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LONG-TERM BEHAVIOUR OF PRECIPITATION AT THREE STATIONS IN SERBIA

DOLGOROČNE SPREMEMBE PADAVIN NA TREH PADAVINSKIH POSTAJAH V SRBIJI

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Abstract

This paper investigates precipitation records at three precipitation stations in Serbia that received the greatest amount of rainfall during the catastrophic floods that struck Serbia, Bosnia and Herzegovina and Croatia in May 2014. The aim is to identify precipitation anomalies by analysing trends in different precipitation indices, including precipitation totals, maxima of durations from one to seven days and the rate of occurrence of precipitation exceeding certain thresholds, while looking at the multi-decadal oscillations in the data that may explain the variability. Three stations in Serbia are considered: Loznica, Valjevo and Belgrade, with record of 62, 65 and 91 years, respectively. The results show somewhat different long-term behaviour at these stations. Significant increasing trends in some indices are detected at Loznica, while most of these trends are not present at the other two stations. Oscillatory behaviour at three stations is also somewhat different and it is difficult to conclude whether the detected trends are consistent with background oscillations seen in the longest Belgrade series. Analysis of long-term behaviour of monthly totals shows a multitude of patterns, indicating that the long-term behaviour of the annual precipitation series has a very complex structure. No significant increasing trend is detected in May series at any station.

Keywords: extreme precipitation, trend, long-term persistence, low frequency oscillations, floods, May 2014 floods in Serbia.

Izvleček

V članku smo analizirali podatke o padavinah na treh padavinskih postajah v Srbiji, kjer je med katastrofalnimi poplavami, ki so maja 2014 prizadele območja v Srbiji, Bosni in Hercegovini ter na Hrvaškem, padlo največ padavin. Cilj je bil prepoznati padavinska odstopanja z analizo trendov različnih padavinskih parametrov, vključno s skupno količino padavin, maksimalno količino padavin trajanja od enega dneva do sedmih dni, in pogostostjo padavin, ki presegajo določen prag, ob upoštevanju večdesetletnih nihanj v podatkih, ki bi lahko razložili razlike. Upoštevali smo tri postaje v Srbiji: Loznico z 62-letnim, Valjevo s 65-letnim in Beograd z 91-letnim nizom meritev. Rezultati kažejo, da se obnašanje padavin na teh postajah v daljšem časovnem obdobju nekoliko razlikuje. Postaja Loznica izkazuje trend znatnega povečanja nekaterih parametrov, drugi dve postaji pa ne. Nihanja na teh treh postajah se namreč nekoliko razlikujejo in težko je ugotoviti, ali so trendi, kot smo jih zaznali, v skladu z nihanji v preteklosti, zaznanimi v najdaljšem

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nizu za Beograd. Na podlagi analize daljšega časovnega niza mesečnih količin padavin smo prepoznali več vzorcev, ki kažejo na to, da je obnašanje letnih nizov padavin zelo zapleteno. V majskem nizu podatkov za nobeno postajo nismo prepoznali značilnega naraščajočega trenda.

Ključne besede: ekstremne padavine, trend, vztrajnost v daljšem časovnem obdobju, nihanja z manjšo pogostostjo, poplave, poplave maja 2014 v Srbiji.

1. Introduction

In May 2014 catastrophic floods struck Serbia, Bosnia and Herzegovina and Croatia with huge consequences. More than 100 people were killed in these countries, and about one million of people were evacuated from their homes. Material damage was enormous; damages in Serbia are estimated at nearly 1.5 billion Euros, which is approximately 5.5% of Serbian Gross Domestic Product (Government of Serbia, 2014). The floods hit the middle and lower Sava River Basin and also a large area of Serbia outside the Sava River Basin. Almost all smaller torrential rivers in central Serbia were affected by the flash floods and multiple landslides. The heaviest damage occurred in towns of Doboj, Bosnia and Herzegovina, and Obrenovac, Serbia, where the water depth and the number of casualties were the greatest.

The flood was triggered on 13th May 2014 by a cyclonic system that was created in the Genoa Bay, travelled via southern Italy toward south-east Europe and then remained there for about 3 days (Nišavić et al., 2014). It brought unprecedented precipitation in both Serbia and in Bosnia (RHMSS, 2014; RHMZ RS, 2014). There was also some snow in the Bosnian mountains, i.e. in the headwater parts of the Bosna River (Vidmar et al., 2016). However, significant precipitation preceded this event. Since mid-April until 13 May 2014 there were very few dry days, resulting in a high degree of soil saturation just before the main event. During 3 to 4 days in mid-May, precipitation exceeded 100 mm at many locations in all three countries, while there were also locations with more than 200 mm (ICPDR and ISRBC, 2015). In western Serbia, several gauges recorded even more rainfall: 270 mm at Kopaonik and 280 mm at Zlatibor 300 mm (Plavšić et al., 2014a).

Precipitation that caused the floods was truly extreme. In Serbia, previous historical maxima were exceeded at monthly scale for April and May at many locations. The greatest exceedance was for summed April and May precipitation in western Serbia: previous maximum was exceeded by 66% at Loznica, and even by 88% at Valjevo (Plavšić et al., 2014b). Frequency analysis of rainfall at Loznica (Prohaska et al., 2015) shows that the 1-day maximum in May 2014 has the return period of 125 years, and the 3-days maximum has the return period of 450 years.

A question was often raised during the 2014 flood both in media and among professionals is whether this event is an indication of climate change impact in the region. It is well known that precipitation is highly variable at all spatial and temporal scales, and even the longest observed precipitation records (e.g. Seoul, from 1770; Koutsoyannis and Langousis, 2011) exhibit significant variability even on the climatic scale of 30 and more years. It is therefore very difficult to prove or decide whether the occurrence of extremes and exceeding the previous maxima is a result of natural precipitation variability or represents a change in climate due to anthropogenic effects.

The present study is therefore set in order to investigate the presence of eventual recent anomalies in precipitation at locations in Serbia that experienced the greatest rainfall in May 2014. The focus was on daily precipitation data and durations from 1 to 7 days because the accumulation over several days in May 2014 was extreme while sub-daily rainfall was not of significant intensity. The key questions addressed are: Is there an increase in precipitation totals? Is there an increase in extreme precipitation? Are the extremes more frequent? Are there any background oscillations in precipitation totals and extremes?

We analysed precipitation totals and extremes at three precipitation stations in Serbia that received the highest precipitation in May 2014 by testing different precipitation indices for trend and for presence of multi-decadal oscillations.

2. Methodology

Identifying long-term persistence in hydroclimatic series has been the subject of many studies and can be performed on various levels of sophistication. Hurst (1951) was the first who studied this type of behaviour in hydrologic series, and the long-term persistence became known as the Hurst phenomenon. The phenomenon pertains to presence of autocorrelation in the series at larger time scales, such as annual and decadal. Some researchers tend to describe such behaviour as non-stationary and usually look for the deterministic components of time series such as trend or long-term periodicity (e.g. Armstrong et al., 2014; Stojković et al., 2014). There have also been attempts to characterise hydroclimatic processes as a series with sudden shifts (Sveinsson et al., 2003). The framework for such analysis can range from stochastic modelling and time series analysis to simple testing of statistical hypotheses on the presence of trends.

Regardless of the approach, a question can always be asked whether the observed hydroclimatic series are sufficiently long for identifying multi-decadal behaviour. A typical problem is when the observed data consists of a single or an incomplete multi-decadal cycle, which can misleadingly result in an apparent trend over the observation period or two sub-periods with opposing trends (Stojković et al, 2014). Analysis of trends should therefore always be accompanied by an analysis of multi-decadal oscillations in order to avoid wrong conclusions based on the trend analysis.

The goal of the present study is to analyse the long-term behaviour of the precipitation at selected locations which experienced in 2014 the unprecedented rainfall over its period of record. We defined the following precipitation indices:

- annual and monthly totals (P_{ann}, P_{mon}),
- annual and monthly maximum 1-day to 7-day precipitation (P_{max1} to P_{max7}),
- annual and monthly number of days with precipitation above a threshold (N_{ann} and N_{mon}).

For the last category of indices, we consider two thresholds: 95th and 98th percentiles of precipitation on wet days. This means that zero precipitation is excluded from daily precipitation data for calculating the thresholds.

The Mann-Kendall (MK) non-parametric test is used to test for presence of monotonic trend in annual data, and the seasonal MK test for monthly data. The Mann-Kendall test is well known and the details related to it can be found in literature (e.g. Helsel and Hirsch, 2002). The test uses the Kendall's *S* statistic:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(X_j - X_i), \tag{1}$$

where n is the sample size, X_i and X_j are the successive values in the series and $\operatorname{sgn}(X_j - X_i)$ is 1 when $X_j > X_i$, –1 if $X_j < X_i$ and 0 if $X_j = X_i$. Significant departure of S from 0 indicates the presence of a trend. For sample sizes $n > 10$, the test statistic

$$Z_S = \begin{cases} (S-1)/\sigma_S, & S>0 \\ 0, & S=0 \\ (S+1)/\sigma_S, & S<0 \end{cases} \tag{2}$$

is normally distributed with zero mean and the variance

$$\sigma_S^2 = \frac{n(n-1)(2n+5) - \sum_{k=1}^{n} t_k \cdot k(k-1)(2k+5)}{18}, \tag{3}$$

where the second part of the nominator takes into account tied values in the sample with t_k groups of k equal values. The null hypotheses of the absence of a monotonic trend is rejected at significance level α if $|Z_S| > Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is the standard normal variate for the probability of non-exceedance $1 - \alpha/2$.

The seasonal MK test is a modified MK test which takes into account autocorrelation in seasonal data (Hamed and Rao, 1998). In this test, the test statistic is the same, but its variance is adjusted according to:

$$V_S = \sigma_S^2 \frac{n}{n^*}, \tag{4}$$

where n/n^* is the correction to be evaluated based on the serial correlation coefficients ρ_i:

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{i=1}^{n-1} (n-i)(n-i-1)(n-i-2)\rho_i \tag{5}$$

To identify eventual background oscillations visually, the series are smoothed with the moving average filter over 5, 11 and 30 year windows. These three windows represent shorter, medium and long term behaviour of the process on the multi-annual scale. The 5-year moving average smooths out year-to-year variations but maintains general variability of the process, while the 11-year moving average is more convenient to visually identify long-term periodicity. The 30-year moving average indicates variability of precipitation average on the climatic scale.

Presence of oscillations is tested by applying the Fourier analysis to detrended series and calculating the periodograms, which are tested for significant harmonics. The periodogram is the sample-based estimate of the series spectrum and its intensity is given with (Box et al., 2008):

$$I(f_j) = \frac{n}{2}(a_j^2 + b_j^2), \quad j = 1,2,...,q \tag{6}$$

where $f_j = j/n$ are Fourier or fundamental frequencies, n is the sample size, q is the number of harmonics, which is either $q = n/2$ for n even or $q = (n-1)/2$ for n odd, and a_j and b_j are the coefficients of the Fourier transform of the series Z_t. The Fourier coefficients a_j and b_j are estimated from the observed detrended series Z_t as:

$$a_j = \frac{2}{n}\sum_{t=1}^{n} Z_t \cos(2\pi f_j t)$$
$$b_j = \frac{2}{n}\sum_{t=1}^{n} Z_t \sin(2\pi f_j t) \tag{7}$$

The tool for identifying periodic components is the normalized cumulative periodogram, which is obtained by successive addition of periodigram intensities $I(f_j)$ and then by dividing with the total variance σ_Z^2 of the series:

$$NCP_i = \frac{\sum_{j=1}^{i} I(f_j)}{n\sigma_Z^2} \tag{8}$$

The normalized cumulative periodogram (NCP) for a random process is a straight line connecting points (0,0) and (0.5,1) of the NCP graph. The 95% confidence interval for the NCP of a random process is defined with limits $\pm K_\alpha \sqrt{q}$ around the straight line, with $K_\alpha = 1.36$ for $\alpha = 0.05$ (Box et al., 2008).

3. Data

Three precipitation stations that received the greatest observed precipitation in May 2014 are chosen for the analysis, namely Loznica, Valjevo and Belgrade (Figure 1). All stations are located in the lowland (at altitudes of 121, 176 and 132 m a.s.l., respectively). Distances between the stations are 60, 75 and 110 km. Area between Belgrade and Valjevo is flat, while Loznica is separated from the other two stations by rolling hills of up to 600 m elevation.

The available daily precipitation record is the longest for the Belgrade station (1923-2014) and shorter at the other two stations: 1952-2014 at Loznica and 1949-2014 at Valjevo). Year 2014 was not included in computations because the precipitation data at the time of the study was available only as preliminary data, without quality control performed.

4. Results

4.1 Annual and monthly precipitation totals

Time series of total annual precipitation at three stations used in the study are shown on the left side of Figure 2. These graphs also show the highest recorded annual precipitation in 2014, which exceeded the previous highest values by 8% at Loznica, by 22% at Valjevo, and by 5% at Belgrade.

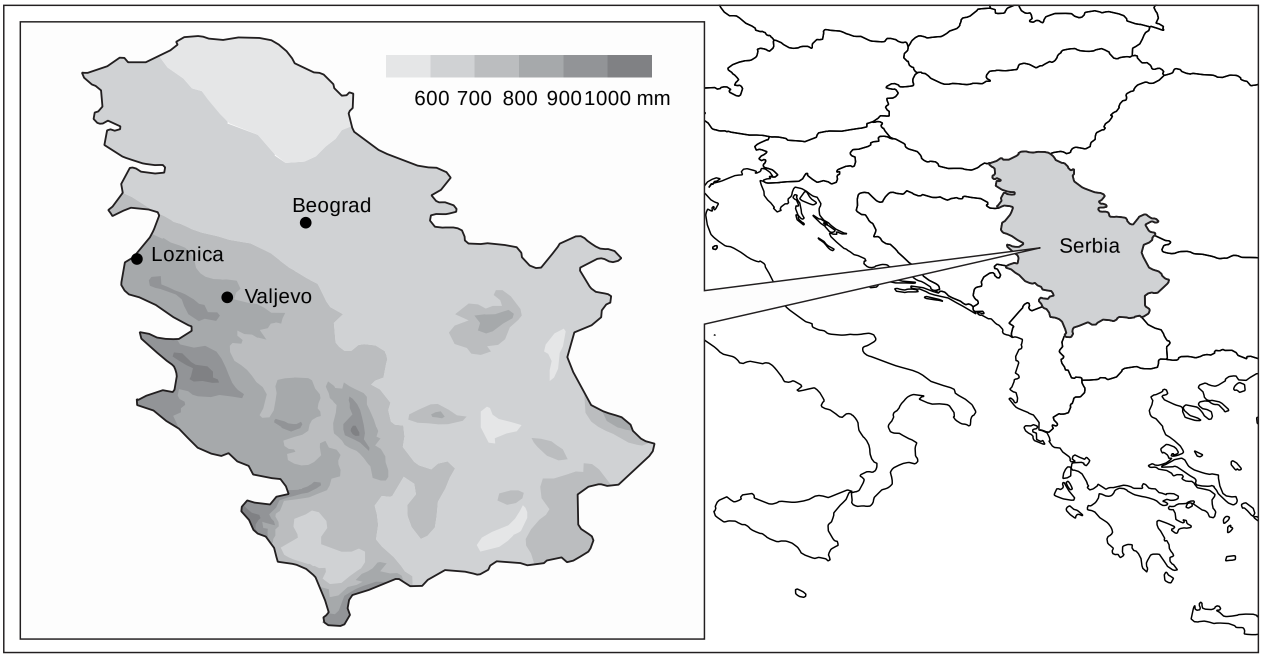

Figure 1: *Map showing mean annual precipitation in Serbia and location of stations used in the study.*

Slika 1: *Karta povprečnih letnih padavin v Srbiji in lokacija obravnavanih postaj.*

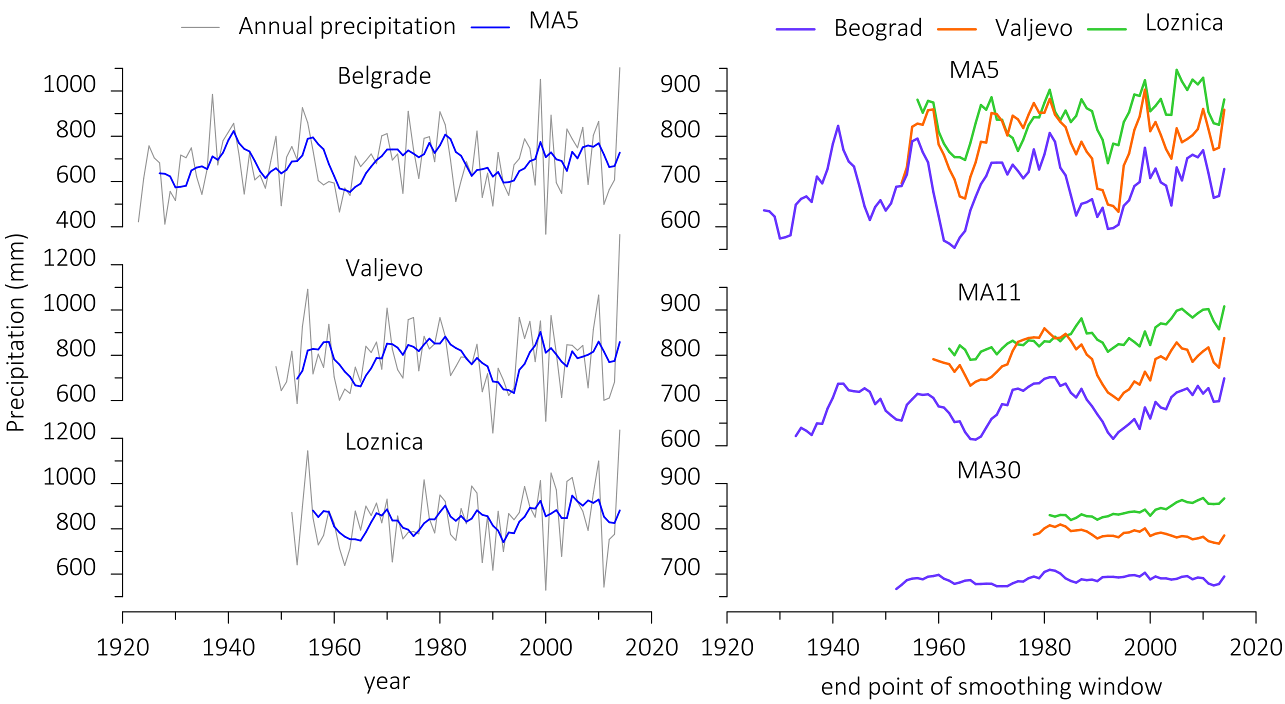

Figure 2: *Annual total precipitation with 5-year moving average series MA5 (left); the same series averaged over 5-year, 11-year and 30-year time windows (right; MA5, MA11 and MA30, respectively).*

Slika 2: *Letne količine padavin s 5-letno drsečo sredino MA5 (levo); ista serija povprečena na 5-letno, 11-letno and 30-letno časovno okno (desno; MA5, MA11 in MA30).*

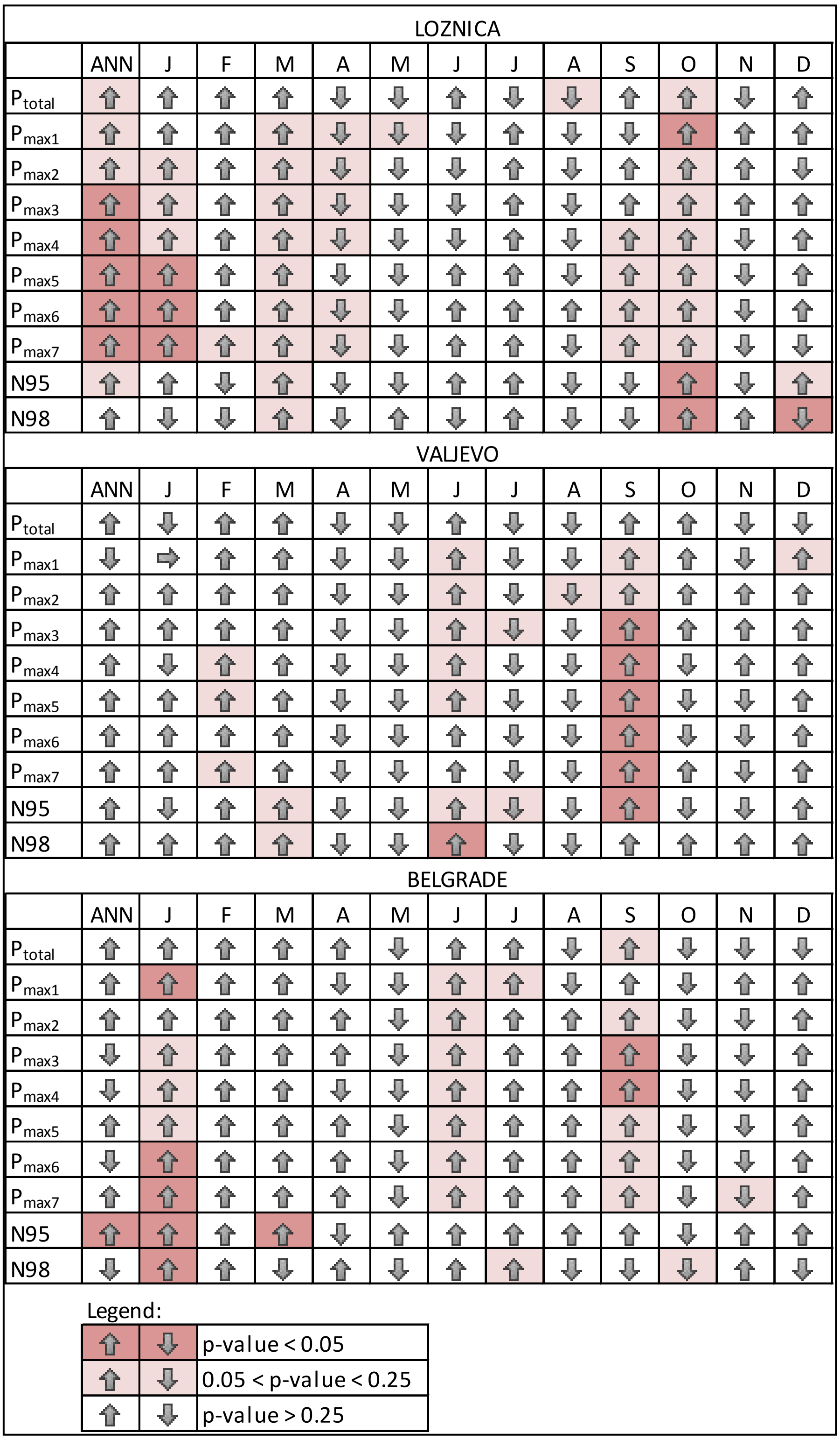

Figure 3: *The results of the Mann-Kendall test for trend in precipitation indices: arrow direction denotes increasing or decreasing trend or stagnation, whereas cell shade indicates statistical significance. First column refers to the annual values, while the remaining ones correspond to monthly values.*

Slika 3: *Rezultati Mann-Kendall-ovega testa trendov padavinskih parametrov: smer puščice ponazarja naraščajoči ali padajoči trend, medtem ko barva celice označuje statistično značilnost. Prvi stolpec se nanaša na letne vrednosti, ostali pa na mesečne.*

By comparing the moving average of annual totals over time windows of 5, 11 and 30 years (on the right in Figure 2), it can be seen that all stations have similar shorter-term oscillations at the 5-year scale. At mid-term scale of 11 years, Valjevo and Belgrade show synchronous oscillations, while the Loznica station is slightly off in the period before 1980. At long-term scale of 30 years three stations exhibit completely different behaviour: Loznica appears to have an increasing trend, Valjevo seems to have a decreasing trend, and Belgrade does not seem to have a trend. However, none of these trends are significant at 5% significance level. Figure 3 shows the results of the Mann-Kendall test (signs of the trends and their statistical significance) for all precipitation indices, indicating significant trends at 5% significance level and those where the *p*-values of the test are between 0.05 and 0.25, meaning that the trend is almost significant. The results indicate increasing trends in total annual precipitation at all three stations, but the trend is almost significant only for Loznica.

No significant frequencies are found in the annual totals (Figure 4), although some frequencies can be identified as a slight persistence in all three series (indicated in Figure 4). Among these, the frequencies between 10 and 13 years consistently appear at all stations. These frequencies explain from 6% to 11% of the variance in the series.

Looking into long-term smoothed precipitation totals at monthly level (Figure 5), a multitude of patterns can be seen. In some months the three stations have perfectly synchronized behaviour (e.g. in February, March, or December), but in other months they are not consistent (e.g. January, April, July or November). Trend direction is different in different months, as illustrated in Figure 3; e.g. at Loznica, increasing March precipitation is followed by decreasing April precipitation, etc. Therefore, it is understandable that it is difficult to detect the resulting trend on the annual level.

However, these graphs also show that the two shorter series of about 60 years are still too short to recognize the long-term oscillations present in the longer series at Belgrade. Two shorter series exhibit only the trends that could be a part of the long-term cycles visible at Belgrade. For example, October precipitation at Loznica and Valjevo shows a rising trend while a very low frequency cycle can be seen in the Belgrade series. On the other hand, very distinct low-frequency cycles emerge in all December series.

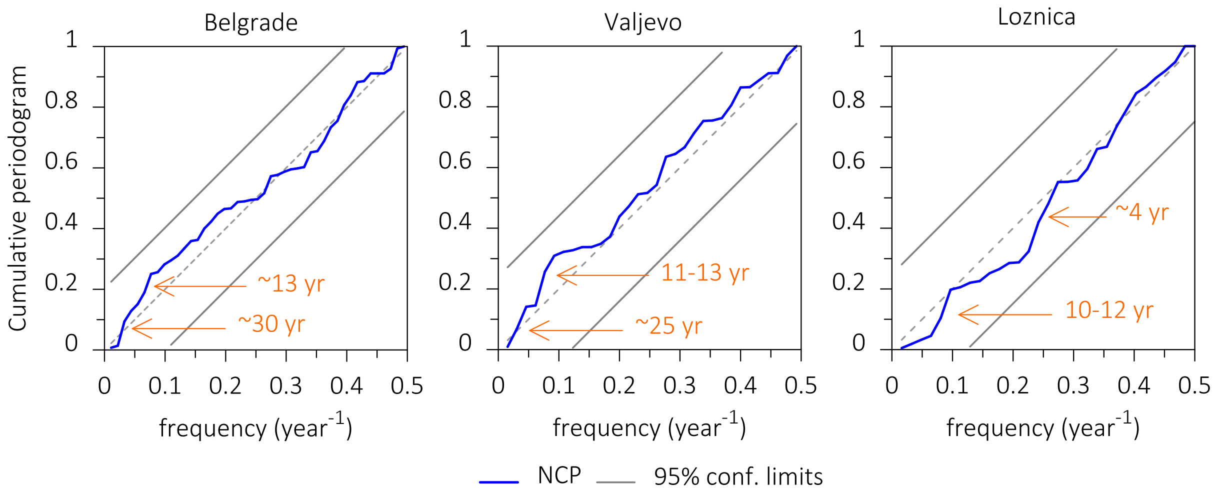

***Figure 4:** Normalized cumulative periodograms (NCPs) for annual total precipitation; orange arrows indicate visible but not statistically significant frequencies.*

***Slika 4:** Normalizirani kumulativni periodigrami (NCPs) za letne količine padavin; oranžne puščice označujejo vidne, a statistično neznačilne pogostosti.*

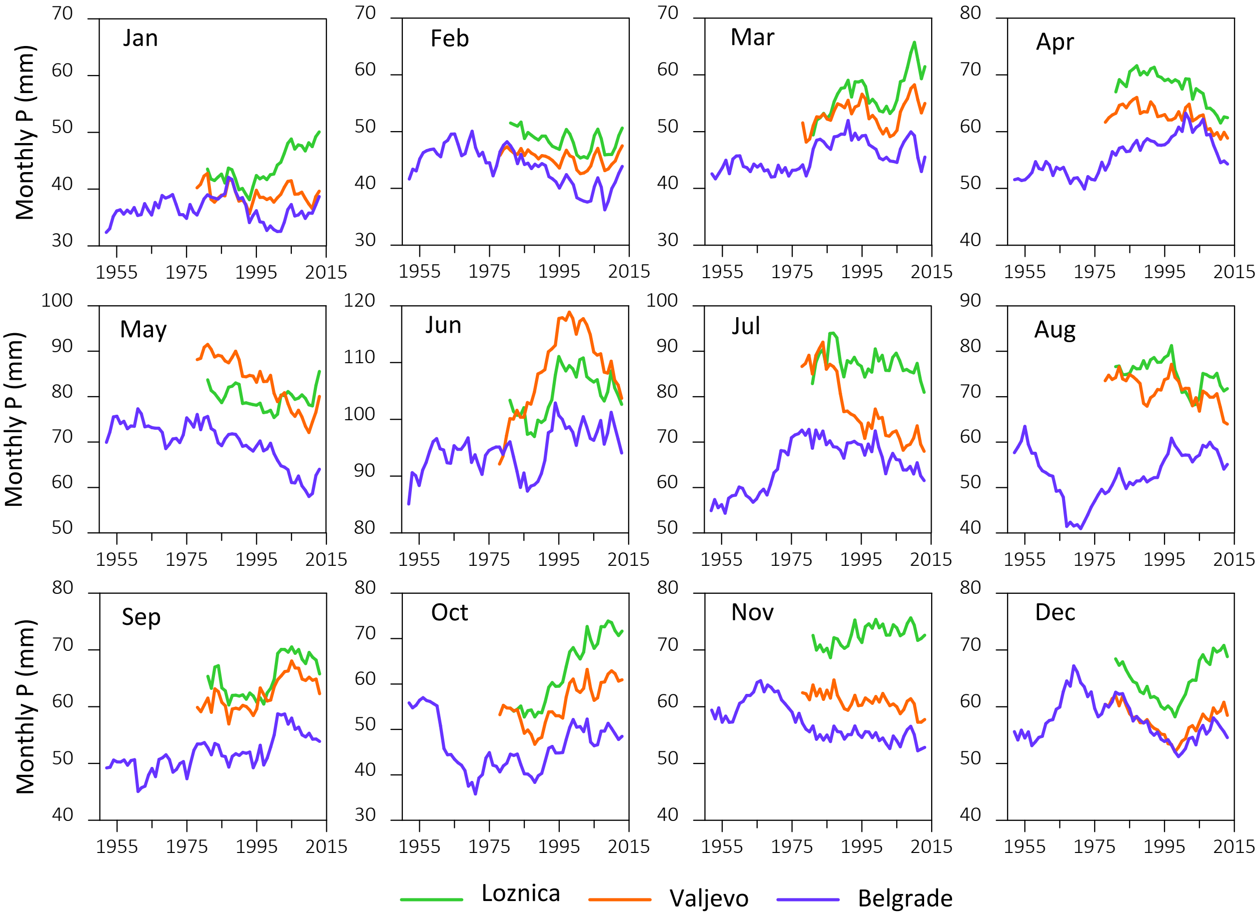

Figure 5: *Smoothed monthly precipitation series (30-year moving average) for the stations used in the study. Horizontal axis shows the end year of the 30-year moving window.*

Slika 5: *Zglajeni mesečni padavinski nizi (30-letna drseča sredina) za obravnavane postaje. Horizontalna os prikazuje končno leto posameznega 30-letnega časovnega okna.*

It is interesting that the May series do not exhibit significant trends at any station (Figure 3), which contradicts the perception that the event from 2014 is a consequence of gradually changing climate.

Devising trends from such series is obviously counterproductive. None of the trends in monthly totals is statistically significant; only a few series (August and October at Loznica, and September at Belgrade) are almost significant (Figure 3).

As a result, we have a changing long-term seasonal distribution of precipitation. At Loznica, increase in autumn, winter and June precipitation obviously contributes to the overall increasing trend at this station. At other two stations, some increasing and some decreasing trends in individual months cancel each other out on the annual level and there is no overall trend.

4.2 Maximum precipitation depths

Annual maximum daily precipitation series are shown on the left side of Figure 6. This graph also shows the maxima recorded in May 2014. The three series look more like random series without low frequency oscillations in comparison to the annual totals. Variation of maximum precipitation for longer durations (from 2 to 7 days, not shown here) is very similar to that of maxima for duration of 1 day.

Smoothed annual maxima series at time windows of 5, 11 and 30 years are given on the right side of Figure 6. The degree of similarity between the oscillations at the three stations is smaller than for the annual totals. At scale of 5 years, oscillations are similar in terms of periods, but not in terms of amplitudes. At scale of 11 years similarity is much smaller, and it almost diminishes at scale of 30 years. The 30-year moving average for 1-day annual maxima vaguely indicates that there is an increasing trend at all stations after 1980, but with different trend slope.

However, the results of the Mann-Kendall test (Figure 3) show that only the Loznica station has significant increasing trends in annual maxima, especially for durations of 3 days and more. The longest series in Belgrade does not exhibit any significant trend, which corroborates the results presented by Todorović et al. (2014).

Significant trends in monthly maxima are generally consistent for all durations from 1 to 7 days. Increasing trends are present in September and October at all stations and in January at Loznica and Belgrade.

No significant frequencies were found in annual maxima of all durations (Figure 7), but a noticeable low frequency of about 15 years at Loznica explains from about 8% to even 20% of variance of the series. The highest contribution of this frequency is found in the annual maximum 3-day and 4-day precipitation.

4.3 Number of days with extreme precipitation

Annual number of days with precipitation exceeding 95th percentile, N95, shows very similar pattern as the annual totals. Left side of Figure 8 shows N95 series averaged at time windows of 5, 11 and 30 years. All stations exhibit similar oscillations at the 5-year scale; Loznica does not have the same behaviour at scale of 11 years as Valjevo and Belgrade, and at scale of 30 years the three stations exhibit completely different behaviour.

The series of the annual number of days with precipitation above the 98th percentile (N98, shown in right side of Figure 8) follow the similar patterns as N95 at 5-year and 11-year scales. At the 30-year scale N98 for Belgrade has a different pattern than N95.

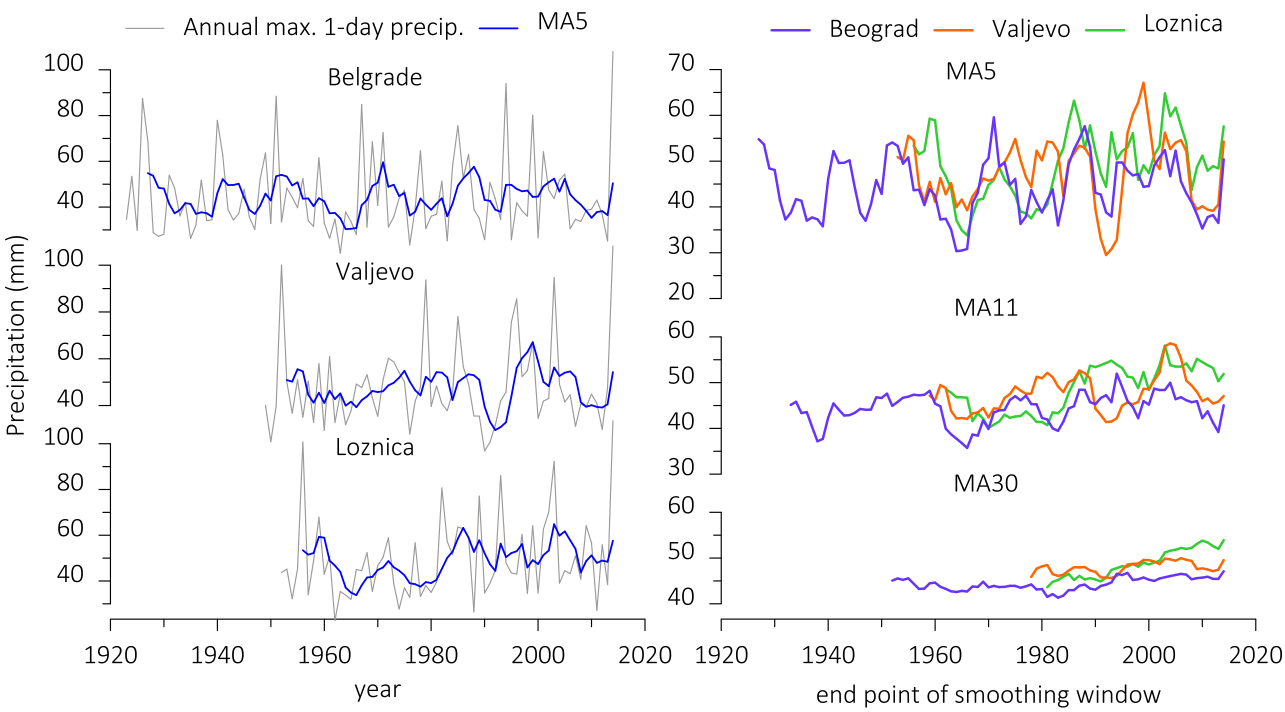

Figure 6: *Annual maximum 1-day precipitation with 5-year moving average series MA5 (left); the same series averaged over 5-year, 11-year and 30-year time windows (right; MA5, MA11 and MA30, respectively).*

Slika 6: *Letne maksimalne 1-dnevne padavine s 5-letno drsečo sredino MA5 (levo); ista serija povprečena čez 5-letno, 11-letno in 30-letno časovno okno (desno; MA5, MA11 in MA30).*

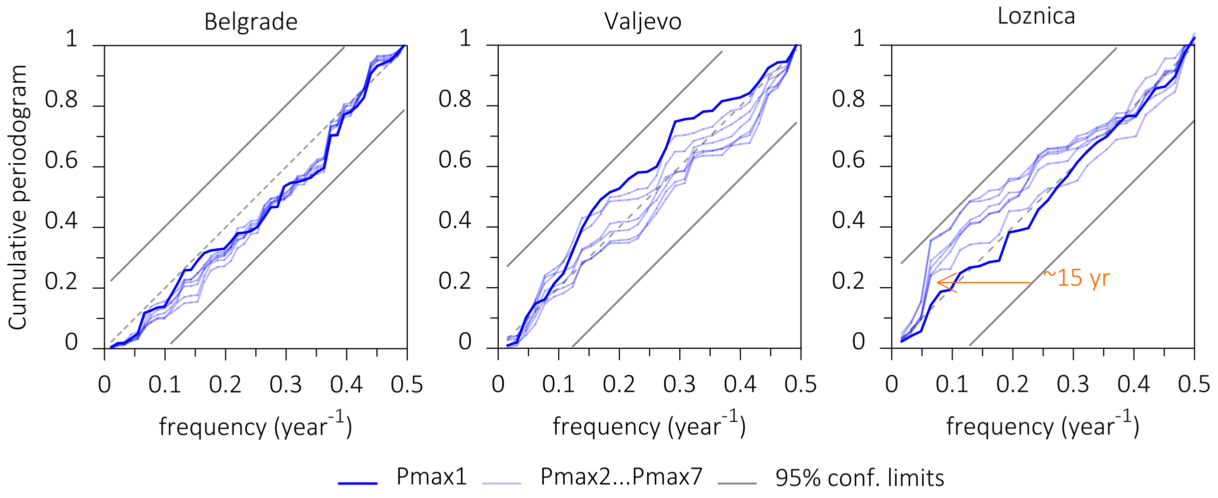

***Figure 7:** Normalized cumulative periodograms for annual maximum 1-day to 7-day precipitation (P_{max1} to P_{max7}); orange arrows indicate visible but not statistically significant frequencies.*

***Slika 7:** Normalizirani kumulativni periodiogrami za letne maksimalne 1-dnevne to 7-dnevne padavine (P_{max1} do P_{max7}); oranžna puščica označujejo vidno, a statistično neznačilno pogostost.*

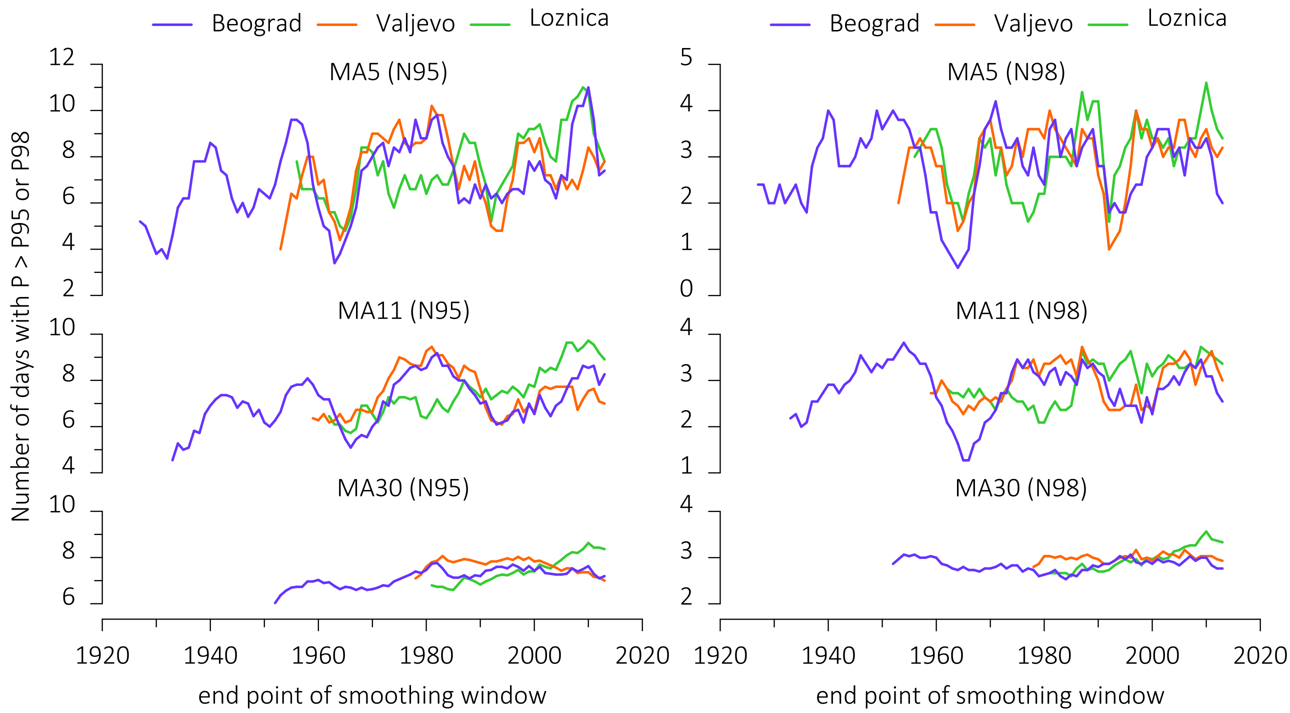

***Figure 8:** Annual number of days N95 with precipitation exceeding 95th percentile (left) and annual number of days N98 with precipitation exceeding 98th percentile (right) averaged over 5-year, 11-year and 30-year time windows (MA5, MA11 and MA30, respectively).*

***Slika 8:** Letno število dni N95 s padavinami, ki presegajo 95. percentil (levo) in letno število dni N98 s padavinami, ki presegajo 98. percenti (desno) povprečeno čez 5-letno, 11-letno in 30-letno časovno okno (MA5, MA11 in MA30).*

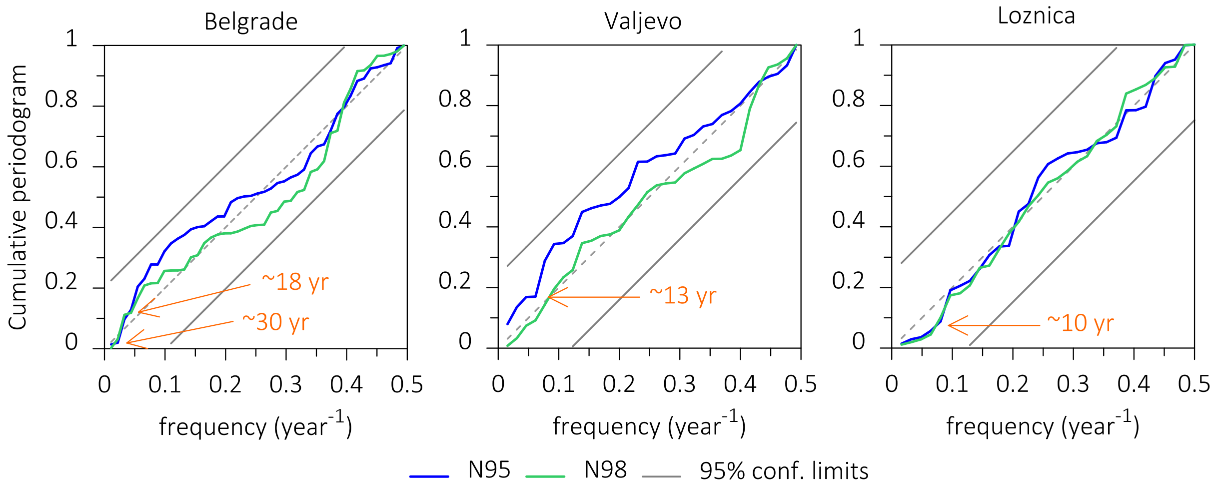

***Figure 9:** Normalized cumulative periodograms for the number of days N95 and N98 with precipitation exceeding 95th and 98th percentile; orange arrows indicate visible but not statistically significant frequencies.*

***Slika 9:** Normalizirani kumulativni periodiogrami za število dni N95 and N98 s padavinami, ki presegajo 95. in 98. percentil; oranžne puščice označujejo vidne, a statistično neznačilne pogostosti.*

The oscillation patterns of smoothed N95 and N98 series in Figure 8 generally resemble the patterns of annual totals in Figure 2. Their periodograms also show some similarities. Again, there are no statistically significant frequencies in N95 and N98 (Figure 9). Noticeable low frequencies visible in these periodograms differ from station to station. Low frequencies of 30 and 18 years for Belgrade can be seen in both N95 and N98, each explaining about 7.5% of total variance in N95 and less in N98. At Valjevo, low frequency of 13 years in N95 series explains 12% of the series variance, while it has a much smaller contribution in the N98 series. At Loznica, frequency of 10 years explains about 10% of total variance. Except for the frequency of 18 years at Belgrade, all mentioned frequencies are also visible in the periodograms of the annual totals and have similar contribution in total variance of the corresponding series.

The results of the Mann-Kendall test in the annual and monthly number of days with extreme precipitation (Figure 3) show that the increasing trend in annual N95 at Belgrade is significant at the 5% significance level, at Loznica it is almost significant with *p*-value of 6%, while no trend for N98 is significant at all stations.

On the monthly level, and for the significance level of 5%, N95 and N98 are significantly increasing at Loznica in October, and at Belgrade in January. In addition, Valjevo has significantly increasing N95 in September and N98 in June, and Loznica has decreasing trend in N98 in December.

4.4 Summary of the results and discussion

On the annual level, the Loznica station exhibits significant or almost significant trends in total precipitation, in annual maxima for all durations from 1 to 7 days and in N95. The trend is not significant only in N98. Trend in N95 is the only significant annual indicator at Belgrade, while Valjevo does not have any significant indicators.

On monthly level, there are no significant trends in monthly totals. However, there are some in monthly maxima, which are generally consistent among durations from 1 to 7 days. Significant increasing trends are present in January at Loznica and Belgrade, in September at Valjevo and Belgrade and in October at Loznica. Additionally, almost significant trends in maxima are present in June at Valjevo and Belgrade, and in March, April and September at Loznica.

Loznica has significantly increasing N95 and N98 in October, and Belgrade in January, which corresponds to the trends in monthly maxima. In addition, Valjevo has significantly increasing N95 in September, and N98 in June, and Loznica also has an almost significant increasing trends in March. However, there are few examples where the increasing number of days is not accompanied by trends in any other indicator, such as the significant trend in N95 in March at Belgrade and opposite trends in N95 and N98 in December at Loznica.

It is interesting to notice that there are no significant trends in number of days with extreme precipitation in May, but it should be noted that the data used did not include the maxima from 2014.

Statistically non-significant long-term oscillations have been identified in annual totals and in the number of days with extreme precipitation, with frequencies ranging from 10 to 13 years and explaining from 6 to 12% of total variance.

Comparing the results from other studies that investigated trends and long-term behaviour of precipitation in Serbia to our results is not straightforward because of different time spans. Tošić and Unkašević (2005) applied the Mann-Kendall test to monthly precipitation at Belgrade for 1889-2000 and found a significant negative trend in February, contrary to the non-significant increasing trend for 1923-2014 in this study. In their study, other monthly trends were not significant as in our study, but with opposite directions than our study for six different months and for the annual scale. Tošić and Unkašević (2005) also investigated periodicity in the Belgrade precipitation and identified 13.3-16 years as significant frequencies in annual totals, which is in general agreement with our results. Unkašević and Tošić (2011) also analysed trends in daily maximum precipitation in Serbia including the Belgrade and Loznica stations for 1949-2007 and found them to be increasing but not statistically significant, similar to our study. Gocić and Trajković (2013) applied the Mann-Kendall test to annual and monthly precipitation totals at 12 stations, including Belgrade and Loznica, over 1980-2010 and did not obtain any significant trends as is the case in this study, but the agreement of trend direction and the significance level between their and our study varies from month to month. Obviously, different periods can yield different trend significance levels and different trend directions, thereby making the trend analysis very sensitive to choice of the data time frame and record length.

5. Conclusions

The aim of the paper was to thoroughly analyse precipitation records at three stations that received the greatest precipitation during the major flood in May 2014 and to look for signs of change. The analysis of trends was accompanied by the analysis of long-term oscillations in the series in order to facilitate interpretation of the trends. The study was performed with the series of annual and monthly precipitation totals, maxima for durations from 1 to 7 days and the number of days with precipitation exceeding 95th and 98th percentile.

The results have shown that long-term oscillations are visible in smoothed series, but are not detectable by periodogram analysis. No significant harmonics can be found in any of the precipitation indices examined in the study, but some of the frequencies could be identified as having a noticeable contribution to the total variance of the series.

The annual totals and the number of days with precipitation exceeding 95th percentile have similar behaviour in terms of oscillations. This makes sense because the significant precipitation events, with their high precipitation depths, contribute to the above-average or extreme annual totals. The noticeable frequencies are not completely consistent across the three stations, but those ranging from 10 to 13 years seem to appear at all stations. On the other hand, 1-day to 7-day precipitation maxima have different behaviour in terms of oscillations compared to the precipitation totals; no noticeable harmonics could be identified, meaning that the maxima series are closer to a completely random process. The only exceptions are the 3-day and 4-day maxima at Loznica, with a visually noticeable frequency of about 15 years.

The analysis of monthly totals has shown that the long-term behaviour at one station can be completely different in different months, ranging from clear increasing or decreasing trend to a complex oscillatory behaviour. It is therefore clear that combination of such different tendencies leads to a very complex structure of precipitation variability on the annual scale.

Significant trends in totals and maxima are mostly detected at the station with the shortest record (Loznica). Annual maxima are significantly increasing for durations from 3 to 7 days, and almost significantly for durations of 1 and 2 days. On the monthly level, significant increases in monthly maxima are detected in October. However, it was impossible to "verify" these trends by comparing to those in longer series (Belgrade) because these two stations exhibit different long-term behaviour in the same period.

Station with the longest record (Belgrade) does not exhibit strong long-term tendencies. Significant increasing trend on the annual scale is detected only for the number of days N95. This index also has significant increasing trends in January and March. Several indices of monthly maxima for various durations have significant increasing trends (mostly in January). At Valjevo station, most trends in the September monthly maxima are significant.

Despite different results for the three stations, it is indicative that significant trends are present in January and in September/October, therefore it could be concluded that these two seasons are most prone to changes. Also, none of the indicators in April and May show a significant increasing trend to support the changing climate perception related to the extreme precipitation in May 2014.

Finally, it must be concluded that the long-term variability is difficult to devise from shorter series, even from 90-year long series such as for Belgrade. The presence of complex oscillatory behaviour on the annual level results from a multitude of different patterns on the monthly level. Devising trends from such series is not only difficult, but also counterproductive for incorporating such results into further water management considerations. We therefore recommend that conclusions about future precipitation totals and maxima should not be made solely on the basis of trend analysis, but rather on a careful analysis of the long-term behaviour of the observed precipitation in a regional context but with an appreciation of specific local conditions.

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