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ANALYSIS OF EXTREME PRECIPITATION INDICES IN THE EAST HERZEGOVINA (BOSNIA AND HERZEGOVINA)

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Abstract: The changes in annual and seasonal extreme precipitation indices over the East Herzegovina region (Bosnia and Herzegovina) were examined. The data on daily precipitation during the period 1961–2016 from 13 meteorological stations were used for the calculation of 12 extreme precipitation indices recommended by the Expert Team on Climate Change Detection and Indices for the climate change assessment. The results show a downward trend in the precipitation on wet days (PRCPTOT) and in the frequency of days with precipitation (R0.1mm, R1mm, R10mm, and R20mm), whereas the duration of dry spells increases (CDD) over the entire East Herzegovina region. The trends that indicate increasing dryness are particularly pronounced and significant in the summer season. Although the total precipitation decreases, the upward trends in heavy precipitation events such as RX1day, RX5day, SDII, and R95p indicate changes towards more intense precipitation (particularly pronounced since the beginning of the 21st century). Precipitation variability was strongly dictated by the large-scale atmospheric circulations—the North Atlantic Oscillation, the East Atlantic/West Russia pattern and the Arctic Oscillation, especially during the winter season—the significant negative correlation was determined for the majority of extreme precipitation indices.

Keywords: extreme precipitation indices; trend; climate change; East Herzegovina region

Introduction

The substantial increase in heavy precipitation events, disproportionately high compared to changes in mean precipitation was found over many mid-latitude regions since the mid-20th century, even in the regions where a reduction in total precipitation had been observed (Intergovernmental Panel on Climate Change [IPCC], 2014). Extreme precipitation indices such as RX5day, SDII, R10mm, and R95p displayed changes towards more intense precipitation over numerous regions in the world (Donat et al., 2013). However, in contrast to the consistent global warming trend observed for temperature, precipitation showed less spatially and seasonally coherent patterns of change and mostly weak trends that have a lower level of statistical significance (Alexander et al., 2006; Donat et al., 2013). These global scale studies' findings were confirmed by numerous regional and local studies all over the world—in Asia (Sheikh et al., 2015), Africa (Ongoma, Chen, & Omony, 2018), America (Brown, Bradley, & Keimig,

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2010; Skansi et al., 2013). Similar results were also obtained for Europe—at the continental level (Klein Tank & Können, 2003) and in its various regions—over the Iberian Peninsula (Bartolomeu, Carvalho, Marta-Almeida, Melo-Gonçalves, & Rocha, 2016), Apennine Peninsula (Boccolari & Malmusi, 2013), Balkan Peninsula (Burić, Luković, Bajat, Kilibarda, & Živković, 2015; Gajić-Čapka, Cindrić, & Pasarić, 2015; Kioutsioukis, Melas, & Zerefos, 2010; Malinović-Milićević, Mihailović, Radovanović, & Drešković, 2018; Unkašević & Tošić, 2011), Carpathian Basin (Bartholy & Pongrácz, 2007; Croitoru, Piticar, & Burada, 2016), Northern Europe (Lupikasza, Hansel, & Matschullat, 2011), etc. Although most of continentally averaged extreme precipitation indices (e.g., RX5day, R10mm, R20mm, R95p, and R95pTOT) have increased significantly since the mid-20th century, the observed trends were not spatially coherent (Klein Tank & Können, 2003).

Previous studies in Bosnia and Herzegovina have also found spatially and seasonally incoherent patterns of change in extreme precipitation—mainly weak, mixed in sign and insignificant trends were detected (Popov, Gnjato, Trbić, & Ivanišević, 2017). However, the results suggest that precipitation intensity generally increased. Given that previous research on climate change in Bosnia and Herzegovina did not cover the East Herzegovina region, this study focuses on the investigation of changes in extreme precipitation over this area in order to overcome the existing gap in knowledge about the climate change over this part of the territory. The main aim of the study was to analyze trends in extreme precipitation indices over the East Herzegovina region during the period 1961–2016. Further, the goal was to investigate the relationship between the observed precipitation trends and the large-scale circulation patterns.

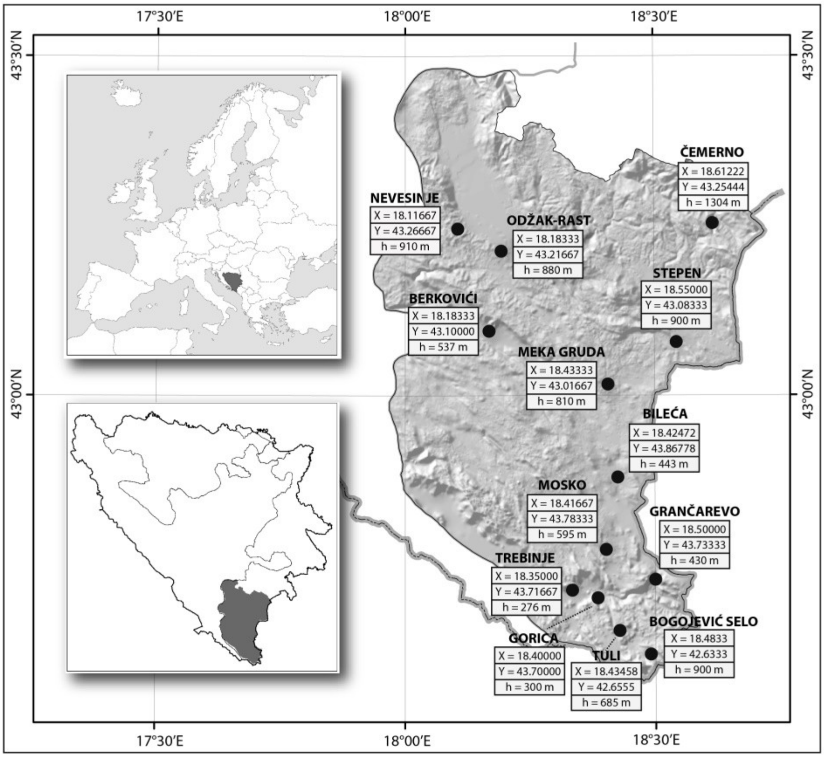

Figure 1. Geographical locations of the meteorological stations used in the study

Study area

The East Herzegovina region is located in the southeastern part of Bosnia and Herzegovina. It encompasses the part of the Herzegovina region east of the Neretva River, within the boundaries of the Republic of Srpska. It is located at 42°33'23"−43°29'22" N and 17°55'23"−18°43'3" E (Figure 1). It has a total area of 3,756 km^2 (it covers 7% of the Bosnia and Herzegovina total area and 15% of the Republic of Srpska territory). Average annual temperature increases from 6 °C in the northern mountainous area (at the highest-located station Čemerno) to a 14−15 °C in lowlands in the south. The East Herzegovina region with the average annual precipitation in the range of 1,500−2,500 mm is the area with the highest rainfall in Bosnia and Herzegovina. Precipitation is very unevenly distributed throughout the year—precipitation maximum occurs in winter months, whereas minimum is recorded in the summer season.

Data and methods

The analysis of extreme precipitation indices during the period 1961–2016 was carried out based on climatological data sets of daily precipitation from 13 meteorological stations and rain-gauge stations located in all the three physical regions of the East Herzegovina: Humine (up to about 400 m)—Trebinje (TR), Gorica (GO), and Grančarevo (GR); Rudine (about 400−600 m)—Berkovići (BE), Bileća (BI), Mosko (MO), and Tuli (TU); and the mountainous area (over 600m)—Čemerno (CE), Nevesinje (NE), Odžak-Rast (OR), Stepen (ST), Meka Gruda-Hodžići (MG) and Ubla-Bogojević selo (UB) (Figure 1). Selected stations cover a wide range of altitudes—from 276m (Trebinje) to 1,304 m (Čemerno)—the relative height difference being 1,028m.

The data on daily precipitation time series were provided by the Republic Hydrometeorological Service of the Republic of Srpska and the Public Company Hydropower Plants on the Trebišnjica River A.D. Trebinje. Given that there were some interruptions in measurements at the majority of stations (particularly in the war and post-war periods), the missing data were extrapolated using the data from Grančarevo station. The basic statistical parameters of the input time series used in the study are given in Table 1.

Table 1
Statistical parameters of annual precipitation time series used in the study

M. s.	*M*	*SD*	*CV*	*MAX*	*MIN*	*SKEW*	*KURT*
CE	1796	342	19.0	2690	1086	0.390	−0.072
NE	1732	402	23.2	2968	1022	0.738	0.626
OR	1568	341	21.7	2465	779	0.194	−0.008
BE	1557	314	20.2	2557	917	0.451	0.531
ST	1558	334	21.4	2712	922	0.747	1.512
MG	1648	361	21.9	2816	934	0.560	0.710
BI	1597	346	21.7	2698	851	0.546	0.745
MO	1893	433	22.9	3369	1135	0.771	1.213
GR	1493	311	20.8	2507	902	0.673	0.726
TR	1678	354	21.1	2734	954	0.370	0.389
GO	1619	362	22.4	2775	910	0.683	0.957
TU	2057	481	23.4	3143	1092	0.275	−0.406
UB	2695	584	21.7	4413	1589	0.562	0.334
REGION	1761	342	19.4	2849	1040	0.524	0.788

Note. *M* = mean (mm); *SD* = standard deviation (mm); *CV* = coefficient of variation (%); *MAX* = maximum (mm); *MIN* = minimum (mm); *SKEW* = skewness; *KURT* = kurtosis.

The input variables were used for the calculation of 12 extreme precipitation indices recommended by the CCl/CLIVAR Expert Team for Climate Change Detection and Indices (ETCCDI) (http://etccdi.pacificclimate.org/list_27_indices.shtml) for climate change assessment. The definitions of the indices used in the study are given in Table 2. The analyzed extreme precipitation indices cover (Alexander et al., 2006):

- Non-threshold based indices representing the indices calculated based on the absolute precipitation at each station (RX1day, RX5day, SDII, and PRCPTOT);
- Fixed threshold-based indices defined as the number of days on which a precipitation value falls above the fixed thresholds (R0.1mm, R1mm, R10mm, and R20mm);
- Percentile-based indices defined as the precipitation amounts exceeding the fixed percentile thresholds (in this study 95th and 99th were chosen for the analysis) calculated from the period 1961–1990 percentiles for each station (R95p and R99p);
- Duration-based indices (i.e., spell indices) defined as periods of excessive wet or dry periods (CDD and CWD).

The indices were calculated using RClimDex (1.0) software package (Zhang & Yang, 2004). The calculations were made by stations individually and then averaged for the whole East Herzegovina region.

Table 2
Definitions of precipitation indices used in the study

Index	Descriptive name	Definition	Units
PRCPTOT	Total wet-day precipitation	Total precipitation in wet days (days with precipitation ≥ 1mm)	mm
RX1day	Highest 1-day precipitation amount	Maximum 1-day precipitation	mm
RX5day	Highest 5-day precipitation amount	Maximum consecutive 5-day precipitation	mm
SDII	Simple precipitation intensity index	Total precipitation divided by the number of wet days in the period	mm/day
R0.1mm	Number of rainy days	Count of days when precipitation ≥ 0.1 mm	days
R1mm	Number of wet days	Count of days when precipitation ≥ 1 mm	days
R10mm	Number of heavy precipitation days	Count of days when precipitation ≥ 10 mm	days
R20mm	Number of very heavy precipitation days	Count of days when precipitation ≥ 20 mm	days
R95p	Precipitation due to very wet days	Total precipitation when precipitation > 95th percentile	mm
R99p	Precipitation due to extremely wet days	Total precipitation when precipitation > 99th percentile	mm
CDD	Consecutive dry days	Maximum number of consecutive days with precipitation < 1mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with precipitation ≥ 1mm	days

Note. Adapted from "Climate Change Indices. Definition of the 27 core indices", by Expert Team on Climate Change Detection and Indices, 2009 (http://etccdi.pacificclimate.org/list_27_indices.shtml).

Trends in annual and seasonal extreme precipitation indices were estimated for the period 1961–2016. The nonparametric Mann-Kendall test was used in order to determine the possible existence of a trend in the time series and its statistical significance. The statistical significance of the estimated trend values was defined at the 99% ($p \leq .01$), 95% ($.01 < p \leq .05$), 90% ($.05 < p \leq .10$) and 75% ($.10 < p \leq .25$) levels. The Sen's nonparametric estimator of the slope was used to determine the trend magnitude (change per unit time). Moreover, differences in average values of extreme precipitation indices between two long-term periods—the 1961–1990 and 1991−2016, were investigated in order to further confirm the observed trends. In order to evaluate the observed precipitation trends, the relationship with the large-scale atmospheric circulations—the North Atlantic Oscillation (NAO), the East Atlantic/West Russia (EAWR) pattern and the Arctic Oscillation (AO)—has been analyzed. The data on these teleconnection patterns indices were collected from the NOAA National Weather Service Climate Prediction Center (NOAA CPC, 2017). For the quantification of links between the precipitation and the teleconnection patterns, correlation analysis was performed. The Pearson correlation coefficients were calculated on annual and seasonal levels for the region-averaged indices. The significance of the obtained correlations coefficients was defined at the 99% ($p \leq .01$), 95% ($.01 < p \leq .05$) and 90% ($.05 < p \leq .10$) levels. All calculations were made in XLSTAT Version 2014.5.03.

Results and discussion

The average annual values of extreme precipitation indices during the observed period 1961–2016 are given in Table 3 by stations individually and then averaged for the whole region. The decadal trends in annual extreme precipitation indices in the period 1961–2016 are shown in Figure 2, Figure 3, and Table 4 by stations individually and averaged for the region. Compared to the observed trends in mean (Trbić, Popov, & Gnjato, 2017) and extreme temperatures (Popov, Gnjato, & Trbić, 2017; Popov, Gnjato, Trbić, & Ivanišević, 2018), consistent with the global warming, extreme precipitation displayed less coherent patterns of change—trends of both signs were present throughout the year. Moreover, most of the estimated trend values were not statistically significant.

The obtained results suggest a general decrease in precipitation amounts—PRCPTOT displayed negative trends in the range from −6.6 to −68.6 mm per decade. Moreover, a reduction in the number of days with precipitation R0.1mm, R1mm, R10mm, and R20mm was registered. The annual number of wet days (R1mm), heavy precipitation days (R10mm) and very heavy precipitation days (R20mm) decreased over the entire East Herzegovina region from −0.8 to −4.4 days per decade, from −0.3 to −2.2 days per decade and from −0.2 to −1.4 days per decade, respectively (except R20mm at several stations where no trend was found).

Although the total precipitation decreases, their intensity displayed an increasing tendency. Predominantly upward trends in heavy precipitation indices such as RX1day, RX5day, SDII, R95p, and R99p suggest changes towards more intense precipitation over the East Herzegovina region. Maximum 1-day precipitation (RX1day) and 5-day precipitation (RX5day) increased in most of the region, except in the north where a downward trend was registered. Simple precipitation intensity index (SDII) displayed an upward tendency over the entire region, which was statistically significant at a number of stations. The most significant changes were detected in precipitation due to very wet days (R95p)— statistically significant increase was found at the majority of stations (in the range from 6.8 to 49.3 mm per decade). Moreover, the elongation of the maximum duration of both dry and wet periods suggests that precipitation variability also increased. Both duration-based indices, CDD and CWD, displayed predominantly positive trends over the region, although very weak and at the majority of stations statistically insignificant (particularly for CWD).

Table 3
Average annual extreme precipitation indices in the East Herzegovina region in 1961–2016

M. s.	PRCPTOT	RX1day	RX5day	SDII	R95p	R99p	R0.1mm	R1mm	R10mm	R20mm	CDD	CWD
CE	1769.2	92.0	186.6	13.7	421.5	119.0	157.4	128.9	54.3	28.3	23.7	9.2
NE	1726.7	98.5	197.8	16.6	367.5	100.4	115.1	103.8	55.0	30.4	31.5	8.9
OR	1575.0	91.9	175.8	15.2	364.2	108.4	108.4	103.7	50.9	26.1	28.7	8.3
BE	1557.6	84.5	165.0	14.3	352.3	106.9	108.5	108.5	51.6	25.3	30.1	8.6
ST	1556.0	86.0	169.7	14.6	389.6	127.4	117.0	106.9	49.6	26.2	27.8	8.3
MG	1638.5	93.4	178.7	16.1	369.1	113.5	103.1	101.2	52.3	27.8	32.1	8.0
BI	1594.2	91.5	177.0	14.5	384.7	131.9	128.3	109.5	50.7	26.3	28.2	9.1
MO	1882.0	115.5	220.2	19.6	448.2	123.4	99.0	96.7	54.4	31.8	31.2	7.9
GR	1484.3	103.1	187.6	14.7	388.5	122.4	112.2	100.7	46.9	24.1	30.4	8.4
TR	1678.9	109.9	200.7	16.5	440.0	130.2	111.2	101.8	52.0	27.9	29.5	8.4
GO	1596.1	110.7	197.9	16.7	415.3	117.1	101.2	95.2	49.0	27.1	36.0	8.0
TU	2041.3	140.5	260.6	19.6	490.3	161.7	115.0	103.5	54.1	32.5	31.0	8.7
UB	2690.0	173.5	342.2	24.5	744.9	226.5	117.5	109.4	60.7	39.7	29.1	9.0
REGION	1753.1	107.0	204.6	16.7	428.9	129.9	114.9	105.4	52.4	28.7	29.9	8.5

Table 4
Decadal trends in annual extreme precipitation indices in the East Herzegovina region in 1961–2016

M.s.	PRCPTOT	RX1day	RX5day	SDII	R95p	R99p	R0.1mm	R1mm	R10mm	R20mm	CDD	CWD
CE	−33.8	−1.9	−2.7	0.2*	−12.4	0.0	−4.6***	−4.4****	−0.6	−0.2	0.6	0.0
NE	−39.2	−1.1	−1.6	0.0	−9.6	0.0	−4.4***	−2.5*	−0.7	−0.7	0.7	0.2*
OR	−18.3	−0.5	−1.1	0.1	6.8	0.0	−2.6**	−1.9*	−0.8	−0.3	0.7	0.0
BE	−23.0	0.4	−3.7	0.0	7.9	0.0	−2.1*	−1.6*	−1.1*	0.0	0.0	0.0
ST	−13.2	2.4*	1.8	0.4***	40.4***	19.5***	−6.2****	−4.0****	−0.8	−0.3	0.8*	0.0
MG	−6.6	4.0**	4.1	0.1	27.0***	3.3*	−1.1	−1.0	−0.8	−0.7	0.6	0.0
BI	−7.0	3.6*	2.9	0.3***	22.6*	9.8***	−4.1***	−2.8**	−0.3	0.0	1.0*	0.0
MO	−20.4	2.5	−2.9	0.6***	21.3**	0.0	−4.7****	−4.1****	−1.1	−0.6	1.3**	−0.3**
GR	−10.9	3.3	0.3**	0.3***	33.1***	2.6**	−4.1***	−2.3*	−1.1	−0.5	0.6	0.0
TR	−27.2	3.1	−2.9*	0.1	27.3**	0.0	2.1*	−2.2*	−1.9**	−0.4	0.8	0.0
GO	6.5	5.0	0.8***	0.3**	29.1**	0.0*	−0.6	−1.1	−0.8	0.0	0.3	0.0
TU	−68.6*	0.8	−2.9	−0.4*	−19.7	0.0	−0.8	−0.8	−2.2**	−1.4**	1.0*	0.2*
UB	−6.4	5.1	6.5*	0.1	49.3**	16.0*	−0.3	−1.4	−0.7	−1.1*	0.3	0.0
REGION	−19.2	2.0	0.7	0.1	14.5*	11.8**	−2.8**	−2.6**	−1.0	−0.6	0.8*	0.1

Note. *.10 < p ≤ .25; **.05 < p ≤ .10; ***.01 < p ≤ .05; ****p ≤ .01.

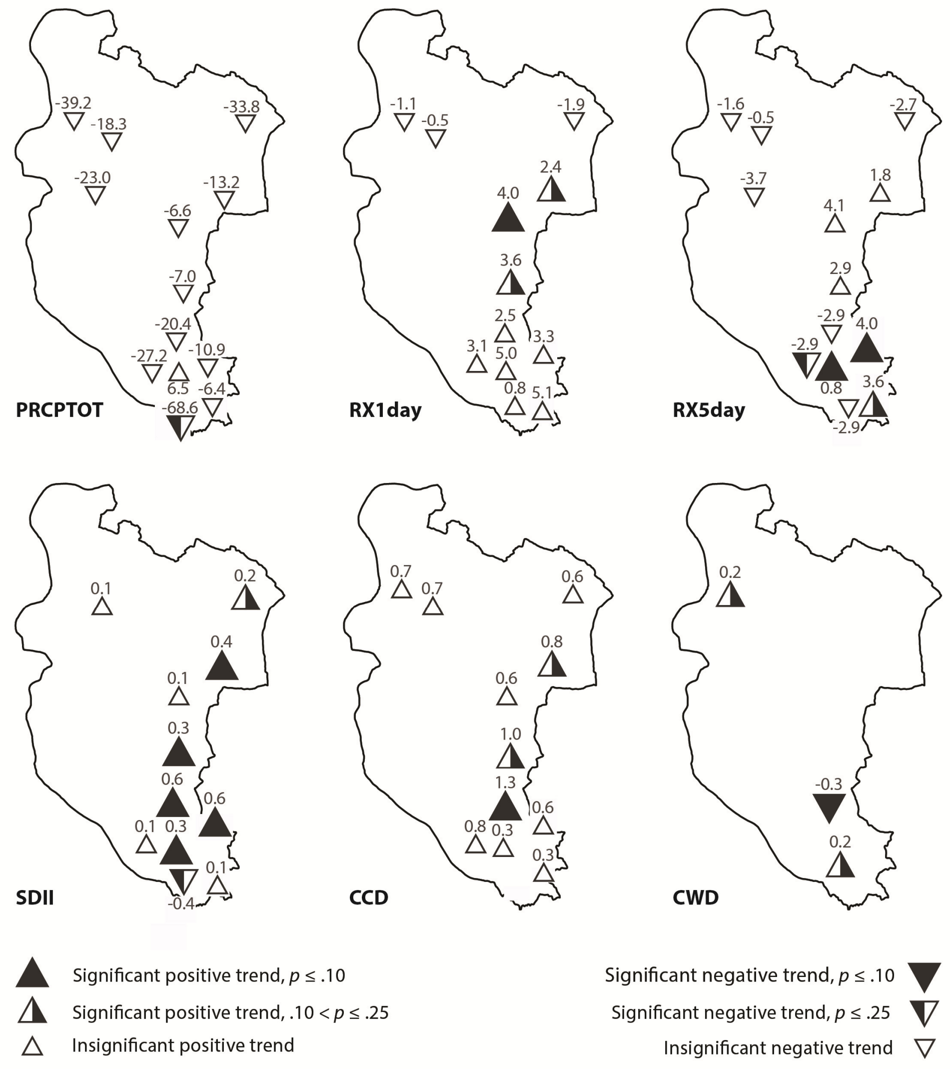

Figure 2. Decadal trends in annual non-threshold based indices and duration-based indices in the East Herzegovina region in 1961–2016

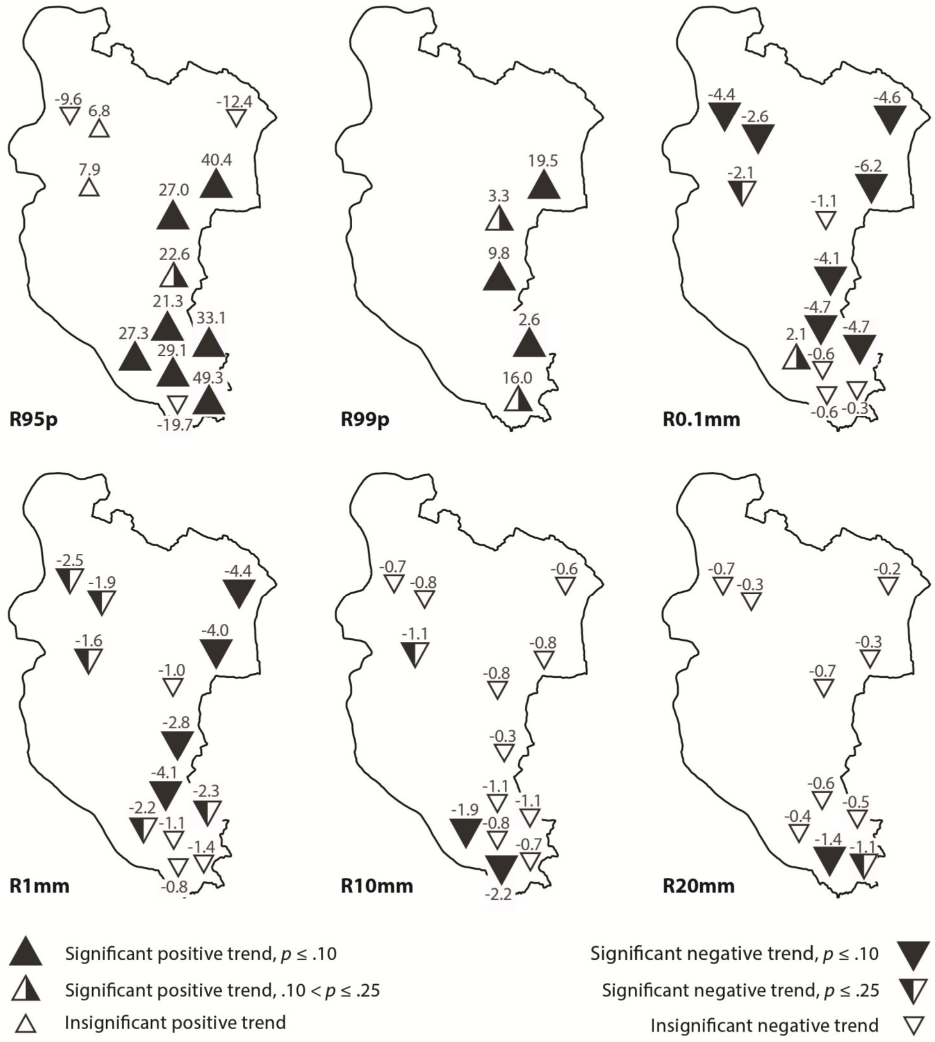

Figure 3. Decadal trends in annual percentile-based indices and fixed threshold-based indices in the East Herzegovina region in 1961–2016

The changes in the average annual values of extreme precipitation indices between 1961–1990 and 1991–2016 further confirm the observed trends (Figure 4). PRCPTOT decreased in most areas compared to the reference period (up to 7%). The number of days with precipitation occurrence also decreased in the latter period. On the other hand, the average values of precipitation intensity indices (e.g., RX1day, SDII, and R99p) increased. The duration of dry periods is prolonged at the majority of stations (up to 14%), whereas the duration of wet periods displayed both positive and negative changes.

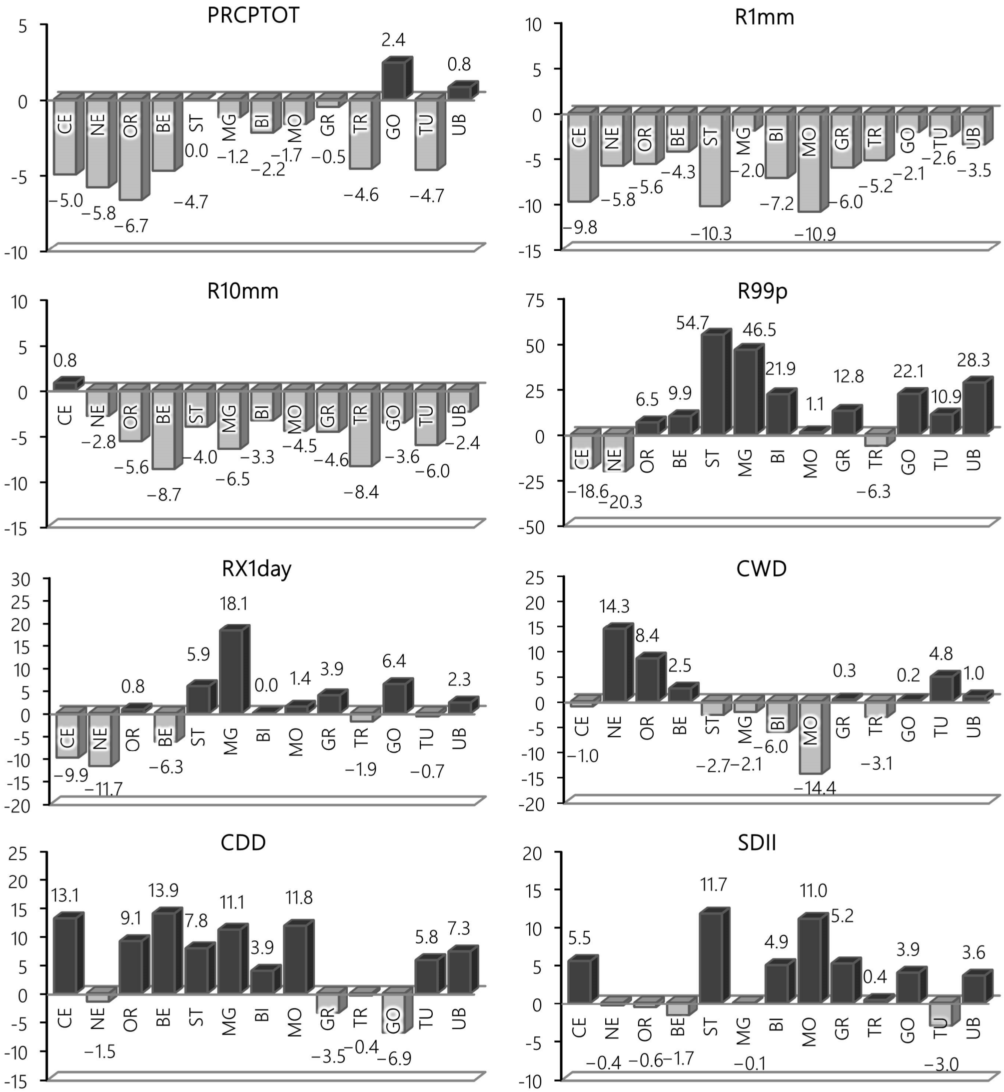

Figure 4. Changes in average annual values of selected extreme precipitation indices in the East Herzegovina region in 1991–2016 relative to 1961–1990 (in %)

Seasonal extreme precipitation indices also did not show coherent patterns of change—the occurrence of trends mixed in sign was registered spatially and temporally i.e., seasonally (Table 5). However, the vast majority of the estimated trend values were not statistically significant.

Table 5
Decadal trends in selected seasonal extreme precipitation indices in the East Herzegovina region in 1961–2016

M. s.	PRCPTOT				RX1day				RX5day			
	w	sp	su	a	w	sp	su	a	w	sp	su	a
CE	−11.3	−3.9	−10.4*	0.1	−0.4	−0.8	−1.7*	−0.3	−1.4	1.1	−0.1	−3.3
NE	2.3	−1.7	−15.5*	−9.8	2.6*	1.8*	−2.4**	0.1	5.5	2.8	−1.0	−5.5*
OR	−7.5	−8.8	−14.3**	5.8	0.1	0.9	−1.5*	0.3	2.2	2.3	−2.1	−1.9
BE	−24.0*	−1.5	−11.7*	−2.6	−2.2*	2.5*	−2.9*	1.6	−1.4	4.7*	−2.7	−2.6
ST	5.0	−0.5	−12.9**	13.8	2.5*	1.6	−1.4*	2.3*	6.2*	5.2*	−1.0	0.3
MG	0.1	−5.6	−9.0*	15.2	1.7	−0.2	−1.8*	3.0*	3.3	1.1	0.2	2.8
BI	3.6	−1.5	−14.1**	12.4	2.4*	1.4	−1.9	2.7*	0.9	3.4*	−1.0	1.5
MO	−9.7	−1.4	−7.4	2.1	−1.0	1.7	0.0	1.7	3.7	4.0	3.4	−1.2
GR	8.5	−0.8	−12.2**	6.9	2.9*	1.9*	−1.0	3.6*	5.4	4.5***	−1.0	−0.7
TR	−4.3	−3.3	−15.7**	−0.4	1.5	2.3*	−1.7	2.4	3.2	4.0	0.4	−3.3
GO	12.0	0.8	−10.5*	7.2	0.5	0.7	−1.6	4.3*	4.0	7.4***	0.9	2.4
TU	−16.1	−7.1	−16.1**	−9.3	−1.2	−0.2	−2.0	2.2	−3.7	3.3	−1.3	−3.4
UB	−3.2	0.9	−15.8**	5.5	3.0	4.3*	−2.9	3.9	−0.2	10.2**	−1.2	1.9
REG.	−4.2	−1.7	−13.0**	5.7	1.1	1.7*	−1.5*	2.3	3.0	4.5*	−0.1	−1.3

Note. *.10 < p ≤ .25; **.05 < p ≤ .10; ***.01 < p ≤ .05; ****p ≤ .01.

Table 5
Continued

M. s.	SDII				R1mm				R10mm			
	w	sp	su	a	w	sp	su	a	w	sp	su	a
CE	0.2	−0.1	0.3*	0.3	−1.5**	−0.6	−1.3****	−0.4	0.0	0.0	0.0	0.0
NE	0.3	0.0	0.0	−0.3	−0.6	0.0	−1.2**	−0.2	0.0	0.0	−0.5*	0.0
OR	0.1	−0.1	−0.3	0.0	−0.8	−0.3	−0.3	0.3	0.0	−0.4*	−0.6**	0.4*
BE	−0.2	0.0	−0.3	−0.1	−1.1**	−0.3	−0.8*	0.0	−0.7*	−0.3	−0.2	0.0
ST	3.4****	2.2****	1.6****	3.6****	−1.3**	−0.6	−1.3***	0.0	−0.3	0.0	−0.5*	0.0
MG	0.3	0.0	−0.2	0.3	−0.6	0.0	−0.5	0.4	−0.6	0.0	0.0*	0.0
BI	0.6*	0.2	−0.3	0.3	−0.5	−0.5	−1.3****	0.0	0.0	0.0	−0.3*	0.5
MO	1.5***	0.2	0.2	0.2	−1.8**	−0.6	−0.5*	0.0	−0.1	−0.2	−0.3*	0.0
GR	0.5**	0.1	0.1	0.1	−0.5	0.0	−1.3****	0.0	0.0	0.0	−0.3*	0.0
TR	0.2	0.1	0.2	−0.1	−0.4	−0.3	−1.3****	0.4	−0.2	−0.3	−0.5**	−0.2
GO	0.0	0.0	0.3	−0.1	0.0	0.0	−1.0***	0.5	0.0	0.0	−0.1	0.0
TU	−0.5	−0.7***	−0.3	−0.8**	−0.2	0.1	−0.9***	0.4	−0.4	−0.2	−0.6**	−0.3
UB	0.5	−0.6*	−0.5*	0.0	−0.4	0.2	−0.6*	0.6	−0.2	0.0	−0.6**	0.2
REG.	0.6***	0.2	0.1	0.3	−0.7	−0.2	−0.9***	0.2	−0.2	−0.1	−0.4*	0.2

Note. *.10 < p ≤ .25; **.05 < p ≤ .10; ***.01 < p ≤ .05; ****p ≤ .01.

The most consistent and prominent were the trends indicating a decrease in rainfall in the summer season. For instance, PRCPTOT, RX1day, and R1mm decreased in this part of the year over the entire territory (from −7.4 to −16.1 mm per decade, from −1.0 to −2.9mm per decade, and from −0.3 to −1.3 days per decade, respectively).

Similar patterns of change with trends spatially and seasonally mixed in a sign and predominantly insignificant had been determined in other studies carried out in the southeastern Europe region—particularly in the Mediterranean and sub-Mediterranean areas. Although global scale studies (Alexander et al., 2006; Donat et al., 2013) found that precipitation indices generally show a tendency toward wetter conditions throughout the 20th century, over this region drying trends prevail and they are particularly pronounced during the summer season. On the other hand, the determined upward trends in intensity indices are in accordance with the tendencies found over a lot of parts of Europe (Alexander et al., 2006; Donat et al., 2013). For instance, in Montenegro, the number of days with precipitation decreased, whereas the number of dry days increased, particularly in the south-western part of the territory. Moreover, over this area, the precipitation intensity indices SDII and R95p displayed upward trends (Burić et al., 2015). During the 20th century, the average annual values of heavy precipitation indices RX1day and R95p across Serbia increased (Unkašević & Tošić, 2011). In Croatia, the mountainous region together with the coastal hinterland is mostly affected by drying tendency, especially during summer (Gajić-Čapka et al., 2015). The results obtained for Greece showed that the total precipitation shifted toward drier climate, but the most influenced factor was the interannual variability of the extremes (Kioutsioukis et al., 2010). A large and consistent decreasing trend in mean precipitation and an increase in precipitation variability during summer (dry and warm) season make the Mediterranean one of the most responsive regions to global climate changes (Giorgi, 2006). Studies in Europe found that trends in extreme precipitation were more significant than changes in mean precipitation, which is in agreement with the Clausius–Clapeyron relation that describes how a warmer atmosphere can hold more water vapor, which in turn produces more intense precipitation (Casanueva, Rodríguez-Puebla, Frías, & González-Reviriego, 2014).

Climate variability in Europe is strongly dictated by the large-scale atmospheric circulations. The correlation between seasonal and annual precipitation over the East Herzegovina region and these teleconnection patterns are shown in Table 6. Strong positive phases of the NAO, the EAWR pattern and the AO are associated with above-average precipitation over northern Europe and Scandinavia in winter, and below-average precipitation over southern and central Europe (NOAA CPC, 2017). Studies found that the NAO had the strongest relation with both mean and extreme precipitation (in the summer season, the NAO had the most important relation, but with an opposite sign to the one in winter) (Casanueva et al., 2014). In spring and autumn, the AO and the EAWR have a stronger effect on the indices variability. Given the stated, the links between these teleconnection patterns and precipitation over the study area are significant and negative. Precipitation trends are strongly dictated by the NAO and the EAWR pattern, especially during the winter season—the significant negative correlation was determined for the majority of precipitation indices. In addition, the EAWR pattern had a significant effect on precipitation in the autumn season, whereas the NAO somewhat affects the precipitation in spring. The AO also has the strongest impact on precipitation variability in the winter season, but also in spring and autumn. It is determined that the NAO had the strongest influence on precipitation totals and its frequency, whereas the EAWR pattern and the AO also had a strong effect on intensity indices. The obtained results on the relationship between precipitation and teleconnection patterns are similar to the findings of other studies carried out in the southeastern Europe region (Burić et al., 2015; Malinović-Milićević et al., 2018).

Table 6
Pearson correlation coefficients between seasonal and annual teleconnection patterns indices and extreme precipitation indices in the East Herzegovina region in 1961–2016

Index	Winter	Spring	Summer	Autumn	Year
NAO					
PRCPTOT	−0.482***	−0.270**	0.263*	−0.075	−0.521***
RX1day	−0.105	−0.191	0.243*	−0.071	−0.104
RX5day	−0.239*	−0.096	0.108	−0.100	−0.230*
SDII	−0.122	−0.108	0.112	−0.033	−0.432***
R1mm	−0.500***	−0.265**	0.313**	−0.064	−0.407***
R10mm	−0.527***	−0.256*	0.240*	−0.034	−0.499***
EAWR					
PRCPTOT	−0.573***	−0.144	0.113	−0.319**	−0.366***
RX1day	−0.352***	−0.158	−0.006	−0.104	−0.089
RX5day	−0.392***	−0.192	−0.095	−0.228*	−0.039
SDII	−0.364***	−0.232*	−0.076	−0.183	−0.449***
R1mm	−0.585***	−0.038	0.236*	−0.320**	−0.176
R10mm	−0.550***	−0.169	0.107	−0.348***	−0.336**
AO					
PRCPTOT	−0.735***	−0.512***	0.011	−0.473***	−0.727***
RX1day	−0.203	−0.243*	0.093	−0.306**	−0.140
RX5day	−0.401***	−0.270**	−0.036	−0.354***	−0.282**
SDII	−0.266**	−0.292**	−0.033	−0.129	−0.542***
R1mm	−0.783***	−0.382***	0.073	−0.503***	−0.622***
R10mm	−0.784***	−0.501***	0.019	−0.424***	−0.724***

Note. *.05 < p ≤ .10; **.01 < p ≤ .05; ***p ≤ .01.

Conclusion

The analysis of changes in 12 extreme daily precipitation indices over the East Herzegovina region in the period 1961–2016 showed mainly weak and statistically insignificant trends of both signs. The obtained results show a decrease in total precipitation and in the number of days with precipitation occurrence, whereas the duration of dry periods is prolonged over the entire East Herzegovina region. The upward trends in heavy precipitation events indicate changes towards more intense precipitation, particularly pronounced since the beginning of the 21st century. The obtained results are in accordance with the findings of similar studies previously carried out in Bosnia and Herzegovina and in other parts of the southeastern Europe region, which also determined spatially and seasonally incoherent patterns of change with the occurrence of trends of both signs but generally with a lower level of statistical significance. The observed trends in extreme precipitation were directly related to the large-scale circulation patterns over the northern hemisphere. Given that extreme precipitation events have a large impact on both natural and socio-economic systems, further research is certainly necessary. It should be focused on the projections of future changes in extreme precipitation, impact assessment studies and the implementation of efficient adaptation and mitigation strategies.

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