in the frequency, intensity or duration of hot extremes, while the cold extremes have shown a downward tendency. However, both trends confirm that the climate system warming is present.
- The highest trend values were estimated for the warm temperature indices: TXx, TNn, TN90p, TX90p, WSDI, SU and TR30.
- Trends in all extreme temperature indices became stronger in last quarter of the 20th century and particularly since the beginning of the 21st century.

This kind of study on the extreme temperature indices that has not been previously conducted for this area can contribute to better understanding of the recent climate change. Moreover, the obtained results can be placed in a wider climate change context and compared with the results of similar studies, providing insight into the trends in extreme temperatures in the Southeast Europe region in the second half of the 20th century and at the beginning of the 21st century. The observed changing patterns in Bosnia and Herzegovina are consistent with the predominant trends in other areas in this part of Europe and with trends observed globally. The main research weakness represents the fact that the vast majority of meteorological stations in Bosnia and Herzegovina have long interruptions in measurements during the war and post-war periods, so the analysis could not be done with more data. Nevertheless, the study provides important new information that will help to overcome the gap in current knowledge about trends in climate extremes in Bosnia and Herzegovina.

The future research should be focused on several major issues regarding the observed trends in extreme climate indices: projecting future changes and comprehensive analyses the possible impacts of the observed trends in the extreme climate events on socio-economic and natural systems. The obtained results can serve as a base for further research on projections of extreme climate indices changes in the future. Moreover, the findings of this study can be useful for various applications in agriculture, forestry, hydrology, energetics, tourism, public health, environment conservation, etc. Increasing warm temperature extremes can damage crops and reduce yields, increase the probability of droughts and wildfires, increase human death rates, disturb energy demands and supply, redistribute tourism activities, etc. This study can provide useful informations for evaluating the impacts extreme climate events on the natural and socio-economic systems in Bosnia and Herzegovina. Given that this kind of studies were so far very rare, a further researches are certainly necessary.

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