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TRENDS IN EXTREME DAILY PRECIPITATION INDICES IN BOSNIA AND HERZEGOVINA

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Abstract: The study investigates trends in extreme daily precipitation indices in Bosnia and Herzegovina. A set of daily precipitation time series from four meteorological stations was used for the computation of 13 indices (mostly recommended by the ETCCDI). Trends were calculated for the 1961–2015 periods using RClimDex (1.0) software package. Given the results, a general increase in the extreme precipitation indices is present over the territory of Bosnia and Herzegovina. Upward trends in heavy precipitation indices such as RX1day, RX5day, SDII, R10mm, R20mm, R95p, R95p%, R99p and R99p% indicate changes toward more intense precipitation in Bosnia and Herzegovina. However, most of the estimated trends are not statistically significant. Registered patterns of change were not spatially and temporally coherent and one of the characteristics was that trend signs were mixed. The analyzed precipitation indices trends are directly linked to changes in the dominant large-scale circulation patterns over Northern Hemisphere. Statistically significant negative correlation with NAO, EAWR and AO is found for majority of extreme precipitation indices, particularly strong during winter. Due to their large impact on natural and socio-economic systems, further research on extreme precipitation events is certainly necessary.

Key words: precipitation extremes, indices, trend, climate change, Bosnia and Herzegovina.

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Introduction

Study and understanding of changes in extreme precipitation events is of great importance because of their large impact on society and ecosystems compared to changes in mean precipitation (Hartmann et al., 2013). Records around the world have shown mixed and non-significant long-term trends in mean precipitation changes (Hartmann et al., 2013). However, averaged over the Northern Hemisphere mid-latitudes, precipitation has increased since 1951 (Intergovernmental Panel on Climate Change [IPCC], 2014). IPCC has reported that substantial increases were found in annual heavy precipitation events (disproportionately high compared to changes in mean precipitation) over many mid-latitude regions between 1951 and 2003, even in the regions where a reduction in annual total precipitation had been observed (Hartmann et al., 2013).

Given that in Bosnia and Herzegovina during the last decade increased frequency of years with extreme precipitation (years with high precipitation and catastrophic floods and years with a very low precipitation and prolonged droughts) has been observed, the preparation of a research on extreme precipitation trends became necessary. Particularly, due to the large impact of extreme precipitation events on the natural and socio-economic systems.

The paper is divided into 4 sections. Section 1 gives an overview of previous research. Section 2 describes data and methods used in the study. Section 3 contains results of extreme precipitation indices trend calculations and in addition, the correlation analysis of the observed extreme precipitation trends and the large-scale circulation patterns. Section 4 sets the conclusion. At the end, there is a literature overview.

Previous research

Global scale studies suggest that, in general, changes in precipitation extremes are consistent with a wetter climate (Donat et al., 2013; Hartmann et al., 2013). There are more regions in the world where the number of heavy precipitation events (i. e. its amounts, intensity, and frequency) has increased than those where it decreased (Donat et al., 2013; IPCC, 2014). Although global scale studies found a general increase in the extreme precipitation indices, they showed less spatially coherent patterns of change and only small scale trends that have lower level of statistical significance (Donat et al., 2013). Contrary, the consistent warming trends were globally reported for the extreme temperature indices (Donat et al., 2013). Most of the extreme

precipitation indices (e. g. RX5day, R10mm, R95p and SDII) show significant changes toward more intense precipitation over numerous regions in the world, but results are not homogeneous in space and time, and form season to season (Donat et al., 2013). Globally, there has been a steady decline in consecutive dry days (CDD) since the 1960s. It also suggests wetter conditions. Shorter duration of dry spells is present over much of Eurasia (Donat et al., 2013). Results of these global analyses that found trends mixed in sign and spatially incoherent were confirmed by numerous regional and local studies all over the Europe (Bartolomeu et al., 2016; de Lima et al., 2015), Asia (Balling Jr. et al., 2016; Fan and Chen, 2016; Sheikh et al., 2015), Africa (Filahi et al., 2016), America (de Melo et al., 2015; Santos and de Oliveira, 2017) and Australia (Alexander and Arblaster, 2017).

In Europe, there have been likely increases in either the frequency or intensity of heavy precipitation (Hartmann et al., 2013). Global analysis of observed trends in extreme precipitation indices were also reported by previous studies in the Southeast Europe region where Bosnia and Herzegovina is located. Heterogeneous changes of annual precipitation, i.e. trends mixed in sign, have been detected in Serbia (Luković et al., 2014), Croatia (Gajić-Čapka et al., 2015), Slovenia (de Luis et al., 2014) and Montenegro (Burić et al., 2015). Trends were predominantly weak and insignificant. Seasonal precipitation also showed trends of both signs – for example in Serbia and Montenegro winter and spring precipitation decreased, whereas autumn increased (Burić et al., 2015; Luković et al., 2014). In Croatia, negative trends were found for summer season, whereas upward in autumn (Gajić-Čapka et al., 2015). Trends in extreme precipitation indices in this part of Europe were mainly weak and mixed in sign – however, the regional results generally suggest that precipitation intensity increased (Burić et al., 2015; Gajić-Čapka et al., 2015; Unkašević and Tošić, 2011).

This study is a continuation of the previous research (Ducić et al., 2014; Mihailović et al., 2015) on precipitation variability and recent climate change in Bosnia and Herzegovina. This territory has been so far poorly documented in terms of trends in precipitation extremes and this kind of studies has not been previously conducted for this area. The main aim of this study was two-fold: 1. To compute and analyze trends in extreme precipitation indices over Bosnia and Herzegovina during the 1961 – 2015 periods. 2. To investigate the relation between observed trends and the large-scale circulation patterns.

Study of this kind can be a useful source of data in a variety of applied research, primarily in the fields of hazard risks management (Miladinović

and Gavrilović, 2012), agricultural planning (Milinčić et al., 2013) and sustainable tourism (Živanović, 2014; Lojović and Gnjato, 2016; Rvović, 2014).

Data and methods

The analysis of trends in extreme precipitation indices during 1961–2015 periods was carried out using climatological data set of a daily precipitation from four meteorological stations in Bosnia and Herzegovina (that represents all of the available daily data): Banjaluka (BL), Doboj (DB), Sarajevo (SA) and Mostar (MO) (Figure 1). The selected meteorological stations covered all three physical macroregions of Bosnia and Herzegovina: Peripannonian, Dinaric and Submediterranean. Data were provided by the Federal Hydrometeorological Institute Sarajevo and the *Republic Hydrometeorological Service of the Republic of Srpska*. During the observed period stations did not change their location and there were no interruptions in measurements (only at DB station during the war period 1992 – 1996).

Figure 1 - The geographical location of study area

The recent precipitation variability in Bosnia and Herzegovina has been determined by trends in annual and seasonal mean precipitation and by trends in extreme precipitation indices. A set of 10 climate indices recommended by the CCI/CLIVAR Expert Team for Climate Change Detection Monitoring and Indices (ETCCDI, 2009) were selected (Table 1). In addition, a few more indices derived from them have been also analyzed – R1mm, R95p% and R99p%.

Table 1 - *Definitions of the indices used in the study*

Index	Descriptive name	Definition	Units
PRCPTOT	Annual total wet-day precipitation	Annual total precipitation in wet days	mm
RX1day	Highest 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
RX5day	Highest 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple precipitation intensity index	Annual total precipitation divided by the number of wet days in the year	mm/day
R1mm	Number of wet days	Annual count of days when precipitation ≥ 1 mm	days
R10mm	Number of heavy precipitation days	Annual count of days when precipitation ≥ 10 mm	days
R20mm	Number of very heavy precipitation days	Annual count of days when precipitation ≥ 20 mm	days
R95p	Very wet days	Annual total precipitation when daily precipitation amount > 95 th percentile	mm
R99p	Extremely wet days	Annual total precipitation when daily precipitation amount > 99 th percentile	mm
R95p%	Precipitation fraction due to very wet days	Percentage of annual total wet-day precipitation due to events with precipitation > 95 th percentile	%
R99p%	Precipitation fraction due to extremely wet days	Percentage of annual total wet-day precipitation due to events with precipitation > 99 th percentile	%
CDD	Consecutive dry days	Maximum number of consecutive days with daily precipitation amount < 1 mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with daily precipitation amount ≥ 1 mm	days

The selected indices can be divided into 4 different categories:

1. Absolute extreme indices: RX1day, Rx5day and SDII.
2. Absolute-based (fixed) threshold indices defined as the number of days on which a precipitation value falls above a fixed threshold: R1mm, R10mm and R20mm.
3. Percentile-based (non-fixed) threshold indices: R95p, R95p%, R99p and R99p%. The 1961–1990 periods was set as the base period for determining the frequency distribution for the this indices.
4. Duration-based indices (spell indices) defined as periods of excessive wet and dry periods: CDD and CWD.

The indices were calculated using RClimDex (1.0) software package developed at Climate Research Division Environment Canada (Zhang and Yang, 2004). Data quality control in RClimDex showed that no outliers in daily precipitation time series were found at all stations. Trends in extreme precipitation indices were computed in RClimDex by linear least square method and locally weighted linear regression (dashed line on plots). Statistics of the linear trend fitting are also displayed on the plots. Trends have been analyzed by stations individually and then the trend for the whole territory of Bosnia and Herzegovina has been calculated. The average data series of extreme precipitation indices for Bosnia and Herzegovina were subjected to the nonparametric Mann-Kendall test. Trend magnitude was determined by the Sen's nonparametric estimator of slope. Calculations were made in XLSTAT Version 2014.5.03. The statistical significance of the observed trends was defined at the 99 % ($p \text{ value} \leq 0.01$), 95 % ($0.01 < p \text{ value} \leq 0.05$), 90 % ($0.05 < p \text{ value} \leq 0.10$) and 75 % ($0.10 < p \text{ value} \leq 0.25$) level.

In order to explain the relationship between the observed precipitation trends in Bosnia and Herzegovina and the large-scale atmospheric circulations, the dominant Northern Hemisphere teleconnection patterns have been investigated. The three primary modes of atmospheric circulation variability over the North Atlantic – the North Atlantic Oscillation (NAO), the East-Atlantic (EA) pattern and the East Atlantic/West Russia (EAWR) pattern – and the Arctic Oscillation (AO) have been analyzed. Data on these large-scale atmospheric circulation indices were collected from NOAA National Weather Service Climate Prediction Center (NOAA CPC, 2017). For quantification of the relation between the analyzed extreme precipitation indices and the large-scale circulation patterns, the Pearson correlation coefficient was used. The coefficients were calculated on annual and seasonal levels for

state averaged indices. The statistical significance of the determined correlations was defined at the 99.9 % ($p \text{ value} \leq 0.001$), 99 % ($0.001 < p \text{ value} \leq 0.01$), 95 % ($0.01 < p \text{ value} \leq 0.05$) and 90 % ($0.05 < p \text{ value} \leq 0.10$) level.

Results and discussion

Statistical parameters of annual precipitation time series for the meteorological stations used in the study are given in Table 2. Table 3 shows regional mean annual and seasonal precipitation for the two periods – for whole study period (1961–2015) and the standard climatological period (1961–1990). Mean annual precipitation during the 1961–2015 periods in Bosnia and Herzegovina is 1102 mm. In general, the sum of the annual precipitation increases with altitude toward central and southern part of the territory. In the northern lowland areas, maximum and minimum precipitation are typical of summer and winter season, respectively. In contrary, in Herzegovina region, in the southern part of the territory, maximum precipitation occurs in colder part of the year – in winter and autumn, whereas substantially less precipitation is present during summer season.

Table 2 - *Statistical parameters of annual precipitation time series of the meteorological stations used in the study*

Station	Mean (mm)	Maximum (mm)	Minimum (mm)	STDEV (mm)	CV (%)	Skewness	Kurtosis
BL	1040.1	1686.2	588.2	186.6	17.9	0.476	1.864
DB	928.8	1494.5	504.1	193.8	20.9	0.709	0.922
SA	942.2	1248.9	626.0	146.6	15.6	-0.187	-0.645
MO	1495.7	2490.7	840.0	336.5	22.5	0.253	0.418

Note: STDEV – standard deviation, CV – coefficient of variation

Table 3 - Annual and seasonal mean precipitation in Bosnia and Herzegovina in 1961 – 2015 (a) and 1961 – 1990 (b) (mm)

Season	BL		DB		SA		MO		BIH	
	a	b	a	b	a	b	a	b	a	b
Winter	227	220	198	188	227	224	486	495	284	282
Spring	266	264	231	221	227	226	356	379	270	272
Summer	283	299	274	263	232	242	191	196	245	250
Autumn	267	246	228	200	259	241	468	450	305	284
Year	1040	1029	929	870	942	932	1496	1523	1102	1088

An overview of the average annual values of the extreme precipitation indices in the observed period (1961 – 2015) and in the standard climatological period (1961–1990) is given in Table 4.

Table 4 - Average values of extreme precipitation indices in Bosnia and Herzegovina in 1961 – 2015 (a) 1961 – 1990 (b)

Index	BL		DB		SA		MO		BIH	
	a	b	a	b	a	b	a	b	a	b
PRCPTOT	1023	1012	903	854	924	914	1485	1512	1088	1073
RX1day	55	54	49	45	50	49	81	77	59	56
RX5day	97	95	84	75	85	81	154	153	106	101
SDII	9	9	8	8	8	8	14	14	10	10
R1mm	111	113	91	110	114	114	103	106	105	111
R10mm	36	35	30	29	31	31	48	49	37	36
R20mm	13	13	10	9	10	9	25	26	15	14
R95p	232	212	221	176	201	202	332	316	247	227
R99p	75	66	82	50	61	56	110	84	82	64
R95p%	22	20	23	20	21	22	22	21	22	21
R99p%	7	6	8	6	6	6	7	6	7	6
CDD	23	21	24	24	22	23	30	30	25	25
CWD	7	6	6	6	7	7	9	9	7	7

Decadal trends in annual and seasonal precipitation in Bosnia and Herzegovina in the 1961 – 2015 periods are shown in Table 5. The estimated trends in mean annual precipitation are not spatially coherent. Trends of both signs were reported. The only positive trend was registered in Dobož (19.69 mm per decade), whereas the most prominent negative trend was present in the south, in Mostar (-42.50 mm per decade). Similar patterns of change were

found for PRCPTOT (annual total of precipitation in days when precipitation amount is $\geq 1\text{mm}$). Analysis of seasonal precipitation trends showed that negative trends were reported in summer over the entire territory (most pronounced in Banjaluka – $-15.63\text{ mm per decade}$). In autumn, the positive trends were found all over the study area, whereas trends for winter and spring were regionally mixed in signs. All of these seasonal trends of both signs are not statistically significant. It should be noted that the strongest negative trends throughout the year were reported for southern (submediterranean) areas (except in autumn when a slight increase has been observed).

Table 5 - Decadal trends in annual and seasonal precipitation in Bosnia and Herzegovina in 1961 – 2015

Station	Winter	Spring	Summer	Autumn	Year
BL	1.90	0.00	-15.63 ^d	9.44 ^d	-9.79
DB	0.83	7.50	-4.48	10.00 ^d	19.69
SA	-3.05	3.32	-4.94	3.53	-0.68
MO	-12.78	-12.04 ^d	-8.50 ^d	2.00	-42.50 ^d

Note: Statistical significance at the 99 % (a), 95 % (b), 90 % (c) and 75 % (d) level

Results of the analysis of trends in annual absolute extreme indices and absolute-based threshold indices are given in Table 6 and Figures 2 – 4. The obtained results indicate a general increase in the extreme precipitation indices. When compared with temperature changes (Trbić et al., 2017), a less spatially coherent pattern of change was registered. Most of the estimated trends are not statistical significant.

Table 6 - Decadal trends in annual absolute extreme indices and absolute-based threshold indices in Bosnia and Herzegovina in 1961 – 2015

Station	PRCP TOT	RX1 day	RX5 day	SDII	R1mm	R10mm	R20mm
BL	-2.06	-0.38	-0.41	0.05	-1.22	0.05	0.18
DB	21.18 ^d	2.25 ^d	6.00 ^b	0.22 ^b	-0.84	0.50	0.46 ^d
SA	0.83	0.83	2.12	0.07	-1.01	0.11	0.15
MO	-22.47	2.52 ^d	0.98	0.10	-2.49 ^c	-0.78	-0.59

Note: Statistical significance at the 99 % (a), 95 % (b), 90 % (c) and 75 % (d) level

Figure 2 - Linear trends in RX1day in Bosnia and Herzegovina in 1961 – 2015

Rare precipitation events (such as the highest annual daily precipitation total) have increased since the 1960. Maximum 1-day precipitation amount (RX1day) has been increasing in all areas, except in Banjaluka where very weak negative trend was registered. Simmilar pattern of change was found for RX5day. Maximum consecutive 5-day precipitation showed statistically significant ($p < 0.05$) upward trend in Doboj area (6.00 mm per decade). Simple pricipitation intensity index (SDII) showed increasing trend, that was significant ($p < 0.05$) only at Doboj station (0.22 mm/day per decade). The negative trends in annual number of wet days (in the range of -0.84 – -2.49 days per decade) and upward trends in numbers of heavy precipitation days and very heavy precipitation days (in the range of 0.05 – 0.50 and 0.15 – 0.46 days per decade, respectively) indicate changes toward more intense precipitation. Only in Mostar area, heavy and very heavy precipitation have decreased. Much larger decline was recorded for R1mm suggesting drier

conditions in this submediterranean part of the country.

Figure 3 - Linear trends in SDII in Bosnia and Herzegovina in 1961 – 2015

The only two of the extreme precipitation indices that have been calculated seasonally (RX1day and RX5day) show that spatially and temporally (seasonally) trends mixed in sign were present (Table 7). Maximum 1-day precipitation amount decreased in summer over the entire territory, whereas increased in autumn. In winter and spring, RX1day did not display a coherent pattern of change. RX5day showed upward trend during spring, autumn and winter (only in the northern part). All trends are mostly not significant.

Table 7 - Decadal trends in seasonal RX1day and RX5day in Bosnia and Herzegovina in 1961–2015

Station	RX1day				RX5day			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
BL	1.06 ^d	-0.08	-0.69	0.04	0.31	1.33	-2.07	1.63
DB	0.55	1.36 ^c	-0.76	1.19	0.6	4.83 ^b	-0.79	3.20 ^d
SA	-0.18	-0.92	-0.06	2.00 ^c	-2.2	1.00	-0.89	2.40 ^d
MO	-1.50 ^d	0.64	-1.23	1.70	-1.17	1.18	1.03	0.87

Note: Statistical significance at the 99 % (^a), 95 % (^b), 90 % (^c) and 75 % (^d) level

Figure 4 - Linear trends in R20mm in Bosnia and Herzegovina in 1961 – 2015

Analysis of decadal trends in annual percentile-based indices (Table 8 and Figure 5) showed that the (percentage) contribution from very wet days and extremely wet days to the annual precipitation total have increased over almost the entire territory of Bosnia and Herzegovina, although trends were mostly insignificant.

Trends in Extreme Daily Precipitation Indices in Bosnia and Herzegovina

Table 8 - Decadal trends in annual percentile-based and duration-based indices in Bosnia and Herzegovina in 1961 – 2015

Station	R95p	R95p%	R99p	R99p%	CDD	CWD
BL	6.49	0.45	1.15	0.00	1.28 ^b	0.31 ^c
DB	22.76 ^b	1.93 ^c	19.46 ^b	0.93 ^c	0.06	0.25 ^c
SA	-1.78	-0.20	5.52	0.00	-0.14	-0.01
MO	3.74	0.12	16.20 ^c	0.38 ^d	-0.24	0.07

Note: Statistical significance at the 99 % (a), 95 % (b), 90 % (c) and 75 % (d) level

Figure 5 - Linear trends in R99p in Bosnia and Herzegovina in 1961 – 2015

The only statistically significant ($p < 0.05$) positive trend in the annual R95p and R99p was registered in Doboj – 22.76 mm per decade and 19.46 mm per decade, respectively. The estimated trend in Mostar (16.20 mm per decade) is significant only at the 10 % level. Duration-based indices displayed spatially incoherent trends, which were mostly insignificant (Table 8). Maxi-

imum number of consecutive dry days (CDD) showed trends mixed in sign. In the northern part of the territory CDD increased (in Banjaluka significantly – 1.28 days per decade), whereas steady decline in CDD in central, and particularly in south, has been present. Consecutive wet days (CWD) mostly showed upward trend during the observed period, more significant in the northern part of the territory (0.25–0.31, $p < 0.1$ %).

Although the observed trends are spatially not homogeneous and mainly statistically insignificant, the results indicate a general increase in the extreme precipitation. Similar patterns of change with trends of different sign (largely insignificant), seasonally and regionally, have been determined in other studies in the Southeast Europe region. Heavy precipitation indices (e. g. R20mm, R95p and R95p%) had increased over almost the entire territory of Serbia (Unkašević and Tošić, 2011). In Montenegro, R20 mm decreased in the south-western areas, whereas positive trends were detected in north-eastern parts of the country (Burić et al., 2015). The annual R95p showed positive trends in central parts of Montenegro (Burić et al., 2015). Frequency of R95p in Croatia showed spatially trends mixed in sign – a weak annual decrease along the coast and in the mountainous regions, while the mainland displayed positive trends (Gajić-Čapka et al., 2015). The SDII trends revealed annual and seasonal increases in Montenegro (Burić et al., 2015). In Croatia, negative trends were present in summer, while in other seasons, they were mixed in sign and mainly insignificant (Gajić-Čapka et al., 2015). The trends in Rx1day and Rx5day were weak in magnitude and mixed in sign (Gajić-Čapka et al., 2015).

Climate variability in Europe is strongly dictated by NAO, especially during winter season. Strong positive phases of the NAO 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). The positive phase of the EA pattern is also associated with above-average precipitation over northern Europe and Scandinavia, whereas below-average precipitation occurs across southern Europe (NOAA CPC, 2017). The positive phase of the EAWR pattern is generally linked to below-average precipitation across central part of Europe (NOAA CPC, 2017).

Table 9 shows that a significant negative correlation was determined between precipitation and the NAO in winter (-0.236 – -0.498). Similar results were obtained in other regions of Southeast Europe (Burić et al., 2015; Luković et al., 2015). Further, even stronger negative correlation in winter season was found for the EAWR (-0.388 – -0.565) and particularly the AO (-0.544 – -0.735). In addition, significant relation with AO is determined in

autumn (-0.282 – -0.482). In this part of the year, the determined negative correlation is only partially significant. EA pattern significantly conditions precipitation in Bosnia and Herzegovina only in summer season.

Table 9 - Pearson correlation coefficient between seasonal teleconnection patterns indices and precipitation in Bosnia and Herzegovina in the 1961 – 2015 periods

Station	WINTER				SPRING			
	EA	NAO	EAWR	AO	EA	NAO	EAWR	AO
BL	-0.065	-0.164	-0.418 ^b	-0.556 ^a	-0.113	-0.099	-0.150	-0.191
DB	-0.042	-0.236 ^d	-0.388 ^b	-0.544 ^a	0.143	-0.084	-0.039	-0.119
SA	-0.243 ^d	-0.329 ^c	-0.441 ^a	-0.596 ^a	-0.030	-0.086	-0.137	-0.202
MO	-0.031	-0.498 ^a	-0.565 ^a	-0.735 ^a	-0.110	-0.253 ^d	-0.007	-0.361 ^b
Station	SUMMER				AUTUMN			
	EA	NAO	EAWR	AO	EA	NAO	EAWR	AO
BL	-0.391 ^b	0.152	0.189	0.037	-0.217	-0.147	-0.143	-0.415 ^b
DB	-0.082	0.070	-0.007	0.101	-0.267 ^c	-0.126	-0.175	-0.282 ^c
SA	-0.285 ^c	0.167	0.072	0.074	-0.213	-0.163	-0.257 ^d	-0.390 ^b
MO	-0.250 ^d	0.190	0.215	-0.131	-0.100	-0.158	-0.257 ^d	-0.482 ^a

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

Table 10 - Pearson correlation coefficient between annual teleconnection patterns indices and extreme precipitation indices in Bosnia and Herzegovina in the 1961 – 2015 periods

Index	NAO	EA	EAWR	AO
PRCTOT	-0.418 ^b	-0.090	-0.307 ^c	-0.621 ^a
RX1day	-0.244 ^d	-0.040	-0.139	-0.251 ^d
RX5day	-0.037	0.037	-0.042	-0.137
SDII	-0.257 ^d	0.154	-0.247 ^d	-0.389 ^b
R1mm	-0.376 ^b	-0.103	-0.236 ^d	-0.434 ^a
R10mm	-0.447 ^a	-0.050	-0.314 ^c	-0.634 ^a
R20mm	-0.385 ^b	-0.043	-0.358 ^b	-0.519 ^a
R95p	-0.253 ^d	0.075	-0.198	-0.359 ^b
R99p	-0.210	0.087	-0.312 ^c	-0.264 ^d
CWD	-0.150	-0.034	-0.157	-0.116
CDD	0.182	0.057	0.125	0.161

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

The investigated precipitation indices seemed to be directly linked to changes in the dominant large-scale circulation patterns over Northern Hemisphere. Table 10 shows that statistically significant negative correlation with NAO, EAWR and AO is found for majority of extreme precipitation indices in Bosnia and Herzegovina – PRCTOT, SDII, R1mm, R10mm, R20mm, R99p (except for NAO) and RX1 day and R95p (except for EAWR).

Conclusion

The study analyzes trends in extreme daily precipitation indices in Bosnia and Herzegovina. Trends in 13 indices recommended by the ETC-CDI were calculated for the 1961–2015 periods using RClimDex (1.0) software. The obtained results suggest that a general increase in the extreme precipitation is present over the territory of Bosnia and Herzegovina. Upward trends in heavy precipitation events such as RX1 day, RX5 day, SDII, R10mm, R20mm, R95p, R95p%, R99p and R99p% indicate changes toward more intense precipitation over the study area. However, most of the estimated trend values are statistically insignificant. Also, trends are not spatially and temporally coherent. Spatially incoherent patterns of change with the occurrence of trends of both sign were registered. Indices that have been calculated seasonally show that there are also variations between change patterns throughout year. Trends that indicate increase in either the frequency or intensity of heavy precipitation are generally most prominent in Dobo area. Exceptionally high rainfall amount that caused catastrophic flooding has been recorded several times just during the last decade. In May and August 2014, for just a few days 146.6 mm and 123.6 mm of precipitation was registered, which is 17 % and 14 % of average annual precipitation in a standard climatological period (1961–1990). Similar weather conditions have occurred in June 2010 when for only two days 178.3 mm of rainfall was recorded (20 % of annual totals). The observed extreme precipitation trends are directly related with changes in the large-scale circulation patterns over Northern Hemisphere. Statistically significant negative correlation with NAO, EAWR and AO is found for majority of extreme precipitation indices, particularly during winter. The results obtained in this survey are similar to the results of other studies that addressed the issue of recent extreme daily precipitation indices in the adjacent regions of Southeast Europe. Due to the heavy precipitation event large impact on natural and socio-economic systems, further research is certainly necessary.

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