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# EXTREME PRECIPITATION INDICES IN VOJVODINA REGION (SERBIA)

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**Abstract:** The evolution of daily extreme precipitation from 1966 to 2013 in Vojvodina Region (Serbia) was investigated. We calculated trends of ten precipitation indices and tested their corresponding significances using the Student's t-test for seven locations. The obtained results suggest that the climate of the northern and central parts of Vojvodina region becomes wetter in terms of precipitation magnitude and frequency, reflecting the characteristic of the central European regime, while the southernmost part of the region is drier, reflecting the characteristic of the Mediterranean regime. In addition, the results indicate an increase in the amount of precipitation in short time intervals. Positive annual trends are strongly influenced by the significant increase of autumn frequency and intensity of extreme precipitation. According to the correlation between extreme precipitation indices and atmospheric teleconnection patterns, it was found that the NAO has the strongest influence on precipitation intensity indices in spring and winter, while during winter it also affects the frequency of dry conditions. The EAWR pattern has a strong influence on the statistically significant positive autumn trends.

**Keywords**: climate extremes, precipitations, atmospheric teleconnection patterns, trends

## Introduction

The last decades were marked by the growing interest of the scientific community in climate change and its consequences. Climate change can be detected and quantified by measuring changes of many elements of the climate system, but primarily the air temperature and precipitation (Malinovic-Milicevic, Radovanovic, Stanojevic, & Milovanovic, 2016). Regarding the precipitations, it has been found that global land precipitation has increased about 2 % during the

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twentieth century (Dai, Fing, & del Genio, 1997). However, monitoring climate changes in local and global scale cannot be based only on the analysis of the total annual precipitations. Sometimes there are far more significant and more pronounced seasonal changes in extreme precipitation events and the frequency and intensity of their characteristic values. Global studies consistently report increasing tendency in intensity and frequency of extreme precipitation events (Frich et al., 2002; Alexander et al., 2006). However, Intergovernmental Panel on Climate Change [IPCC] (2014) indicates a strong spatial variability of precipitation and differences in trends in different regions of the world. Increasing trends are found for mid with an extension to high latitudes in Europe, north and central Asia and eastern parts of North and South America, while decreasing trends are observed in South Africa, the Sahel, the Mediterranean region, and in many parts of southern Asia (Toros, 2012). According to Intergovernmental Panel on Climate Change (IPCC, 2014), the basic projection is that changes in the amount and intensity of precipitation will not be uniform, while the extreme precipitation events will become more intense and frequent in many regions.

Similar to global trends, in Serbia, changes in the amount and regime of precipitation were also observed in the past few decades. An increase in precipitation amount was observed in most parts of Serbia in the period 1946-2006. Vojvodina region had a higher increase in the amount of precipitation than the rest of Serbia, during summer, autumn and on an annual basis (Ministry of Environment and Spatial Planning, 2010). According to the results based on the dynamic downscaling of the EBU-POM coupled regional climate model under the SRES-A2 scenario, the mean annual precipitation in Vojvodina region will increase to the end of the first half of the 21st century and decrease for the last 30 years of the 21st century (Malinović-Milićević et al., 2015). Although precipitation amount and extremes were investigated comprehensively in different areas of the world, only a few studies have been conducted in Vojvodina region. Some previous studies for Vojvodina region have been focused on seasonal precipitation variability (Tošić et al., 2014), aridity (Hrnjak et al., 2014) or considered very few extreme indices for only two stations situated in Vojvodina region, as a part of the study area covering the whole territory of Serbia (Unkašević & Tošić, 2011; Malinovic-Milicevic et al., 2016). In this paper we are focused on the following points: (i) exploring the specific regional behavior of extreme precipitation and (ii) identifying the changes in different extreme precipitation indices for Vojvodina region. The analysis presents more details as regards the number of stations used and analyzed indices than the previous studies dealing with this issue.

## Data and methodology

### *Study area*

The territory of Vojvodina region (21,500 km$^2$, with approximately 2 million inhabitants) is situated in northern part of Serbia (44°37'−46°11' N, 18°51'−21°33' E) and mainly overlaps the bottom of the former Pannonian Sea (Figure 1(a)). For this reason, the relief of Vojvodina is extremely flat and displays low altitude. The only higher forms of relief are low mountains, Fruška Gora in the south (539 m) and the Vršac Mountains in the southeast (641 m). Vojvodina has moderate continental climate characterized by hot and humid summers and cold and dry winters. The average annual temperature is about 11 °C. Summer temperatures are between 21 °C and 23 °C and winter around -2 °C. However, temperatures can be extreme, so that the difference between the highest and lowest temperatures reaches over 70 °C. The amount of precipitation is relatively low and unevenly distributed throughout the year. The average annual precipitation amount ranges from 550 to 600 mm. An extremely rainy period can be distinguished in early summer (June) and in the periods with a small amount of precipitations (November and March).

### *Data description*

To describe changes in precipitation extreme indices we used daily precipitation time series from the weather station network of the Republic Hydrometeorological Service of Serbia (RHMSS) for the following sites:

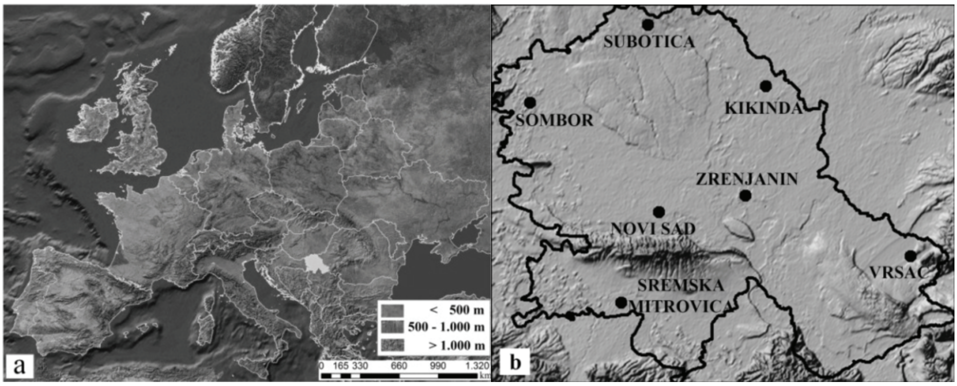

Figure 1. (a) Location of Vojvodina region in Europe (designed by N. Drešković in Mihailović Malinović-Milićević, Arsenić, Drešković & Bukosa, 2013) and (b) meteorological stations used in this study.

Novi Sad, Subotica, Sombor, Kikinda, Zrenjanin, Vršac and Sremska Mitrovica (Figure 1(b)).

The stations analyzed in this study are located at altitudes between 80 m and 102 m. The datasets cover a period of 48 years (1966–2013). Missing data were found only in Subotica station, but the amount of data gaps was small (June 1999). Although data quality control was provided by RHMSS, we additionally checked the existence of very long occurrences of zero values and the same values. The homogeneity test procedure was performed using ACMANT homogenization software (Domonkos, 2015).

### *Precipitation indices*

We used ten precipitation indices in this study (Table 1) that are defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) (http://etccdi.pacificclimate.org/indices_def.shtml).

Table 1. Definitions of the precipitation extremes used in this study. R represents precipitation amount

| Index | Descriptive name | Definition | Units |
|---|---|---|---|
| RX1day | Maximum one-day precipitation | Highest precipitation amount in one-day period | mm |
| RX5days | Maximum five-day precipitation | Highest consecutive five-day period precipitation amount | mm |
| PRCPTOT | Total wet-day precipitation | Amount of precipitation cumulated in wet days ($R \geq 1$ mm) | mm |
| SDII | Simple daily intensity index | Mean precipitation amount on a wet day | mm |
| R95pTOT | Precipitation due to very wet days | Amount of precipitation when $R^* >$ 95th percentile | mm |
| R99pTOT | Precipitation due to extremely wet days | Amount of precipitation when $R >$ 99th percentile | mm |
| CDD | Consecutive dry days | Maximum number of consecutive days where daily precipitation amount $R < 1$ mm | days |
| CWD | Consecutive wet days | Maximum number of consecutive days where $R \geq 1$ mm | days |
| R10mm | Heavy precipitation days | Count of days where $R \geq 10$ mm | days |
| R20mm | Very heavy precipitation days | Count of days where $R \geq 20$ mm | days |

Source: Klein Tank, Zwiers, & Zhang, 2009

The selected indices provide the combination of intensity (Rx1day, Rx5days, PRCPTOT, SDII, R95pTOT and R99pTOT) and frequency (R10mm, R20mm, CDD and CWD) indices. The indices can be classified as follows:

- Fixed threshold-based indices are defined on the basis of fixed threshold of measured precipitation amount that can vary depending on region (Hundecha & Bardossy, 2005). We used four fixed threshold defined indicators: heavy precipitation days (R10mm), very heavy precipitation days (R20mm), consecutive dry days (CDD) and consecutive wet days (CWD).
- Percentile-based indices are defined on the basis of thresholds calculated from long-term percentiles for each station. These indices are comparable between different regions and commonly used to determine the extreme values (Alexander et al., 2006; Croitoru, Piticar, & Burada*,* 2016). In this study we calculated percentiles from the reference period 1971–2000. We analyzed only two percentile-based indices: precipitation due to very wet days (R95pTOT) and precipitation due to extremely wet days (R99pTOT).
- Non-threshold indices include the indices calculated on the basis of the absolute amount of precipitation in a particular area (Croitoru, Piticar, & Burada, 2016). They are sensitive to the climate of the region and hardly comparable between regions with different climates. In this category, we analyzed four indices: maximum one-day precipitation amount (Rx1day), maximum five-day precipitation amount (Rx5days), simple daily intensity index (SDII), and total wet-day precipitation (PRCPTOT).

The annual and seasonal variations of ETCCDI indices are discussed. Seasons are defined as follows: spring from March to May, summer from June to August, autumn from September to November and winter from December of the previous year to February of the calendar year. In this work, the analyses were carried out for the full period (1966–2013) and for two consecutive subperiods of the same length: 1966–1989 and 1990–2013. In addition to the precipitation trends of individual stations, we also calculated trends of regional indices, which were obtained by averaging over all stations.

### *Atmospheric teleconnection patterns*

We investigated the relationship between the extreme indices and the following teleconnection patterns: the North Atlantic Oscillation (NAO), the East Atlantic (EA) and the East Atlantic/West Russia (EAWR) patterns. The NAO impacts on the climate of the North Atlantic region and surrounding continents. It occurs in all seasons however, it is dominant during winter (Hurrell, 1995). When the NAO is in negative phase, increased storm activity and precipitation in southern

Europe are registered. During the NAO positive phase amount of precipitation in southern and central Europe is below-average. In addition to the NAO, below-average amount of precipitation in southern Europe is associated with the positive phase of EA. Positive phase of the EAWR causes drier weather over central Europe and the Mediterranean Region, while the negative phase leads to wetter conditions (Ionita, 2014). In this study we used the seasonal indices of the NAO given by Hurrell (1995) and EA and EAWR indices given by the Climate Prediction Center (http://www.cpc.ncep.noaa.gov/).

### *Statistical parameters*

The slopes of the annual and seasonal trends and their statistical significances were calculated based on least squares linear method and Students t test. The significance of the trend was assessed at the 5% ($p \leq 0.05$), 10% ($0.05 < p \leq 0.10$) and, as recommended by Nicholls (2001), 25% ($0.10 < p \leq 0.25$) significance level. Correlation between the teleconnection patterns and extreme indices was estimated by applying Pearson's correlation analysis at the 1% ($p \leq 0.01$) and 5% ($0.01 < p \leq 0.05$) significance level.

## Results and discussion

As a general overview, increasing trends are the most frequent, with about 73% of the series. The obtained results follow other studies which confirmed that the increasing trend of extreme precipitation indices is the most common one, either at global or regional level (Frich et al., 2002; Alexander et al., 2006). In comparison with changes in extreme precipitation indices in Central and Eastern Europe, where usually less than 20% of the trends were found significant at $p \leq 0.1$ (Lupikasza, Hansel & Matschullat, 2011), the extreme precipitation indices in Vojvodina region have a lower level of statistical significance (7% at $p \leq 0.1$).

### *Changes in indices based on fixed thresholds*

The spatial distributions of the decadal trends for four frequency indices based on fixed threshold are shown in the Figure 2, while regional seasonal trends and annual trends in two different periods are listed in the Table 2. Increasing annual trends in heavy (R10mm) and very heavy (R20mm) precipitation indices are the most frequent, whereas series with negative slopes are dominant in the southern area. However, most trends are not statistically significant. These results are in agreement with different studies made at global (Frich et al., 2002) and regional level — Europe (Klein Tank & Konnen, 2003) that confirmed a positive trend in R10mm and R20mm. Although regional annual trends in the entire period 1966–2013 show increase in R10mm and R20mm, the Table 2 shows their decrease in

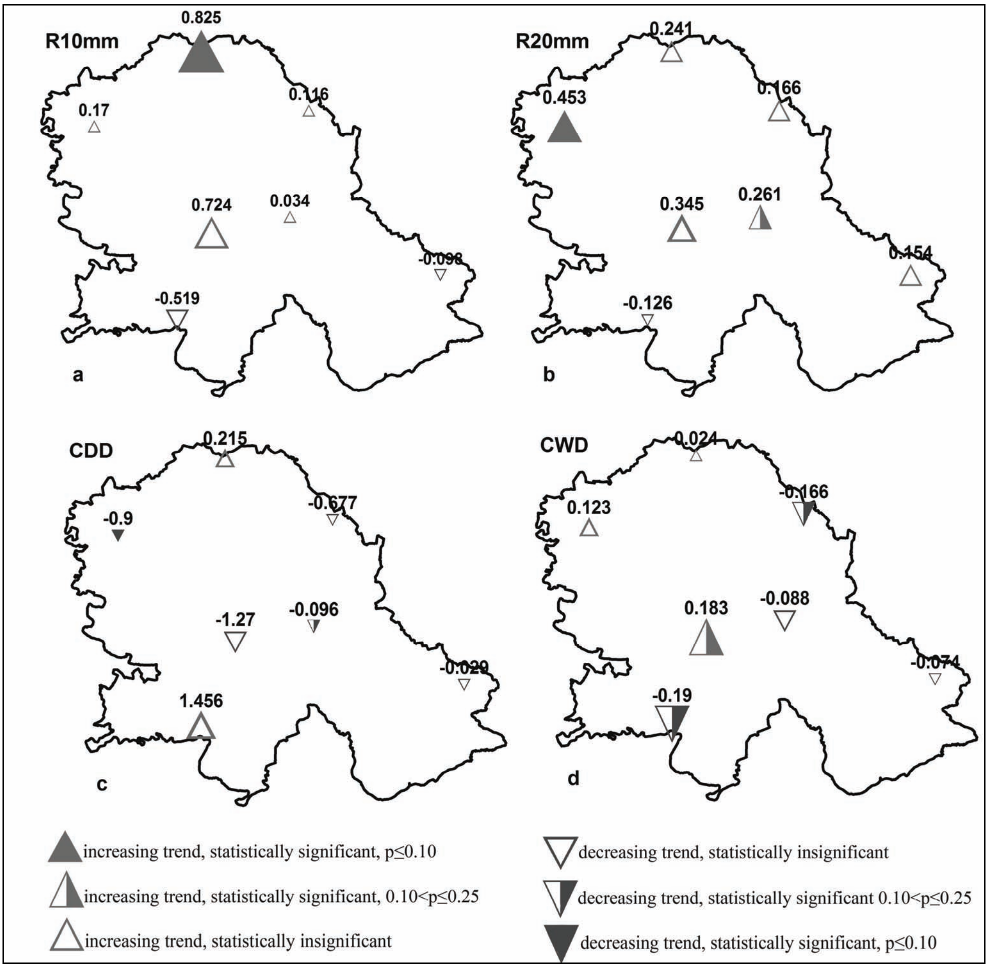

Figure 2. Trends for indices based on fixed thresholds in Vojvodina region

Table 2. Linear decadal trends in indices based on fixed thresholds in Vojvodina region

| | Period | R10mm | R20mm | CDD | CWD |
|---|---|---|---|---|---|
| 1966–1989 | Year | -1.240$^{c}$ | -0.404 | 3.014$^{c}$ | -0.120 |
| 1990–2013 | Year | 0.470 | 0.576 | -1.242 | 0.396 |
| 1966–2013 | Year | 0.179 | 0.213 | -0.184 | -0.027 |
| | Spring | 0.063 | 0.112$^{c}$ | 0.752$^{c}$ | -0.038 |
| | Summer | -0.259 | -0.045 | 0.175 | -0.029 |
| | Autumn | 0.328$^{c}$ | 0.186$^{a}$ | -1.507$^{a}$ | 0.129$^{c}$ |
| | Winter | 0.058 | -0.027 | -0.100 | -0.029 |

$^{a}p \leq 0.05$, $^{b}0.05 < p \leq 0.10$, $^{c}0.1 < p \leq 0.25$

the period 1966–1989. The analysis of seasonal R10mm and R20mm trends shows decrease during summer and an increase in rest of the seasons. However, only autumn trends are statistically significant.

Two frequency indices in this category, CDD and CWD, became less frequent for the 48-year period in most stations. The Table 2 indicates the occurrence of longer dry and shorter wet periods in the first subperiod (1966–1989) and vice versa in the second (1990–2013). Analyzed by seasons, shortening dry periods and lengthening wet periods was statistically significant only in autumn. Statistically significant increase in R20mm and CDD in the spring season indicates higher frequency of isolated days with very heavy precipitation.

### *Changes in indices based on percentile thresholds*

The Figure 3 shows that very wet days (R95pTOT) and extremely wet days (R99pTOT) have similar behavior, which is the increasing trend in the majority of stations. The territorial distribution of R95pTOT and extremely wet days trends is similar to the distribution of R10mm and R20mm: dominant increase in the northern and central part of the region and decrease in the south.

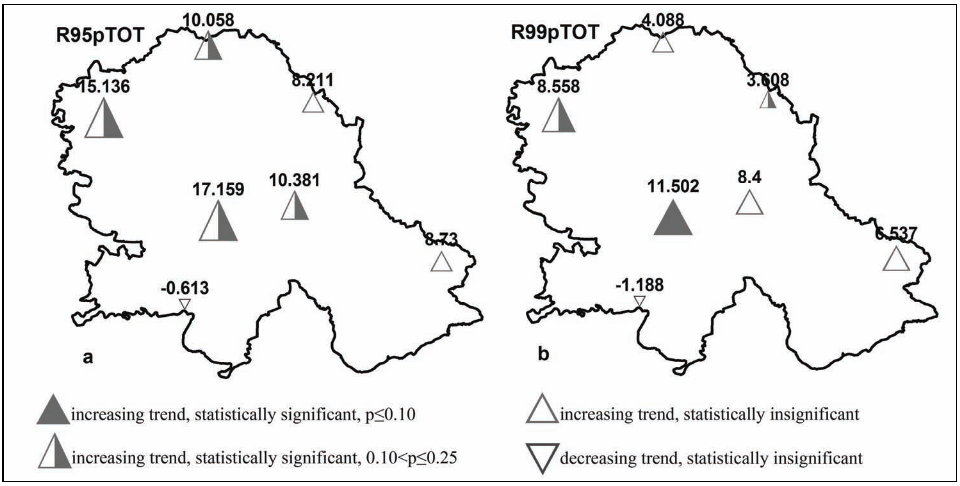

Figure 3. Trends for indices based on percentile thresholds in Vojvodina region

Regional precipitation amount during very wet and extremely wet days increases in average for 9.886 mm/decade and for 5.929 mm/decade, respectively, at the 25% significance level (Table 3). The increase R99pTOT is constant during the whole observed period, while R95pTOT in the period 1966–1989 shows a decline and then increase until the year 2013.

The Figure 4 shows that the contribution of extreme precipitation events to the annual precipitation amount increases with time, which is similar to other regions (Groisman et al., 1999; Wong, Mok & Lee, 2011). The average contribution of the annual precipitation amount due to very wet days to the total precipitation amount in Vojvodina region is 22% for the period 1966–2013 (range 9% to 38%), while the average contribution of extremely wet days is 7% (range 0–19%).

Table 3. Linear decadal trends in indices based on percentile thresholds in Vojvodina region

| Period | Period of year | R95pTOT | R99pTOT |
|---|---|---|---|
| 1966–1989 | Year | -9.090 | 0.463 |
| 1990–2013 | Year | 21.460 | 8.501 |
| 1966–2013 | Year | 9.886$^{c}$ | 5.929$^{c}$ |
|  | Spring | 4.185$^{c}$ | 2.348$^{c}$ |
|  | Summer | 1.251$^{c}$ | 0.781 |
|  | Autumn | 6.326$^{a}$ | 2.882$^{b}$ |
|  | Winter | 0.197 | -0.413 |

$^{a}p \leq 0.05$, $^{b}0.05 < p \leq 0.10$, $^{c}0.1 < p \leq 0.25$

The results indicate the higher concentration of precipitation in short time intervals. This is also confirmed by other earlier studies (Ramos & Martínez-Casasnovas, 2006; Croitoru et al., 2016).

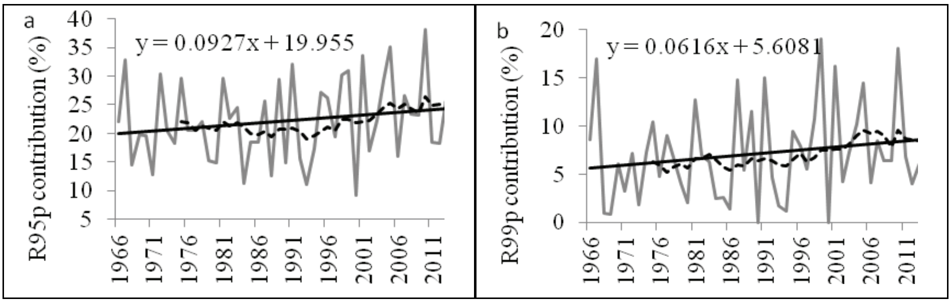

Figure 4. Contribution of precipitation due to (a) very wet days and (b) extremely wet days to total precipitation amount. The dashed line is the 10-year moving average

### *Changes in non-threshold indices*

Generally, intensity-related non-threshold indices show increasing trends in most stations, of which only 17% of series was statistically significant. Statistically significant rise of fixed-period indicators (Rx1day and Rx5days) during spring and autumn indicates an increase in extreme shower events, which increases the risk of high water levels. During spring, extreme shower events coupled with the melting of snow can also cause floods.

The average precipitations from rainy days (SDII) and total wet day precipitation (PRCPTOT) display an increasing trend, except for the most southernmost stations of the region (Fig. 5).

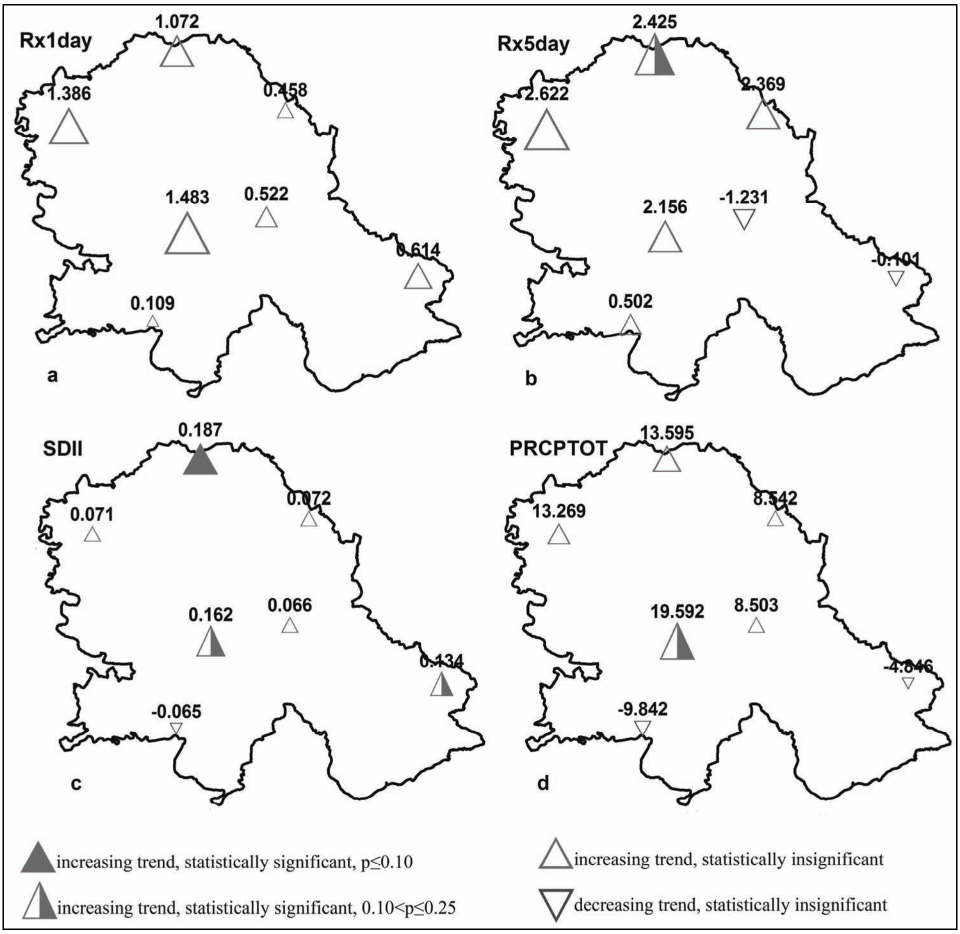

Figure 5. Trends for non-threshold indices in Vojvodina region

Similar to the fixed-period indicators, the Table 4 shows the decline of the values of these two intensity indices in the first half of the period, and an increase in the second. The trends of the SDII and PRCPTOT were statistically significant only in the autumn (Table 4).

Although we analyzed ten extreme precipitation indices, we selected four indicators to examine the relationship between the intensity and frequency of precipitation with large atmospheric patterns. R95pTOT was chosen to represent the intensity of very heavy events, which could be responsible for floods and soil erosion (Casanueva, Rodríguez-Puebla, Frías, & González-Reviriego, 2014). Characteristics of average precipitation events were represented by the PRCPTOT. CDD and CWD were chosen to represent frequency of dry and wet conditions. The trend of CDD may indirectly indicate the frequency of drought, which is of great interest for agricultural activities.

Table 4 Linear decadal trends in non-threshold indices in Vojvodina region

| | Period | Rx1day | Rx5days | SDII | PRCPTOT |
|---|---|---|---|---|---|
| 1966–1989 | Year | -0.490 | -1.891 | -0.085 | -26.254 |
| 1990–2013 | Year | 2.853 | 1.979 | 0.150 | 35.222 |
| 1966–2013 | Year | 0.806 | 1.249 | 0.090 | 6.973 |
| | Spring | 1.344[c] | 1.795[c] | 0.143 | 2.565 |
| | Summer | -0.041 | -0.064 | 0.055 | -5.876 |
| | Autumn | 1.435[a] | 2.883[a] | 0.239[b] | 8.645[b] |
| | Winter | 0.297 | 0.653 | 0.082 | 1.397 |

[a] $p \leq 0.05$, [b]$0.05 < p \leq 0.10$, [c]$0.1 < p \leq 0.25$

*Relationships between extreme indices and atmospheric teleconnection patterns*

The correlation analysis (Table 5) indicates that, in spring and winter, the NAO has the strongest influence on precipitation intensity indices, while during winter the NAO also affects the frequency of dry conditions. The negative correlations of CWD and PRCPTOT, as well as the positive correlation of CDD, with the EAWR pattern during winter reflect the relationship with drier conditions, which is caused by the penetration of the cold air from north into the Balkan Peninsula.

Table 5. Seasonal correlation coefficients between extreme precipitation indices and atmospheric teleconnection patterns

| | | Spring | Summer | Autumn | Winter |
|---|---|---|---|---|---|
| NAO | PRCPTOT | -0.298[b] | - | - | -0.483[a] |
| | R95pTOT | -0.298[b] | - | - | -0.284[b] |
| | CDD | - | - | - | 0.358[b] |
| | CWD | - | - | - | - |
| EA | PRCPTOT | - | - | -0.297[b] | - |
| | R95pTOT | - | - | - | - |
| | CDD | - | - | - | - |
| | CWD | - | - | - | - |
| EAWR | PRCPTOT | - | - | -0.355[b] | -0.497[a] |
| | R95pTOT | - | - | -0.308[b] | - |
| | CDD | - | - | 0.339[b] | 0.307[b] |
| | CWD | - | - | -0.320[b] | -0.389[a] |

[a]$p \leq 0.01$, [b]$0.01 < p \leq 0.05$

Statistically significant positive autumn trends of all intensity and frequency indices (except for CDD that have negative trend) have the strongest relation with the EAWR. We did not find significant correlations between extreme precipitation indices and atmospheric teleconnection patterns during summer.

## Conclusions

This paper investigates spatial and temporal variability of extreme precipitations in agriculturally oriented Vojvodina region. We have analyzed changes in the intensity and frequency of extreme precipitation conditions using time series for a 48-year period. The obtained results suggest that the trends in the extreme precipitation indices are consistent with the observations made in Central and Southern European regions.

Generally, we can conclude that the climate of Vojvodina region has become wetter in terms of precipitation magnitude and frequency for the period 1966-2013. Extreme climate regarding the precipitations is indicated by the increasing trends of most of the indices, which reflects the characteristic of the central European regime. The only exception is the southernmost station, where most of the trends of the extreme precipitation indices indicate the characteristics of the Mediterranean region. Most of detected trends are not statistically significant, which is a general characteristic at global scale. Positive annual trends are strongly influenced by the significant increase observed in all autumn extreme precipitation indices. The results also indicate an increase in the amount of precipitation in short intervals of time and a growing contribution of extreme events to the total amount of precipitation. It is shown that the NAO has the strongest influence on precipitation intensity indices in spring and winter, while it also affects the frequency of dry conditions during winter. The EAWR pattern affects statistically significant positive autumn trends of all intensity and frequency indices. In winter, the EAWR has an impact on the frequency of dry and wet conditions and intensity of the precipitations.

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